Australian Almond Industry - Liaison and Extension Project

Ben Brown
Almond Board of Australia (ABA)

Project Number: AL09021

AL09021

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the almond industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of:
Almond Board of Australia (ABA)
the almond industry

All expressions of opinion are not to be regarded as expressing the opinion of Horticulture Australia Ltd or any authority of the Australian Government.

The Company and the Australian Government accept no responsibility for any of the opinions or the accuracy of the information contained in this report and readers should rely upon their own enquiries in making decisions concerning their own interests.

ISBN 0 7341 3018 X

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

© Copyright 2012

HAL
Horticulture Australia

AUSTRALIAN ALMOND INDUSTRY LIAISON AND EXTENSION PROJECT

Ben Brown et al.
Almond Board of Australia Inc

Project Number: AL09021
(Completion Date: 15 August 2012)

HAL Project No. AL09012

PROJECT LEADER
Ben Brown
Industry Development Manager
Almond Board of Australia
PO Box 2246
Berri SA 5343
T: +61 8 8582 2055
F: +61 8 8582 3503
admin@australianalmonds.com.au

KEY PERSONNEL
Brett Rosenzweig – Almond Board of Australia
Ross Skinner – Almond Board of Australia
Julie Haslett – Almond Board of Australia
Jo Ireland – Almond Board of Australia
Shannon Harkins – Almond Board of Australia
Bronte McCarthy – Almond Board of Australia
Dr. Michelle Wirthensohn – University of Adelaide
Dr. Ben Robinson – Production Committee member and retired researcher

PURPOSE OF REPORT
This Final Report has been prepared to document the activities undertaken to ensure adoption of the research and development program undertaken by the Almond Board of Australia.

ACKNOWLEDGMENTS
This project has been funded by HAL using the almond industry levy, voluntary contributions from industry and matched funds from the Australian Government.

The project team would also like to acknowledge the valuable and voluntary contributions by industry members and stakeholders; in particular those who participate in the Production committee, Plant Improvement committee, Processing committee, Industry Advisory Committee, and ABA Board. Furthermore, the project team would also like to acknowledge the proficiency and efforts of the almond research community and the vital industry partners who host the industry trials, extension and technology transfer activities.

DATE OF REPORT
September 2012

DISCLAIMER
Any recommendations contained in this publication do not necessarily represent current Horticulture Australia policy. No person should act on the basis of the contents of this publication, whether as to matters of fact or opinion or other content, without first obtaining specific, independent professional advice in respect of the matters set out in this publication.

Contents

INDEX OF TABLES

INDEX OF FIGURES

1 MEDIA SUMMARY

The almond industry of Australia has recently undergone rapid expansion and with production expected to reach greater than 80,000 tonnes by 2015 there was a requirement to undertake an industry development project to inform and empower the industry to make better business decisions.

The Almond Board of Australia (ABA) was contracted to undertake the Australian Almond Industry Liaison and Extension project and delivered the industry development function by: identifying issues; developing detailed strategies; identifying gaps in the outputs (i.e. goods, service or information) required to achieve the strategies; ensuring delivery of the outputs through scoping and commissioning R&D; and assisting implementation of the strategies that achieve industry outcomes through extension and technology transfer activities.

Industry supply chain committees, field days, workshops, invited experts, grower meetings, domestic and international study tours, trials, participation in stakeholder committees, gap analysis workshops, participation in state and federal government consultative committees, topical publications, website updates, fact sheets, decision support tools, regular email circulars, industry conference presentations, the provision of useful published research articles and website links, prioritisation of minor use permit applications, and more, were all used to achieve key outcomes.

The project team were actively involved in the industry's two largest R&D projects, "Sustainable Optimisation of Australian Almond Production" and "Australian Almond Breeding Program Stage 2 – Secondary Evaluation". Furthermore, the project team were actively involved in providing and managing the industry's true to type and pathogen tested germplasm for the continued development of the industry.

The implications of this project have contributed towards: informing and empowering the industry to make better business decisions; and achieving the industry's R&D vision, *as a profitable industry to lead in the efficient production, processing and marketing of quality almonds and secure a position of preferred supplier*.

It is recommended that an industry development project continues for the Australian almond industry.

2 INTRODUCTION

The almond industry of Australia has recently undergone rapid expansion with production increasing from 36,403 tonnes in 2009 when the project commenced to greater than 50,000 tonnes in 2012 when the project completed.

Due to the expansion of the industry and the requirement to inform and empower the industry to make better business decisions, the Almond Board of Australia (ABA) employed an Industry Development Manager (IDM) and Industry Development Officer (IDO) to undertake an Australian Almond Industry Liaison and Extension project (AL07008). Nearing the completion of AL07008, the industry undertook an Industry Development Needs Assessment (IDNA) in order to assess the success of past industry development outcomes and receive recommendations for the future. One of the key outcomes from the IDNA was that the ABA continue to be the body contracted to deliver the development program for the almond industry, and as such this project (AL09021) was developed and commissioned.

The project began with an initial focus of completing the extension and development activities from the major project, Sustainable Optimisation of Almond Production (AL07005), in addition to numerous emerging issues as they evolved. The later part of the project has focused on the development and implementation of the almond industry's Strategic R&D Plan, 2011-16 which provided further guidance and allowed the team to align itself and be responsible for: issue identification; detailed strategy development; identification of gaps in the outputs required to achieve the strategies; ensuring delivery of the outputs through scoping and commissioning R&D; and assisting implementation of the strategies that achieve industry outcomes through extension and technology transfer.

Industry supply chain committees, field days, workshops, invited experts, grower meetings, domestic and international study tours, trials, participation in stakeholder committees, participation in state and federal government consultative committees, topical publications, website updates, fact sheets, decision support tools, regular email circulars, industry conference presentations, the provision of useful published research articles and website links, prioritisation of minor use permit applications, and more, were all used to achieve key outcomes.

The project team was actively involved in the industry's two largest R&D projects, "Sustainable Optimisation of Australian Almond Production" (Project AL07005) and "Australian Almond Breeding Program Stage 2 – Secondary Evaluation" (AL08000). Furthermore, the project team managed the industry's true to type, pathogen tested germplasm for the continued development of the industry.

The implications has contributed towards: informing and empowering the industry to make better business decisions; and achieving the industry's R&D vision of *as a profitable industry to lead in the efficient production, processing and marketing of quality almonds and secure a position of preferred supplier*.

3 TECHNOLOGY TRANSFER STRATEGY AND METHODOLOGY / ACTIVITIES

3.1 Staffing

Industry development needs were delivered through a diverse but structured strategy and methodology, primarily revolving around the engagement and responsibilities of Ben Brown as the Industry Development Manager (IDM), Brett Rosenzweig as the Industry Development Officer (IDO), Ross Skinner and Julie Haslett as Chief Executive Officers (CEO), Jo Ireland (Communications Manager), Shannon Harkins and Bronte McCarthy (Finance Managers), and Debbie McMahon (Administration). The roles were 0.90 FTE, 1.00 FTE, 0.10 FTE, 0.10 FTE, 0.10 FTE and 0.10 FTE respectively.

3.2 Alignment with almond industry objectives

The project aligned itself to delivering strategies under the almond industry's key four objectives:

- Objective 1 - Develop and maintain market opportunities (volume sold)
- Objective 2 - Increase product value (quality and price)
- Objective 3 - Improved efficiency and sustainability (costs and risks)
- Objective 4 - Provide a supportive environment (skills and communication)

3.3 Steering committee

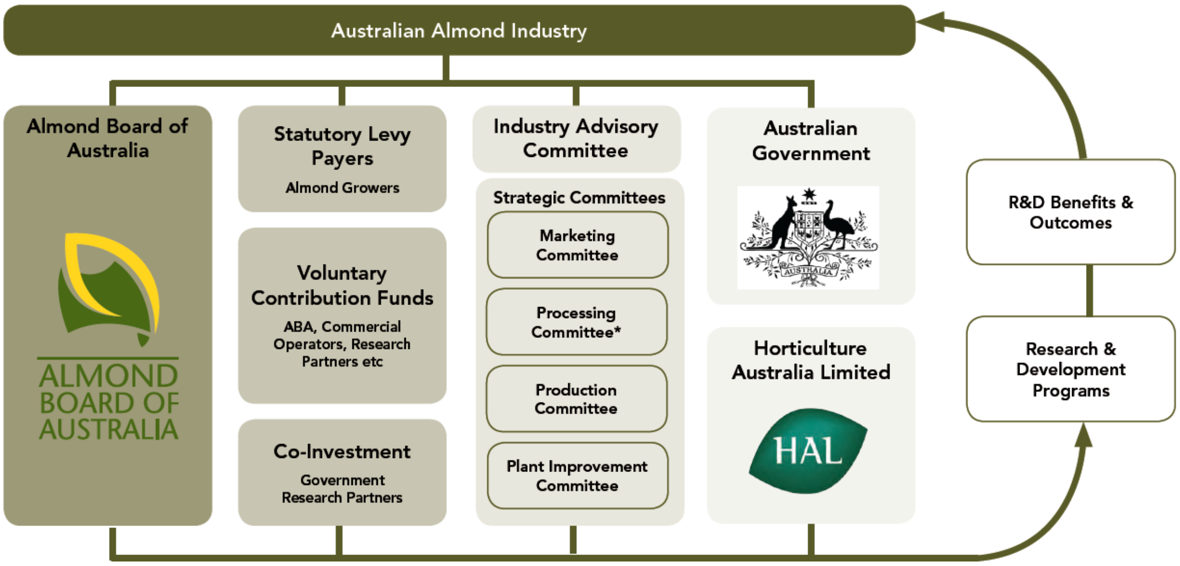
The project obtained guidance and direction from the industry's Production sub-committee: Denis Dinicola, Robert Gulack, Graham Johns, John Kennedy, Drew Martin, Paul Martin, Tim Millen and Ben Robinson and the HAL Industry Services Manager. The steering committee represented approximately 70% of Australian almond acreage and levy collections and provided an ideal forum to ensure industry development needs were being addressed. The committee generally met quarterly and the venues were alternated between the two largest growing regions: Riverland and Sunraysia.

3.4 Industry consultation and issue identification

In addition to the direction provided by the steering committee; industry consultation and issue identification was acquired from: the three further strategic sub-committees (Plant Improvement, Production and Processing); the almond IAC; and the ABA Board. The Processing sub-committee was a new initiative of the project team and was activated in 2011. The ABA Board and strategic sub-committees generally met quarterly, and the almond IAC met twice per year. The industry R&D structure and consultation pathway is provided in Figure 1.

The project team, in particular the IDM, IDO and CEO, also represented the industry in several other consultative committees and forums: HAL industry and member forums; HAL regional visits; Plant Health Australia (PHA); Rural Industries Research and Development Corporation (RIRDC) Pollination R&D Advisory Committee; Varroa Continuity Strategy Management Committee (VCSMC); Australian Honeybee Industry Council (AHBIC) annual conference; NSW Apiarists Association conference; Australian Nut Industry Council (ANIC); Post Entry Plant Industry Consultative Committee (PEPICC); Department of Primary Industries Victoria (DPI) Horticulture Industry Network (HIN); Primary Industry Centre for Science Education (PICSE); and Murray Darling Basin (MDB) regional drought committees.

The IDM, IDO and CEO developed annual operating plans and their performances were assessed on a six monthly basis against Key Performance Indicators (KPIs).



* The processing committee was a new industry initiative implemented by the project team during the term of the project

Figure 1: Almond industry committee structure

3.5 Development of detailed strategies for each of the issues/objectives

To assist the strategic direction of the project team, the industry's R&D plan was developed in 2010 with numerous R&D strategies (Figure 2). It was a significant role of the project team to actively participate and facilitate the development of the plan and subsequent implementation.

Figure 2: Almond industry R&D objectives and strategies

The project primarily focused on the following strategies:

- Strategy 2.1 - Establish practices to enhance product quality throughout the value chain
- Strategy 2.2 - Promote food safety practices from production through to consumption
- Strategy 2.3 - Develop and enhance product differentiation
- Strategy 3.1 - Improve productivity and competitiveness across the value chain

- Strategy 3.2 - Safeguard industry production and marketing systems from potential biosecurity threats
- Strategy 3.3 - Support sustainable almond production
- Strategy 3.4 - Facilitate access to superior plant material
- Strategy 4.1 - Enhance skills and capacity to support current and future industry needs
- Strategy 4.2 - Develop and deliver effective R&D programs that support the Strategic Plan
- Strategy 4.3 - Support adoption of R&D outcomes by effective extension
- Strategy 4.4 - Facilitate the two-way flow of information through the value chain

3.6 Identify gaps in the outputs required to achieve the strategies

The IDM and IDO facilitated gap analyses of the outputs required to achieve the strategies. The gap analyses were undertaken via consultation with the industry strategic committees, ABA staff, industry members and other key stakeholders.

A further key step in identifying gaps was an Advanced Almond Production System workshop held on 16th and 17th August 2011 in Adelaide, South Australia. The workshop was also part funded by project AL10009 – Investigating almond harvesting systems to improve product quality and efficiency.

34 participants including both industry members and outside expertise attended the workshop, with the key objective of undertaking a holistic evaluation of the supply chain, ensuring the Australian almond industry further enhances its quality reputation and safeguard it from food safety risks.

Almond industry advanced production system workshop, 16th and 17th August 2011 in Adelaide, South Australia

The need for such a workshop was born following a clear reminder in 2010 and 2011 that almond growing areas along the River Murray suffer from rainfall during harvest. 2010 alone incurred crop losses estimated to be greater than $20 million and tree deaths totalling approximately 200,000.

An analysis of historical weather records (Figure 3) indicated the wet weather experienced during the 2010 and 2011 harvests was not uncommon in Australia and something California does not experience (Figure 4). Yet, the Australian almond industry is exclusively based on Californian technology and planted to Californian varieties, which whilst widely accepted in the market place, are vulnerable to food safety concerns, especially when harvest occurs during wet weather. This vulnerability arises from their soft shell, lack of shell seal, susceptibility to fungal and microbial contamination, ground harvesting techniques, variable moisture levels and open storage facilities.

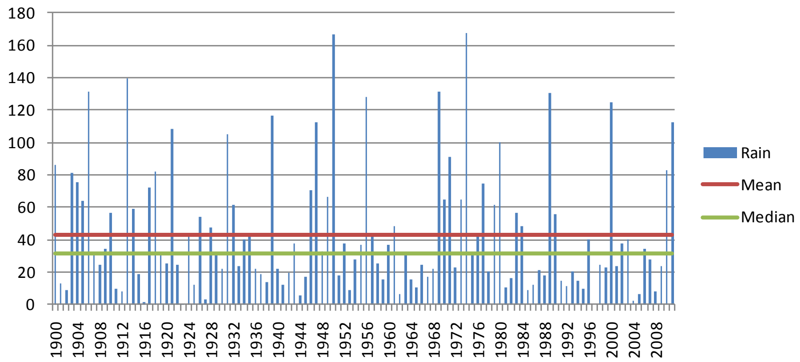


Figure 3: Mildura rainfall (mm), 15th February to 15th April 1900 to 2011. Mean average rainfall of 43mm or 1 in 3 years receive >50mm during the harvest period.

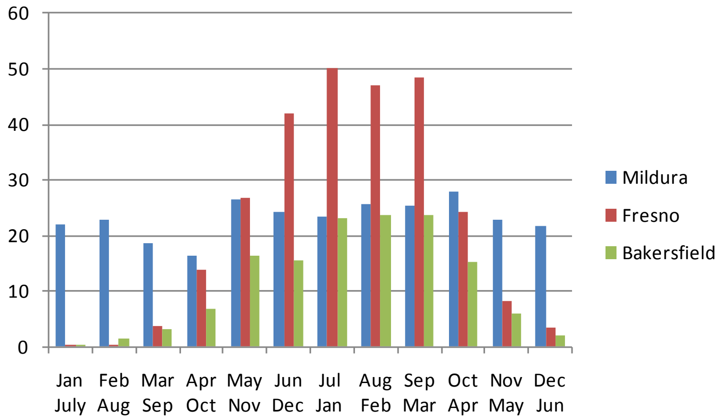


Figure 4: Average monthly rainfall (mm), Mildura (Australia), Fresno (California) and Bakersfield (California).

The workshop program consisted of presentations that set the scene by: attempting to outline a "normal" weather pattern for the period of almond harvest; describing experiences from the mechanisation and change in production system of the dried grape industry; experiences of a tree fruit contract mechanical harvester using both traditional almond harvesting equipment and shake and catch machinery; industry trials of alternative harvesting equipment; potential technological advances in almond processing; highlights from an international study tour; and a marketing view of product quality.

The participants were also divided into separate groups that spanned the current and newly proposed almond production system: production; harvest; aeration/dehydration; hulling on-farm; storage; processing; and marketing. Each group was asked to discuss the opportunities to maintain or improve yield, reduce production input costs, reduce crop loss, improve product quality and reduce food safety risks. Following this, the groups were asked to rate their discussions for feasibility of R&D and uptake by industry.

The R&D initiatives from the day's proceedings are summarised across the annual production cycle in Table 1. Many of the initiatives have been included in new R&D projects or are high priorities for future R&D as levy funds become available.

Table 1: Summary of workshop R&D initiatives across the annual almond production cycle necessary to advance the production system

Annual Production Cycle	R&D Initiative
Dormancy	• Improve methods of orchard sanitation; for example, engineering solutions to remove unharvested fruit (i.e. mummies). • Introduce almond varieties with lower chill requirement to assist earlier harvest and avoid autumn rains; for example, introduce harvest date as breeding selection criteria and evaluate overseas cultivars.
Bud Burst	• Promote evenness of bud burst to promote evenness of fruit maturity at harvest; for example, dormancy breaking chemicals, irrigation practices, nutrition practices, tree architecture, light interception and bud development.
Flowering	• Increase flowering efficiency; that is, flowers to canopy size ratio, thereby promoting a compact, efficient tree. Introduce these criteria in the evaluation of the Australian bred selections and overseas cultivars. • Investigate the effect of irrigation practices, nutrition practices, tree architecture, light interception and bud development on these criteria.
Fruit set	• Introduce self fertile and self pollinating (i.e. flower autogamy) almond varieties to remove the challenges of multiple passes and the mixing of harvested almonds. Evaluate this as part of the selection criteria within the Australian almond breeding program and evaluation of overseas cultivars.
Vegetative Growth	• Improve tolerance to diseases. For example, introduce varieties with good disease tolerance, particularly rust, thereby avoiding premature leaf drop and bud development. Research disease management strategies such as chemical choice and spray application. • Improve sustainable soil practices through organic matter, manures, cover crops, mulches, etc.
Fruit Growth	• Improve tolerance to pests and diseases; for example, breed or evaluate varieties with good pest and disease tolerance, particularly varieties with a complete shell seal, tolerance to insect damage and hull rot - thereby reducing mummification, avoiding point of infections, reducing crop loss, improving orchard sanitation and improving crop quality. • Research pest and disease management strategies with respect to irrigation and nutrition practices, chemical choice and spray application. • Improve sustainable soil practices through organic matter, manures, cover crops, etc.
Hull Split	• Improve the choice of varieties with improved shell seal; for example, breed or evaluate varieties with adequate shell seal.
Fruit Maturation	• Improve the choice of varieties with earlier harvest to avoid the autumn rains; for example, introduce harvest date as breeding selection criteria and evaluation criteria for overseas cultivars. • Increase the choice of varieties with minimal or no windfalls; for example, introduce this as breeding selection criteria and evaluation criteria for overseas cultivars. Research the potential for new management strategies to minimise chemical applications and the potential for earlier ('greener") harvesting.

	• Improve the evenness of fruit maturation; for example, canopy structure, tree architecture, light interception, etc. • If avoiding windfalls is a function of earlier harvest, at what point can "immature" fruit be harvested and dehydrated with no negative effects on fruit quality. Understand the causes and thresholds that lead to deteriorating product quality, in particular "soft" "doughy" fruit, unappealing browning of kernel skin, etc.
Harvesting	• Reduce or eliminate fruit contact with the ground; for example, evaluate and/or modify existing harvesting equipment or alternatives from other industries. Focus on achieving a one pass collect off the ground and/or shake and catch, reducing operator fatigue, increased efficiency, improved automation, improved guidance, yield mapping, the role of orchard design, tree densities, tree architecture, etc. • If shake and collect is successful, investigate efficient techniques to harvest and salvage saleable windfalls.
On-Farm Storage	• Improve methods and practices of de-hulling and storing both dried and "wet" fruit on-farm; for example, conditioning hulls for optimum de-hulling and contaminant removal/pre-cleaning on farm, silo storage, bunker storage, "bag" storage, dehydration, aeration, etc. • If de-hulling on-farm is successful, research techniques to re-use the hull as a soil amendment or fuel source (i.e. biofuel or co-generation) for dehydration.
Hulling & Shelling	• A desktop review of current equipment, processes and technology available from the most common and current hulling and shelling manufacturers. • A more thorough investigation of a hulling and shelling plant(s) to quantify and develop a better understanding of the sources of chips and scratches, i.e. on arrival (i.e. on farm) and/or at what stage(s) through the processing. • Storage in controlled environment to manage moisture; biological and physical contamination; shell and kernel damage. • Techniques to re-use the hull and shell as a soil amendment or fuel source (i.e. biofuel or co-generation) for dehydration. • Aeration / dehydration at huller and sheller of whole fruit. • Aeration / dehydration at huller and sheller of kernel. • Investigate the potential of de-husking (e.g. pin rollers) at the beginning of the lines to optimise in-shell yield and minimise what is being asked of the shear rolls and shear rolls over belts. That is, don't ask shear rolls to hull and shell, maybe use a pin roller for hulling and shear rolls for shelling. • Early removal of stones and other smaller contaminants prior to hulling and shelling. • Techniques and equipment to optimise flow and through put of product between stages. • Techniques and equipment to size grade in-shell product (i.e. small, medium & large) after the de-husking to enable more accurate setting of the shear roll tolerances. Then run the size grades through specifically adjusted shear rolls. • Investigate the shear rolls, shear roll over belts and cushioning to examine the cause of the damaged kernel and determine more optimum settings. If settings can be improved, investigate more efficient alternatives such as multiple stacks of shear rolls, etc. If settings can't be improved investigate other alternatives to shell almonds.

	• Investigate efficient physical cleaning processes via screening and air separation - after shelling but prior to sizing to remove broken shell, etc. This has a high success rate for cleaning product and can remove 90+% of most physical contaminants. Laser cleaning is not an appropriate sorting procedure here. • Size graded product (i.e. small, medium & large - not full industry sizing at this stage) over gravity tables once passed through the first physical clean. • Investigate efficient physical cleaning processes via screening, air separation & gravity tables - after size grading to small medium & large, to remove mouldy kernel, etc. Mostly based on density. This also has a high success rate for cleaning product and can remove 99+% of most physical contaminants. Laser cleaning is not an appropriate sorting procedure here. • Techniques and equipment to better size product to full range of industry sizes (i.e. 20/22, etc). • Performance and settings for laser cleaners removing discoloured contaminants from product already sized to full range of industry sizes. This is done prior to secondary processing.
Secondary Processing	• Performance and settings for repeat laser cleaning to remove chips, scratches, insect and rodent damage from industry sized product, at the packers, based on customer orders and specifications. However; ideally, if you have already: a) identified the causes of the chips and scratches and made machinery modifications to alleviate the issues, and b) laser sorted based on mould, the last laser sort will just be tuned (but highly tuned) to insect and rodent damage. Let packers decide the quality and value of pack but remove them of the pressure to clean contaminated product.
Marketing/Consumer	• Investigate the causes and therefore reduce detrimental colour, moisture, mould, kernel and shell staining, microbial contamination, physical contamination, chips and scratches. • Determine objective measurements for assessing product quality. • Determine and validate differences between Australian almonds and Californian almonds to assess whether there is a point of difference to obtain a competitive advantage in the market, e.g. flavour, colour, etc.

3.7 Ensure delivery of the outputs through scoping and commissioning R&D

The project team was actively involved in researching and determining the most appropriate R&D provider(s) by consulting with the R&D community, undertaking literature reviews, consulting with other industries, undertaking referee checks, etc. DPI Victoria were a critical partner in the almond industry's R&D program as they were and continue to be the almond industry's lead R&D agency under the Primary Industries Standing Committee (PISC) framework. However; where appropriate, multiple R&D providers were utilised to ensure R&D capability is optimised.

A list of the commissioned and pending R&D projects, developed by or with assistance from the project team, is provided in Table 2.

Table 2: Alignment of commissioned and pending R&D projects with the industry's R&D objectives and strategies

		Strategy										
HAL Project Code	**Project**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**4.3**	**4.4**
AL11703	Almond international networking	✓			✓	✓	✓	✓	✓			
AL11009	Food safety in almonds - Stage 2	✓	✓	✓	✓		✓					
AL12004	Managing carob moth in almonds	✓	✓	✓	✓		✓					
AL12003	Advance processing of almonds	✓	✓	✓	✓							
N/A	Renewable energy production from almond waste (Australian Renewable Energy Agency)				✓		✓					
N/A	Almond tree spray coverage and dose assessment (Geoff Furness)		✓		✓		✓					
AL12014	Parent project for minor use permits and chemical registrations for the almond industry				✓		✓					
AL09022	Herbicide efficacy, crop safety and residues in almonds when trifluralin is applied via sub-surface drip irrigation				✓		✓					
AL10018	Generation of phosphorus acid residue data to support the renewal of a MUP in almonds				✓		✓					
AL11013	Generation of residue data for pesticide minor use permit applications in almond tree crops (abamectin permit)				✓		✓					
N/A	Screening almond rootstocks for resistance to *Meloidogyne* nematodes (CSIRO)				✓		✓	✓				
AL11012	Evaluation of potential *prunus* rootstocks for almond production				✓		✓	✓				
AL12010	Impact of strategic deficit irrigation for almonds on tree phenology, bloom, nut set and hull rot				✓		✓					
AL12008	PhD student to investigate fruit set and plant physiology in Almonds				✓		✓					
AL10001	Review of PEQ conditions for imports of almond germplasm				✓	✓	✓	✓				
MT12005	Development of molecular diagnostic tools to detect endemic and exotic pathogens of Prunus species for Australia				✓	✓	✓	✓				
AL12011	Monash remediation				✓	✓	✓	✓				
AL10009	Developing almond harvesting systems to improve product quality and efficiency	✓	✓	✓	✓		✓		✓	✓	✓	
AL12013	Usage of robotics technology for the Australian almond industry				✓		✓					
AL11003	Enhancing almond pollination efficiency				✓	✓	✓					
MT09026	Protecting pollination for the Australian horticultural industry Stage 2					✓	✓					
MT10058	Biosecurity implementation to strengthen Australia's honey bee and pollination responsive industries					✓	✓					
MT10063	Remote sensing of beehives to improve surveillance					✓	✓					
MT11033	Surveillance of Asian Honey Bee - proof of concept					✓	✓					

		Strategy										
HAL Project Code	**Project**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**	**3.3**	**3.4**	**4.1**	**4.2**	**4.3**	**4.4**
MT11034	National honey bee pest surveillance workshop					✓	✓					
AL12009	Quantitative benchmarking for the Australian almond industry				✓		✓					
AL09014	Australian almond industry study tour of California				✓		✓		✓			
AL09017	Phil Watters award				✓		✓		✓			
AL09021	Australian almond industry - liaison and extension project		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AL12000	Australian almond industry - liaison and extension project		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AL11702	Australian almond industry conference 2011 & 2012	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AL09029	Australian almond industry R&D strategic plan 2011-16	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AL12800	2012/13 almond industry annual report										✓	✓
AL12910	Almond funding agreement 2012-13								✓	✓		✓
MT11006	Attracting and retaining young professionals in horticulture								✓			
AL10011	Developing a capacity to weigh and process almonds at harvest for R&D trials									✓		
AL12005	Benchmarking for current strategic investment plan 2011-16									✓	✓	

3.8 Assist implementation of the strategies that achieve industry outcomes through extension and technology transfer

The activities and outputs achieved by the project team through extension and technology transfer are provided in Table 3.

All Fact Sheets mentioned in Table 3 are available on the Australian almond industry website.

Table 3: Extension and technology transfer activities and outputs achieved by the project team

Issue	Industry R&D Strategy	Activity	Output
Breeding and Evaluation			
Australian bred almond cultivars • The Australian almond industry is largely planted to three cultivars (Nonpareil, Carmel and Price) which all have certain agronomic limitations and consequently reduced productivity and increased Biosecurity risks. The industry has invested in a cultivar breeding program (AL08000) to improve on the current choice. Some of the early selections are nearing commercialisation.	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 3.4 • Strategy 4.3	• Extension and technology transfer of AL08000.	• 1 x field day with AL08000 project leader and Burchell Nursery Inc from California, in Lindsay Point, Victoria. • Short list of promising varieties selected for a pre-commercialisation trial. • 1 x Fact Sheet (Appendix 1.1): *Breeding for Self-Fertility in Almonds*.
Californian bred almond cultivars • The ABA has imported several cultivars from California which haven't been evaluated in Australian conditions.	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 3.4 • Strategy 4.3	• A field day (September 2010) with Californian almond breeder and nursery (Burchell Nursery Inc). • 2 years of phenological and yield evaluations.	• 1 x field day. • Fact Sheets on the performance of the Californian varieties are in draft preparation.

Issue	**Industry R&D Strategy**	**Activity**	**Output**
Spanish bred almond cultivars The ABA and AL08000 have imported several cultivars from Spain which haven't been evaluated in Australian conditions.	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 3.4 • Strategy 4.3	• 1 year of phenological and yield evaluations.	• Too early for trees to be selected for Australian commercialisation as the trees have only had one small harvest. Further evaluation is planned. If commercialisation of a variety(s) is applicable, PBR applications and Fact Sheets will be completed.
Screening almond rootstocks for resistance to *Meloidogyne* (Root-Knot) nematodes. • Glasshouse based screening of Almond rootstocks for root-knot nematode resistance undertaken by CSIRO, Plant Industry.	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 3.4 • Strategy 4.2	• Supply 18 rootstocks at 20 tree replicates to CSIRO. • Almond orchard soil sampling in three of the major almond growing regions (Adelaide, Riverland and Sunraysia). • Identification of root-knot species. • Bulking up of root-knot species from almond orchards.	• Sub-contracting of CSIRO, Plant Industry. • Trial is in progress.

Issue	Industry R&D Strategy	Activity	Output
Tree Production			
Facilitate access to superior plant material	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 3.4	• Site management of almond industry budwood repository. • Agreement on minimum criteria to enable the development of an almond industry budwood/nursery certification and trademark scheme.	• Supply of pathogen tested, true to type almond budwood to nurseries.
Pollination			
Almond pollination efficiency • The almond industry is Australia's largest user of paid pollination services. Because of this dependent relationship between growers and beekeepers, the growers are vulnerable to the effects of rises in beekeepers fees or a shortage of hives to perform the crucial service. In this light it is important the almond growers know how to maximise the efficiency of the pollination service.	• Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.2 • Strategy 4.4	• Preliminary extension and technology transfer of Enhancing Almond Pollination Efficiency (AL11003).	• 1 x Fact Sheet (Appendix 1.2): *Pollination Basics 101*.

Irrigation and Fertiliser Management			
Irrigation and integrated orchard management			
• Dr. Bruce Lampinen travelled to Australia for an international conference and a visit to the almond growing regions (Adelaide and Riverland) was organised followed by a workshop on: irrigation and canopy management as it relates to light interception, spur longevity and ultimately orchard productivity; and the role of orchard management and stockpiling of almonds in food safety risks (e.g. orchard and stockpile conditions as related to Salmonella and aflatoxin potential).	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.3 • Strategy 4.2	• Several orchard visits. • A workshop (February 2009) in the Riverland presented by Dr. Bruce Lampinen (University of California, Davis).	• 1 x workshop. • 1 x presentation handout provided to attendees and available on the website.

Issue	Industry R&D Strategy	Activity	Output
Irrigation maintenance • Programmed preventative maintenance of irrigation systems is an important management practice to ensure uniform water distribution. This was of even more importance through the drought period when minimal water applications were adopted.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Workshops (May 2009) in each of the four major growing regions (Adelaide, Riverland, Sunraysia and Riverina) with Netafim, a major irrigation manufacturer.	• 4 x workshops. • 1 x irrigation maintenance manual distributed to all growers and available on the Netafim website.
AL07005 – Sustainable optimisation of Australian almond production • The extension and technology transfer of AL07005 has been a major role for the project team through this current project and the previous industry development project (AL07008).	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Hard copy and verbal activities to extend and transfer the results of AL07005.	• Presentation at the 2009 and 2011 almond industry conference with the proceedings available on CD. • 4 x Fact Sheets (Appendix 1.3, 1.4, 1.5 and 1.6): *Crop Nutrient Removal; Almond Orchards and Soil Acidification; Balancing Nutrient Inputs and Outputs – CT Trial Results; and Timing Nutrient Inputs for the Best Effect*. • 1 x Final Report including a database management support tool.

Issue	Industry R&D Strategy	Activity	Output
AL08009 –Optimising water use of Australian almond production through deficit irrigation strategies • Under Australian inland climatic conditions there is currently limited information on the potential for deficit irrigation on water balance and production of almonds. Given that water is an increasingly limited resource along the lower Murray River there is a need to systematically assess the sustainability of deficit irrigation in almonds and provide clear and definitive guidelines to industry.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Hard copy and verbal activities to extend and transfer the results of AL08009.	• Presentation at the 2009 and 2010 almond industry conference with the proceedings available on CD. • 1 x field day at the trial site to discuss and observe the findings.
Almond nutrition management: leaf • A leaf nutrient composition survey was undertaken across representative orchards to understand nutrient composition and accumulation versus yield effects and tree performance.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Industry survey and statistical analysis.	• 1 x Fact Sheet (Appendix 1.7): *Leaf Tissue Analysis Review*. • Proposed new critical values (CV's) for leaf nutrient analysis.
Almond nutrition management: fruit • A fruit nutrient composition and removal survey was undertaken across representative orchards to understand nutrient composition and accumulation versus fertiliser applications.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Industry survey.	• 2 x Fact Sheets in draft format.

Issue	Industry R&D Strategy	Activity	Output
Almond nutrition management • Optimal almond nutrition management has been a key management priority across the industry. The interaction of plant physiology and fertiliser applications is critical in optimising yield and minimising unnecessary fertiliser costs.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• A workshop (September 2009) with Professor Patrick Brown (University of California, Davis), was organised by a third party company. An additional almond session was organised by the project team to complement the general horticulture session.	• 1 x workshop and handout.
Pest and Disease Management			
Minor Use Permits	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Liaising with industry to determine gaps in chemical control of pests and diseases. • Renew minor use permit applications.	• Renewal of 9 x Minor Use Permits (MUP): Phosphoric Acid, Chlorpyrifos, Propiconazole, Trifluralin, Pirimicarb, Abamectin, Pymetrozine, Azoxystrobin and Bifenazate.
Strategic Agrichemical Review Process (SARP) • The project team helped facilitate and organise the 2012 almond SARP workshop.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• The 2012 almond SARP workshop was attended by 20 individuals. The attendees were a mixture of growers, IPDM consultants, quality assurance staff and chemical manufacturers.	• 1 x workshop. • A shortlist or potential chemical control options for gaps in the pest management of almonds.

Issue	Industry R&D Strategy	Activity	Output
Almond Pest and Disease Management • The project team joined with Fruit Doctors Pty Ltd, a leading pest and disease consultant; and Peter Magarey, project leader of Improving the Management of Almond Rust (AL06007) to educate the industry on integrated pest management and extending the results of AL06007.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Workshop (September 2010) in each of the four major growing regions with Fruit Doctors Pty Ltd and Peter Magarey.	• 5 x workshops (2 x Sunraysia). • 10 x hand lens supplied to workshop participants for pest identification. • 1 x Fact Sheet (Appendix 1.8), *Managing Rust in Almonds*.
AL09022 – Herbicide efficacy, crop safety and residues in almonds when trifluralin is applied via sub-surface irrigation systems • 90% of the Australian almond industry is irrigated with drip irrigation and there is potential to increase water use efficiency and ease of orchard operations by burying the drip lines.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2	• The project team assisted project AL09022 in preparing, implementing and assessing the effectiveness of trifluralin to prevent root-intrusion, when it is applied to almonds via subterranean drip-irrigation across two trial sites.	• Data to support registration of trifluralin.
AL10018 – Generation of phosphorus acid residue data to support the renewal of a MUP in almonds • The Australian almond industry required additional data to extend and expand the MUP that existed.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.2	• The project team assisted project AL10018 in preparing, implementing and assessing the effectiveness of phosphorus acid to control *Phytophthora* in almonds.	• Data to support the MUP application of phosphorus acid.

Issue	Industry R&D Strategy	Activity	Output
Spray Coverage, Spray Drift, Sprayer Maintenance and Accreditation • A 2 day workshop was organised with Craig Day and James Wright to educate the industry on Drift Reduction Technology (DRT), spray coverage, sprayer maintenance and obtain chemical user accreditation to level 3 or 4.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.2 • Strategy 4.3	• Workshops (November 2010 and 2011) in each of the four major growing regions with Craig Day and James Wright.	• 4 x workshops. • Level 3 or 4 chemical user accreditation for course participants.
Spray coverage and dosage assessment • The 2011 season highlighted vast differences in the control of almond rust in the industry. Before continuing a disease epidemiology R&D project (AL06007), a survey of practices was conducted. Survey results concluded there were both good and poor control and the variation lay in better management decisions such as: chemical choice; spray timing; spray equipment; and application practices. The survey highlighted both the need for best practice adoption and provided a strong insight into the requirements of high disease pressure periods. To assist this, Geoff Furness (ex SARDI) who is an acknowledged expert in the field of spray application, was engaged to undertake field and laboratory evaluations of various spray coverage and dosage scenarios.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.1 • Strategy 4.2 • Strategy 4.3	• Evaluation and assessment of three spray machines and various set-up combinations (2011/12 season). • Demonstration of the results to those co-operating orchards.	• Preliminary report outlining the effectiveness of the three spray machines (Appendix 2).

Issue	Industry R&D Strategy	Activity	Output
Weather forecasting and observations • A workshop was organised with the Bureau of Meteorology (BOM) to educate the industry on weather forecasting, interpreting weather observations, understanding weather patterns etc, and navigate the BOM website.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.1 • Strategy 4.2 • Strategy 4.3	• Field days in each of the four major growing regions with BOM staff.	• 4 x field days.
Mice • Liaise and engage Dr Peter Brown of CSIRO to assess the likely threat of mouse numbers during the 2011/12 season. This was considered critical as the 2011 mouse plague and lack of suitable information lay at the heart of salmonella detections within industry in 2011.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.1 • Strategy 4.3	• Various activities of extension and technology transfer.	• 2 x field days. • Personal visits to 3 (of 4) hullers and shellers. • Personal visits to 2 (of 4) packers. • Almond industry report for the management of mice (Appendix 3). • 1 x Fact Sheet (Appendix 1.9) to summarise: *Managing Mice for the Australian Almond Industry*.
Carob moth • The wet and mild seasons of 2010/11 and 2011/12 have led to an explosion in Carob Moth populations, mainly in the Riverland and Sunraysia growing regions. Carob Moth causes boring damage to the almond kernel and thus reduces final product quality and increases food safety risks. If left unaddressed, this issue could have damaged product worth tens of millions of dollars.	• Strategy 2.1 • Strategy 2.2 • Strategy 3.1 • Strategy 3.2 • Strategy 3.3 • Strategy 4.1 • Strategy 4.2 • Strategy 4.3	• To bring this pest under control work was undertaken with APVMA, Peter Dal Santo, chemical companies, and producers in pursuing one Emergency Use Permit for chemical control. • Chemical company (DuPont and Dow Agro) R&D, trialling efficacy and residue for full chemical registration.	• 1 x Emergency Use Permit for Chlorantraniliprole. • 1 x new R&D project, Managing Carob Moth in Almonds (AL12004).

<table>
<tr><th>Issue</th><th>Industry R&D Strategy</th><th>Activity</th><th>Output</th></tr>
<tr><td colspan="4">Food Safety</td></tr>
<tr><td colspan="4">AL09027 – Food safety in almonds</td></tr>
<tr><td>The Australian almond industry and scientific community will benefit from improved awareness of the field and post-harvest conditions that influence food safety in almonds. This project undertook three main tasks to increase awareness and understanding of the potential for food safety issues in almonds. This project also provided direction for the development of a more detailed food safety project (AL11009).</td><td>Strategy 2.1
Strategy 2.2
Strategy 3.1
Strategy 3.2
Strategy 3.3
Strategy 4.1
Strategy 4.2
Strategy 4.3</td><td>Hard copy and verbal activities to extend and transfer the results of AL09027.</td><td>1 x Fact Sheet (Appendix 1.10): What Threatens the Safety of Almonds?
Presentation at the 2010 almond industry conference with the proceedings available on CD.</td></tr>
<tr><td colspan="4">Post Harvest</td></tr>
<tr><td colspan="4">Advanced production systems: post harvest</td></tr>
<tr><td>The wet harvests of 2011 and 2012 revealed deficiencies in the production systems that have Californian origins. To advance this area, a relationship with the Associate Professor John Fielke from the University of South Australia was developed.</td><td>Strategy 2.1
Strategy 2.2
Strategy 2.3
Strategy 3.1
Strategy 3.2
Strategy 3.3
Strategy 4.1
Strategy 4.2
Strategy 4.3</td><td>Preliminary review of almond orchards and processing facilities.
4th year mechanical engineering students undertook almond industry projects as part of their undergraduate degree.
Industry communication.</td><td>1 x preliminary report (Appendix 4): Review of Australian almond processing industry.
1 x Honours Thesis (Appendix 5): Identifying sources of mechanical damage in almond processing.
2 x reports by travelling overseas students (Appendix 6 and Appendix 7): Performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell; and Understanding the performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell.
Several presentations by John Fielke in separate forums, communicating the results to date to industry.</td></tr>
</table>

Issue	Industry R&D Strategy	Activity	Output
Alternative uses of almond waste • Almond waste (hulls and shells) are approximately 70% of the harvested weight and with the increase in production waste quantities are expected to reach over 200,000 tonnes by 2015. The objectives of this project were to: establish current energy demand across almond industry producers, processors and packers; assess technological options for energy production, including multi-use options that may enhance attractiveness of bioenergy; and conduct a preliminary economic analysis of the commercial viability of energy production. In conducting the energy demand analysis sufficient data will be collected to prepare a carbon footprint analysis.	• Strategy 1.2 • Strategy 2.3 • Strategy 3.1 • Strategy 3.3 • Strategy 4.2	• Industry visits and energy audits. • Preliminary investigations into the range of alternative uses and economic feasibility for almond waste.	• Successful grant application for funding from the Australian Renewable Energy Agency (ARENA). • Sub-contracting of a consultancy team. • 4 x orchard visits and information collected for energy audits. • 4 x visits to processing facilities and information collected for energy audits. • 4 x visits to packing facilities and information collected for energy audits.

Issue	Industry R&D Strategy	Activity	Output
Operating Environment			
International networking • Enhance and further develop relations with our competitors and international colleagues.	• Strategy 4.1	• Two international tours were undertaken to learn from advances occurring outside of Australia. • One international trip to speak at the 2009 Californian almond conference. • Host reciprocating visits by Californian and Spanish colleagues.	• 1 x Californian study tour (AL09014) organised by the project team for 26 industry participants and completion of study trip report. • 1 x Californian and Spanish study tour (AL10009) organised by the project team for 3 industry participants and completion of study trip report. • 1 x Californian visit by the IDM to present at the 2009 Californian almond conference. • 1 x hosting a visiting contingent of 10 Spanish colleagues undertaking a 10 day Australian almond industry tour. • 1 x hosting 2 colleagues from the Almond Board of California who spoke at the 2011 Australian conference and undertook a 3 day Australian almond industry tour.
Domestic networking • Enhance and further develop relations with horticultural commodities and research.	• Strategy 4.1	• One domestic study tour to Shepparton to learn from advances in: soil (i.e. “super soils”) research conducted by Dr. Bruce Cockroft; and pomefruit industry management practices related to almonds.	• 1 x two day domestic study tour to Shepparton undertaken by 38 industry participants.

Issue	Industry R&D Strategy	Activity	Output
AL09017 - Phil Watters award • The aim of the award was to recognise service to the almond industry, in particular a dedication to research and development, adoption of best practice and promotion of horticulture to the community.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.1 • Strategy 4.3 • Strategy 4.4	• 2009 and 2011 nominations sought. • 2009 (Craig Spilsbury) and 2011 (Dean Dinicola) recipients awarded.	• 1 x international study tour (California and Israel), final report and industry presentation (Craig Spilsbury). • 1 x international study tour to California (Dean Dinicola).
Almond industry regional meetings • The project team undertook annual regional meetings in each of the four major growing regions.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.1 • Strategy 4.3 • Strategy 4.4	• Presentations outlining marketing and supply chain R&D activities.	• Presentations outlining marketing and supply chain R&D activities.
General grower education • Select Harvest Ltd (SHV) is Australia's second largest almond producer with over 4,000 ha of orchards. The project team has supported SHV in up-skilling and building the capacity of their orchard staff.	• Strategy 3.1 • Strategy 3.3 • Strategy 4.1 • Strategy 4.3 • Strategy 4.4	• Industry presentations, orchard walks and tours for approximately 15 key orchard staff.	• Numerous industry presentations, orchard walks and tours for approximately 15 key orchard staff.
AL10011 – Developing a capacity to weigh and process almonds at harvest to enhance the efficiency of trials • With the industry R&D investment increasing and the consequential need to infield weigh and efficiently process statistical sub-samples, a new method and purchase of more efficient equipment was required.	• Strategy 4.2	• Research and purchase the most appropriate local and imported equipment to weigh and process small sub-samples of almonds.	• 2 x pallet scales. • 1 x mini almond huller and sheller from California.

Communications			
• 2009, 2010 and 2011 Australian almond conference – active involvement in conference program. • In preparation for producing the production manual for the Australian almond industry a solar powered, weather proof time lapse camera was purchased and gathered photos on fruit and canopy development to illustrate the phenological growth stages. • General photography • Social media	• Strategy 4.3 • Strategy 4.4	• Industry presentations. • Photography. • Preliminary development of a social media platform.	• Presentations at the 2009, 2010 and 2011 industry conference. • Pictorial library of almond phenology and management activities. • Almond industry Facebook page, YouTube account, Twitter account, and Blog page.

4 EVALUATION AND MEASUREMENT OF OUTCOMES – IMPACT AND ADOPTION

The project team have employed various forms of evaluation and measurement to assess the outcomes of the AL09021 project, including:

- Feedback forms following field days, workshops, seminars and conferences.
- Facilitate and provide the opportunity for feedback, evaluation and measurement through industry and member representation within its committee structure, in particular the Production, Plant Improvement and Processing Sub-committees.

4.1 Feedback Forms

Feedback forms are given out at field days, workshops and seminars (Appendix 8). Feedback (Table 4) indicates the extension activities provided the participants with more information than expected and were delivered with high quality. The most pleasing feedback indicates 83% of participants intended to implement the knowledge from the activities into their business.

Table 4: Almond grower feedback summary from field days, workshops and seminars (life of project)

	Less than expected			More than expected	
	1	2	3	4	5
Did the course provide you with what you expected to learn?	0%	2%	38%	45%	14%
Was the level of detail enough? If not, what else could be included?	0%	0%	23%	59%	18%
Overall, how satisfied are you with the quality of the course content?	0%	0%	23%	37%	40%
Overall, how satisfied are you with the quality of the course materials?	1%	1%	5%	35%	49%
Overall, how satisfied are you with the way the course was presented by the presenter?	1%	1%	17%	27%	54%

	YES	NO	UNSURE
Do you intend to implement the knowledge from this training into your business?	83%	1%	14%

	Particular Need	Course Content	Location	Timing	Training Provider	Training Delivery Style	Other
What was the main reason for choosing this training?	7%	55%	35%	22%	16%	5%	5%

	Email	Internet	Fax	Post	Other
How did you find out about the course?	95%	0%	1%	7%	2%

4.2 Testimonials

On the bottom of each feedback form there is a space for further comments on the activities undertaken by the project team. A selection of representative comments is provided below.

- "Very good course for top up information and a few new ideas."
- "It was good to see the ABA in the Riverina and would like to see more of you."
- "All good. Everything was relevant and easy to understand."
- "A very good day, well organised."
- "Good to keep in touch with overseas researchers."
- "Excellent presentation but bit too hard to hear. Possibly use loudspeaker as air-conditioning drone was noticeable at back."
- "Very informative."
- "Good presentation/time allocation, good discussion, good venue, good materials provided - well done!"
- "Great course, well run. Got more than expected out of the course and would definitely recommend to others."
- "Good informative session - thanks. Would like a follow up with more specific almond industry info including orchards, storage & processing facilities."
- "Well delivered, packed a lot in, but more time required for such a complicated topic."
- "Nice to have regional meetings."
- "More of these events. A bit more info or handouts would be helpful. Thank you for the organising of the event, these things are so important to the grower. Well done guys."

5 DISCUSSION

The Australian Almond Industry Liaison and Extension project (AL07008) was undertaken over the 2009/10, 2010/11 and 2011/12 seasons. The project essentially occurred in two sections. Firstly, it began with an initial focus of completing the major extension and development activities from Sustainable Optimisation of Almond Production (AL07005) in addition to numerous topical issues that evolved. Secondly, a focus on issue identification, gap analyses, development of detailed strategies, scoping and commissioning R&D, and further extension and technology transfer of R&D outcomes and emergent issues. The expanded role in the second half of the project was due to a greater than 100% increase in levy collection (from the end of the AL07008 to the end of AL09021) resulting from the maturing orchards planted through the expansion period of the mid 2000's. The expanded role was critical in facilitating R&D investment to meet the growing industry's needs. The second half of the project was made possible through additional resources with the employment of Brett Rosenzweig as the IDO.

The project achieved a successful, hands-on connection between industry, R&D providers and other stakeholders by undertaking, developing or facilitating:

- Scoping and commissioning 37 new R&D projects.
- Management of almond industry budwood repository.
- R&D decision support tool (water and fertiliser management spreadsheet, AL07005).
- 9 minor use permits.
- Greater than 30 field days/workshops/seminars.
- 10 Fact Sheets.
- Numerous project reports.
- Hosting international study tours.
- 16 industry committee meetings representing greater than 90% of Australian almond acreage.
- 8 regional meetings.
- 5 international study tours incorporating 32 (17%) of industry members or greater than 20% of Australian almond acreage.

- 1 domestic study tour incorporating 38 (20%) industry members or approximately 80% of Australian almond acreage.

Outcomes from the project include:

- Australian almonds have maintained their high quality reputation.
- Industry safeguarded from potential Biosecurity threats.
- Pollination management has become a minor risk.
- Orchards have maintained productivity.
- Increased environmental sustainability.
- Improved understanding of almond water and nutrient requirements.
- Australian almond industry provided with consistent supply of world leading rootstocks and varieties.
- Improved pest and disease management.
- Improved packouts and grower returns.
- Reduced food safety risk.
- Stakeholders across the value chain are engaged and informed.
- Decision making across all areas of the almond value chain are supported through access to timely and relevant information.
- Outputs from R&D projects are communicated to industry.
- R&D projects commissioned achieve outputs through decision support tools.
- R&D projects commissioned achieve outputs through effective extension.
- High level uptake of R&D outcomes by industry.
- Industry capacity enhanced through knowledge development.

Evaluation of change as a result of the industry development project is illustrated with 83% of participants who attended the various field days, workshops and seminars intending to implement the knowledge and training into their businesses.

6 RECOMMENDATIONS

It is a consequence of the need to continue almond industry development that a new project be lodged, contracted and further evaluated to ensure: industry issues are identified; detailed R&D strategies are developed; gaps are identified in the outputs to achieve the strategies, delivery of the outputs through scoping and commissioning R&D, and implementation of the strategies that achieve industry outcomes through effective extension and technology transfer.

7 ACKNOWLEDGMENTS

This project would not have been possible without funding by HAL using the almond industry levy and voluntary contributions from industry and matched funds from the Australian Government. The project team would also like to acknowledge the valuable and voluntary contributions by industry members and stakeholders; in particular those who participate in the Production Committee, Plant Improvement Committee, Processing Committee, Industry Advisory Committee, and ABA Board. Furthermore, the project team would also like to acknowledge the proficiency and efforts of the almond research community and the vital industry partners who host the industry trials, extension and technology transfer activities.

8 BIBLIOGRAPHY

AL01001: Developing Optimal Nutritional and Irrigation Requirements for Almonds, Milestone Reports, Horticulture Australia Ltd, 2001 -2004

AL04009a: Developing Optimal Nutritional and Irrigation Requirements for Almonds, Milestone Reports, Horticulture Australia Ltd, 2004 - 2005

AL05002: Developing Optimal Nutritional and Irrigation Requirements for Almonds, Milestone Reports, Horticulture Australia Ltd, 2005 - 2006

AL06004: Developing Optimal Nutritional and Irrigation Requirements for Almonds, Milestone Reports, Horticulture Australia Ltd, 2006 – 2007

AL06004: Developing Optimal Nutritional and Irrigation Requirements for Almonds, 2006-2007 Grower Progress Report, August 2008

AL07005: Sustainable Optimisation of Almond Production, Milestone Reports, Horticulture Australia Ltd, 2007 – 2009

AL07005: Sustainable Optimisation of Almond Production, 2007-2008 Grower Progress Report, September 2008

AL07005: Sustainable Optimisation of Almond Production, 2008-2009 Grower Progress Report, February 2010

AL07008: Australian Almond Industry Liaison and Extension Project, Milestone Reports, Horticulture Australia Ltd, 2008 -2009

AL07011: Final Report: European Study Tour 2007, Horticulture Australia Ltd, 2007

AL08000: Australian Almond Breeding Program Stage 2 – Secondary Evaluation, Milestone Reports, Horticulture Australia Ltd, 2008 -2009

Australian Almond Statistics 2011 Report, Almond Board of Australia, 2012

Industry Development Needs Assessment Process: Guideline 2:1 - Understand What is Industry Development, Horticulture Australia Limited, July 2008

9 APPENDICES

Appendix 1 – Fact Sheets – All About Almonds

Appendix 1.1 – Fact Sheet: Breeding for Self-Fertility in Almonds

Breeding for self-fertility in almonds

Dr Michelle Wirthensohn
The University of Adelaide, PMB 1, Glen Osmond,
South Australia 5064, Australia

This example illustrates the importance of self-incompatibility and self-fertility in the breeding of a tree crop.

Many commercial cultivars of almond *(Prunus dulcis)* are self-sterile (self-incompatible) (Figure 1a and 1b).
When a self-sterile cultivar is grown in a commercial orchard, polleniser varieties must also be planted to ensure fruit set. Self-fertility would therefore be very useful for almond producers.

Self-fertility occurs in peach and could be introduced into almond by breeding, but many years of backcrossing would be needed to eliminate peach characters. Graselly and Olivier (1976) discovered that some Italian almond cultivars are naturally self-fertile. These cultivars can be used as sources of self-fertility in almond breeding.

Self-incompatibility and self-fertility

In almond, self-incompatibility is under the genetic control of a gene on chromosome 6 (Ballester *et al*. 1997), with at least 40 alleles (*S1* to *S39*, and *Sf*) which encode glycoproteins known as S-RNases. When expressed in the style of a flower, S-RNases recognise and degrade RNA from pollen tubes that have grown from pollen grain with matching *S* alleles. For example, an almond cultivar with the genotype *S1S2* will express *S1* and *S2* S-RNases, which will stop the growth of *S1* and *S2* pollen tubes (Figure 2) but allow other pollen tubes (*S3*, *S4*, etc.) to continue growing (Figures 2 and 3). This type of self-incompatibility, which occurs in the Rosaceae, Solanaceae and Gramineae families, is called gametophytic self-incompatibiltiy because it relies upon recognition of the haploid genotype of the male gametophyte (pollen).

Naturally self-fertile almond trees carry a dominant *Sf* (self-fertility) allele, which is thought to encode a non-functional S-RNase which does not recognise its own pollen and does not degrade the pollen tube.

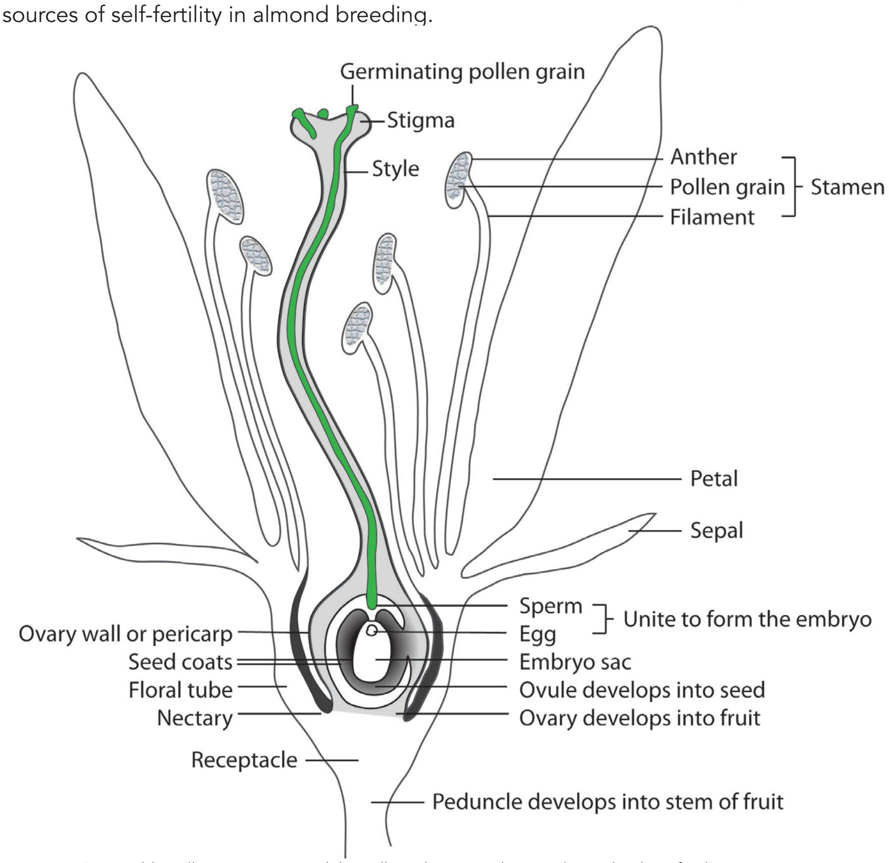


Figure 1a. Compatible pollen germinates and the pollen tube grows down to the ovule where fertilization occurs.

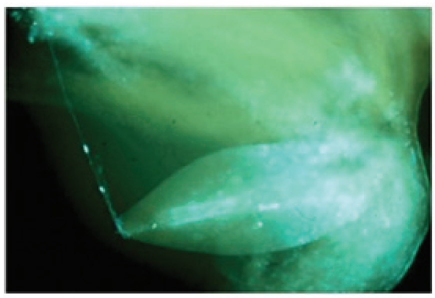


Figure 1b. Compatible pollen tube enters micropyle end of ovule

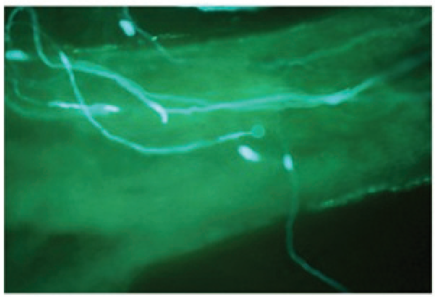


Figure 2. Pollen tubes arrested in the top one-third of the style due to S-allele incompatibility

Self-incompatibility and self-fertility in almond breeding

With knowledge about the *S* genotypes of trees, almond breeders can predict which crosses will be possible and what *S* genotypes can be expected among the progeny (Table 1).

The Australian Almond Breeding Program has used molecular markers based on PCR primers designed from the sequences of the introns of the *S*-alleles (Channuntapipat *et al.* 2003; Ortega et al. 2005) to identify the *S*-alleles of Australian cultivars. These markers have been used to confirm genotypes of imported parental cultivars and to test selected progeny. For a breeder, knowledge of which incompatibility group a tree belongs to is important. For example when pollen from an S1Sf tree is applied to the stigmas of an *S1S2* tree the breeder can expect that all *S1* pollen tubes will be degraded and that all progeny will be *S1Sf* or *S2Sf* and will be self-fertile.

The Australian Almond Breeding Program has used selected clones from France and Spain as sources of self-fertility. When these parents (genotypes *SfS1*, *SfS2*, *SfS3*, *SfS8* and *SfS9*) are crossed with self-incompatible cultivars such as Nonpareil (an important cultivar in Australia, genotype *S7S8*) some progeny are self-fertile and others are self-incompatible. Several self-fertile progeny clones are now in advanced stages of testing, with the objective of selecting one that will combine self-fertility with the desirable horticultural and product quality traits of Nonpareil.

Conclusion

Most almond clones will not set fruit unless pollinated by trees of different incompatibility genotypes. Accurate identification of *S* genotypes is useful in designing crosses and selecting progeny in breeding programs and for choosing compatible combinations for use in commercial orchards. Discovery of a naturally occurring allele for self-fertility made it possible to develop self-fertile cultivars of almond.

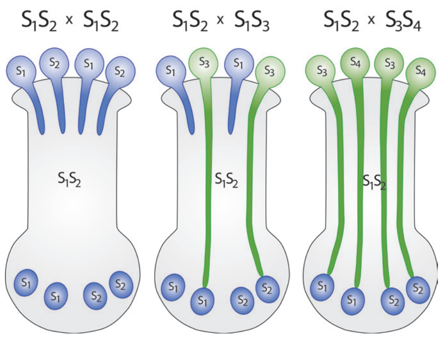


Figure 3. Gametophytic self-incompatibility system. Germination of pollen grains, which carry one of the same S-alleles as the pistil, is inhibited in the upper style.

Table 1. Expected genotypes and self-fertility status of progeny from various crosses.

Female parent	Male parent	Compatible	Progeny	Self-fertile progeny
S1S2	S1S2	No		
S1S2	S1S3	Yes	S1S2, S1S3	No
S1S2	S3S4	Yes	S1S3, S1S4, S2S3, S2S4	No
S1S2	S1Sf	Yes	S1Sf, S2Sf	100%
S1S2	S3Sf	Yes	S1S3, S2S3, S1Sf, S2Sf	50%

References

Ballester J, Boskovic R, Batlle I, Arùs P, Vargas F and de Vicente MC, (1997) Location of the self-incompatibility gene on the almond linkage map. *Plant Breeding* 117,69-72.

Channuntapipat C, Wirthensohn M, Ramesh SA, Batlle I, Arùs P, Sedgley M and Collins G (2003) Identification of incompatibility genotypes in almond (Prunus dulcis Mill.) using specific primers based on the introns of the S-alleles. *Plant Breeding* **122**,164-168.

Dicenta F and Garcia JE (1993) Inheritance of self-compatibility in almond. *Heredity* **70**,313-317.

Grasselly C and Olivier G (1976) Demonstration of some self-compatible types amongst almond tree cultivars (P-amygdalus Batsch) of Apulian population. *Annales de L Amelioration des Plantes* **26**,107-113.

Ortega E, Sutherland BG, Dicenta F, Boskovic R and Tobutt KR (2005) Determination of incompatibility genotypes in almond using first and second intron consensus primers: detection of new S alleles and correction of reported S genotypes. *Plant Breeding* **124**,188-196.

For further information contact Brett Rosenzweig, Industry Development Officer

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

HAL Horticulture Australia

ACKNOWLEDGEMENTS
The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER
Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.2 – Fact Sheet: Pollination Basics 101

Pollination Basics 101

Brett Rosenzweig[1]; Dr Saul Cunningham[2]; Dr Michelle Wirthensohn[3]

[1]Almond Board of Australia, Berri; [2]CSIRO, Canberra;
[3]University of Adelaide – Plant Research Centre, Waite Campus

Background

As almond growers, we all know that bees are needed to pollinate our trees so that we can get a crop. If the pollination is reduced due to adverse weather conditions or the poor synchronisation between varieties is reduced, low yields can result. But why is this? What is the biology involved in an almond tree that requires bees and multiple varieties in order to get a crop? This fact sheet aims to provide the basics between self-incompatibility and self-fertility, why bees are essential for pollination and why more than one variety is needed in the orchard. Honey bee flight and the requirements for successful pollination will also be discussed.

Pollination & Germination

In almonds and many other tree crops, fruit (or nuts) will only develop when a flower is correctly pollinated. How does this occur? A flower has male and female parts called the stamen (male) and pistil (female) (Fig. 1). The stamen contains an anther on the end of the filament, which produces pollen grains. The pistil contains the stigma, which receives the pollen grains, and a style which connects the stigma to the ovary. For an outcrossed pollination to occur pollen grains must be transferred from the anther of one flower to the stigma of another either by insects or wind. The pollen grain germinates on the stigma, and then a pollen tube grows down the style to the ovary. Here fertilisation occurs and an embryo is formed which eventually becomes the almond kernel. There are a number of reasons why a flower may not develop into a fruit. It could be that no pollen is received on the stigma (ie lack of pollen transfer) or pollen may be transferred and a pollen tube starts to grow but then aborts. Also the pollen tube may reach the ovary and the embryo starts to grow but aborts before becoming fully developed. The pollen may also be incompatible.

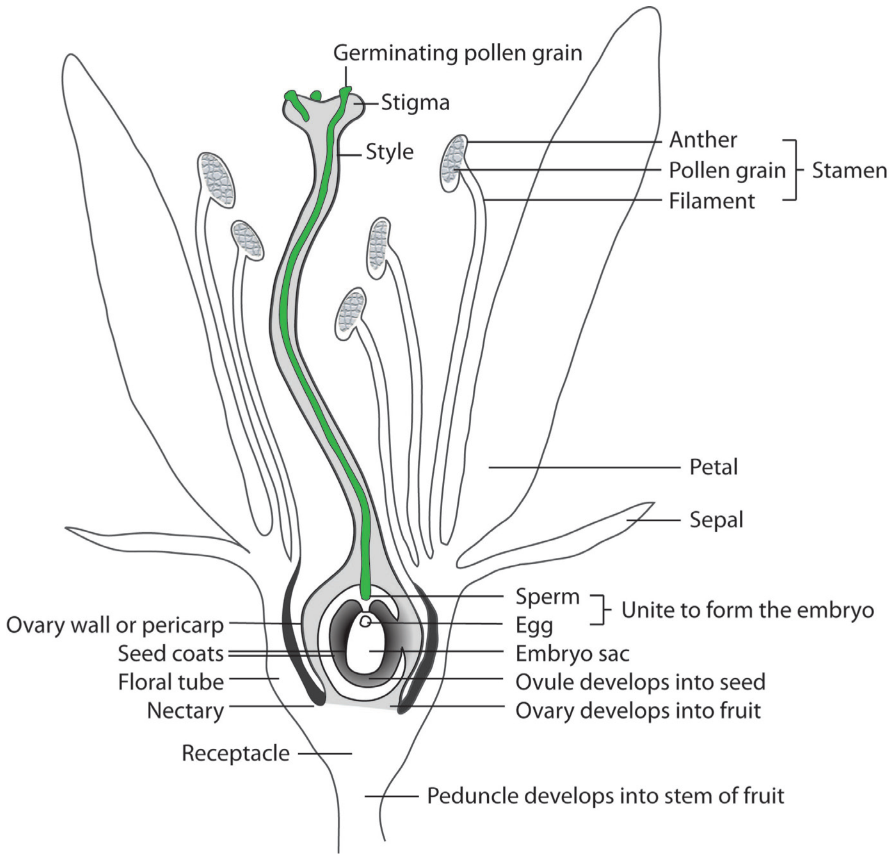


Figure 1: Compatible pollen germinates and the pollen tube grows down to the ovule where fertilization occurs.

Self-incompatibility & self-fertility

Self-incompatibility is a widespread mechanism in flowering plants that prevents inbreeding and promotes outcrossing. The self-incompatibility response in almonds is genetically controlled by S-alleles, and relies on a series of complex cellular interactions between the pollen and pistil. An S-allele refers to a specific variation of the DNA at a given locus, or a specific location on a chromosome. You might have heard of 'Gene Mapping'. Gene mapping is the process of determining which biological trait is associated with each locus, or location on a chromosome. In the case of almonds the S-allele is associated with fertility. The list of known alleles for common almond varieties in Australia is shown in Table 1.

Although self-incompatibility functions ultimately to prevent self-fertilization, flowering plants have evolved several unique mechanisms for rejecting the self-incompatible pollen. In almonds the alleles produce proteins which are either compatible or not. In short, if the allele has the same number for both the pollen donor and recipient (and therefore produces the same protein) it is not compatible and will abort the germination process. This means that after the pollen has been transferred from the anther (male) to the stigma (female) the resulting pollen tube growth is aborted, no embryo develops and ultimately no fruit grows. If the allele number is different, then germination is possible (Fig. 2).

By referring to Table 1, you can see that each almond cultivar has a pair of numbered alleles which in turn can be grouped together. Cultivars within the same group (ie the same numbered alleles) are 100% incompatible and therefore cannot fertilise each other to produce fruit. Therefore a cultivar from one group will only be compatible with a cultivar from a different group. However, if two cultivars share a common allele ie Nonpareil and Carmel, then the pollen produced will be partially incompatible. Pollen produced containing S8 alleles will be incompatible, but pollen containing either the S7 or S5 allele will be 100% compatible. Genetically 50% of pollen produced by Nonpareil and Carmel is compatible. In the orchard this is normally not a problem due to the abundance of pollen. Conversely the pollen from Nonpareil and Peerless is 100% compatible (due to all S-alleles having a different number). Cultivars in group 'O' are mutually compatible with each other and cultivars of all other groups. In the case of some cultivars (ABA breeding selections 1, 2, & 5) this is due to the presence of the Sf allele which is responsible for self-fertility. The Sf allele is dominant and when present, pollen from the same group or cultivar has the potential to produce fruit.

For more information on the technical side self-incompatibility and self-fertility in almonds, refer to the fact sheet 'Breeding for self-fertility in almonds'.

Table 1: Almond cultivars and S-allele compatibility

Variety	S-alleles	Incompatibility group
Nonpareil	S_7S_8	I
Wood Colony	S_5S_7	III
ABA Breeding selection 6	S_5S_7	III
Aldrich	S_1S_7	IV
Price	S_1S_7	IV
Carmel	S_5S_8	V
Livingston	S_5S_8	V
Avalon	S_1S_8	VI
Butte	S_1S_8	VI
Monterey	S_1S_8	VI
Sonora	S_8S_{13}	VII
Peerless	S_1S_6	XIV
Chellaston	S_7S_{23}	XXVI
ABA Breeding selection 4	S_7S_{23}	XXVI
Marcona	$S_{11}S_{12}$	O
Padre	S_1S_{18}	O
ABA Breeding selection 1	S_7S_f	O
ABA Breeding selection 2	S_7S_f	O
ABA Breeding selection 3	S_3S_8	O
ABA Breeding selection 5	S_7S_f	O
Johnston's Prolific	$S_?S_{23}$	?
Keanes	$S_?S_7$	?
ABA Breeding selection 7	$S_?S_8$	?

The Bugs & The Bees

Now the basics of germination and fertility have been covered, how does that apply to the everyday almond orchard? Also, why do we need bees for pollination? No commercially grown almond cultivars in Australia contain the S_f allele and therefore another compatible cultivar is required for successful cross pollination. This is why there are alternating rows of Nonpareil and pollinators. When the weather is suitable for good pollination conditions in August, there will be enough pollen produced by most cultivars to pollinate Nonpareil and vice versa. However if the weather conditions are not optimal and/or flowering is light, pollen compatibility may be a limiting factor in the potential yield. This may have had some relevance to the flowering and pollination period in spring 2011 and the resulting low yields in 2012. It certainly may not have been the primary factor but may still have played its part. It is interesting to note the recent popular planting pattern of 50% Nonpareil, 25% Carmel and 25% Monterey might deliver profitable yields in a good year but genetically from a pollen compatibility point of view it is less than ideal as each of the cultivars contains the S_8 allele. Hence

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343
P + 61 8 8582 2055 | **F** + 61 8 8582 3503
E admin@australianalmonds.com.au | **W** www.australianalmonds.com.au

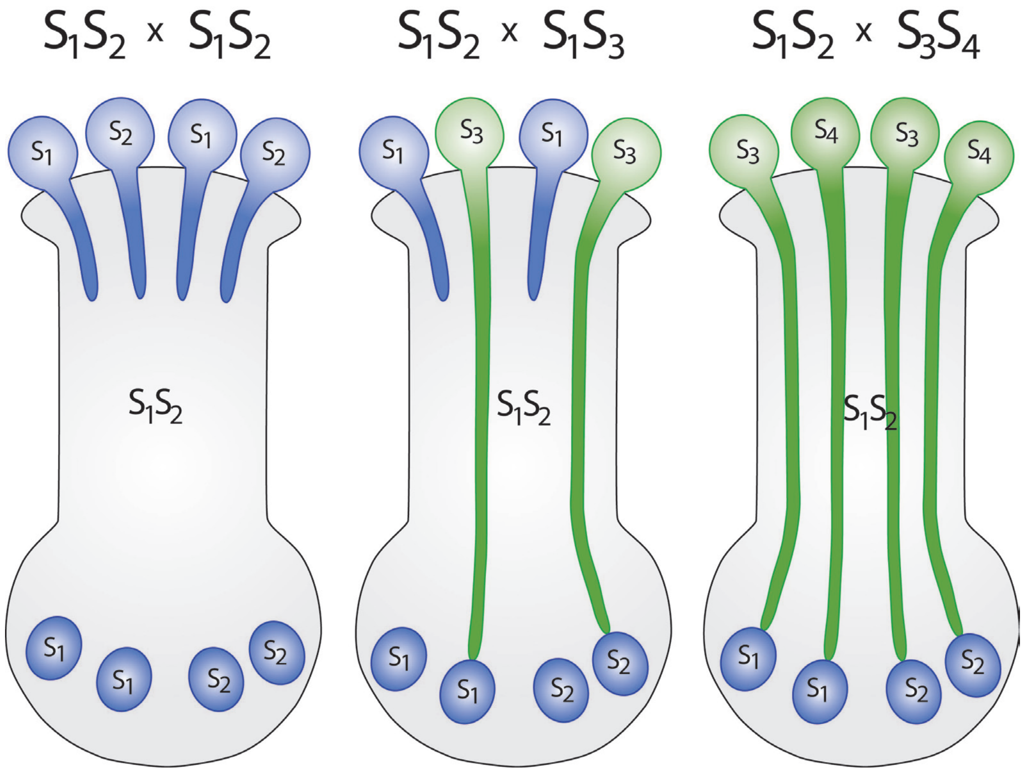


Figure 2: Gametophytic self-incompatibility system. Germination of pollen grains, which carry one of the same S-alleles as the pistil, is inhibited in the upper style.

flower numbers (ie pollen production) and synchronisation must be favourable as only 50% of the pollen from each cultivar is compatible to pollinate another cultivar. Another popular planting example is Nonpareil, Carmel and Price. In this case both Carmel and Price are only 50% pollen compatible with Nonpareil but are 100% pollen compatible with each other.

Bees are required for pollination to transfer the pollen from one cultivar to the next ie one row to the next. Since almonds are so dependent on pollen transfer in large numbers, bees and their ability to be managed in colonies is the obvious choice. Wind and other insects are also capable of transferring pollen from the anther to the stigma but because almonds are completely dependent on cross pollination, there is a risk of poor pollination outcomes when there are too few flower visiting insects, or too little wind.

A literature study by Cunningham (2011) confirms the amount of fruit set is related to the amount of cross pollination. Almond trees are generally not resource limited and the potential may exist for every flower to become a fruit if successfully pollinated, although the literature states that as many as 22-31% of flowers can be female sterile. Where almond flowers are hand pollinated the rate of fruit set is higher than when flowers are open pollinated (by bees). The rate of fruit set could be as high as 30-50% but rarely above 60%. The literature study by Cunningham (2011) suggested a 'normal' fruit set may be approximately 25%. No studies have shown whether an almond tree that flowers prolifically can successfully sustain a high crop load to maturity. Another interesting observation that came out of the literature study was that unfavourable weather during flowering doesn't have as much impact on nut set as first thought. A study in 2007 examined yields in California over 23 years against the weather conditions during flowering and found there was no significant link despite the fact bee activity at the hive is clearly less during cold and wet weather.

It is widely known bees can forage for nectar and pollen over large distances but prefer to focus on one resource over shorter distances. What does this mean in the context of an almond orchard? Bees will forage for nectar or pollen closer to the hive and more likely down the row than across the row. Studies have indicated the preference for bees to forage for nectar or pollen will vary according to the amount of storage in the hive. The amount of pollen foraging can therefore be increased by limiting the amount of pollen entering the hive by using pollen traps on the hive entrance. One study in 1985 used pollen traps to strip the bees of pollen and showed a higher rate of fruit set, however the study was not replicated so it is too early to generalise from this. The Almond Board of Australia's R&D project AL11003 – Enhancing Almond Pollination Efficiency will investigate bee flight patterns and the use of artificial methods to increase pollination efficiency. Stage 1 of the project occurred in 2011-12 in a number of orchards in the Riverland. Selected parts of the orchard where chosen to deliberately reduce the hive density to see what effect bee density will have on fruit set. The observations so far conclude that bees preferred moving in the row that contained the hive (N.B. the hive was placed in the middle of the orchard which is not a standard commercial practice) until late in the day when pollen and nectar levels run low. High bee density was sometimes associated with poor fruit set which suggests the link between bee density and fruit set is weak. The main factor associated with poor nut set is poor cross pollination which has been confirmed by hand pollination tests in the field. In other words, even when a tree is exposed to a very high level of bee visits, some flowers still do not receive any cross pollen, probably because self pollen is overwhelming the system. Adding more and more bees to the system will not solve this problem. The second year of the project in 2012-13 will examine pollination with lower bee numbers, and will pilot methods to change foraging behaviour.

References

Mechanisms of self-incompatibility in flowering plants; 2001, Silva NF, Goring DR

Breeding for self-fertility in almonds; 2012, Wirthensohn, M

Enhancing almond pollination efficiency - AL11003; 2011, Cunningham, S

For further information contact Brett Rosenzweig, Industry Development Officer

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

HAL

Horticulture Australia

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia

All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.3 – Fact Sheet: Crop Nutrient Removal

All About Almonds

Fact Sheet 08 – Crop Nutrient Removal

Welcome to the eighth edition of "All About Almonds", Crop Nutrient Removal. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the almond growers' section of the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

Historically, fertiliser programs for most horticultural crops have been monitored using leaf analysis at a particular period of the growing season. Whilst this technique has been useful in assessing nutrient status and nutrient levels, it does not either directly indicate the quantity of nutrients required to produce a crop or provide an accurate assessment of the nutrient ratios which the season's fertiliser program should be based around. The more recent introduction of "new" intensive water and fertiliser management systems such as the CT Optimisation Trial and Hydroponic systems has made it possible to adjust fertiliser inputs quite precisely, so understanding how much nutrient is removed when the crop is harvested could be very helpful in setting input quantities and ratios.

Measuring crop removal at harvest could be used three ways:

1. Evaluation of the current season's fertiliser program against a set of standards or past results, the same way leaf analysis is used.
2. Calculating the **minimum** quantity of nutrients required in a fertiliser program to at least replace the nutrients removed at harvest. This could involve the replacement of both macro elements (i.e. N, P, K, Ca, Mg) and micro elements (i.e. Cu, Zn, Mn, Fe and B).
3. Understanding the approximate ratio of nutrients that should be included in the fertigation program

Although an understanding of the composition of the harvested nuts and calculation of nutrient removal provides the manager an important basis for the preliminary design of a fertiliser program, it does have limitations. It does not help us understand; a) when best to apply the nutrients to match the trees' requirements at the different phenological (development) stages of the growing season, b) how much, or which nutrients are being supplied to the tree from other sources, such as soil mineralisation, c) how much, or which additional nutrients are required to grow new foliage and roots, d) what the inefficiencies and limitations of on-farm fertiliser and water application may be, e) which nutrients are lost through volatilisation, leaching below the active root zone or soil fixation, or f) which nutrients are left behind at harvest and stored within the tree. In the future, information on crop nutrient removal will be extremely helpful as the basis of modern, best practice fertiliser programs and after a number of years will allow mangers to benchmark against previous seasons and, estimate the majority of nutrients required to produce a crop and in what ratio.

Until better research information is available, a rough rule of thumb can be used to estimate the additional nutrient required to meet the other growth demands (e.g. foliage and root growth) and losses. Present information would suggest applying further 20-30% to the crop nutrient removal figures.

Methodology

Growers who would like to begin to measure crop removal could use the nut sampling method used on the CT Trial. Samples are collected just prior to **harvest.** The same trees used for leaf analysis are visited and the same sampling criteria are used, that is:

Sampling

- **Small to medium sized trees** - if good light interception is present around the whole tree, the sample should include four fruit (one from each of the north, east, south and west sides of the tree) from twenty to twenty five trees at shoulder height.
- **Large trees or hedgerow plantings** - the sample should include four fruit (two from each side of the tree) from twenty to twenty five trees at shoulder height.
- **A representative area** - Regardless of the situation, the sample should take into account variety (commonly Nonpareil is the only variety sampled), rootstock, age, soil type, topography, etc and avoid diseased, damaged, irregular sized, water stressed fruit, end trees and end rows. Commonly a diagonal transect is taken from one corner of the patch to the opposite corner. In hedgerow plantings an up and back loop through the orchard may be used. The sampling track should be recorded so that the same trees can be sampled each year.

The fruit should be hand cracked by the grower into the three fruit components, husk, shell and kernel (no blanks or part thereof are to be included in the sample) and each sample placed in three separate, well labelled paper bags. The fruit could be analysed as whole fruit but more information such as hull boron levels, nutrient partitioning, etc can be obtained from the separate analysis.

Analysis

The bags should be delivered to the same laboratory used in previous year's fruit or leaf analysis. However, to satisfy quality control or curiosity, additional sub-samples may be sent to another laboratory for cross checking.

Commonly used laboratory:

Geoff Proudfoot
CSBP Soil & Plant Laboratory
2 Altona Street
Bibra Lake, WA, 6163
Phone: (08) 9434 4600

Growers will need to specify to the laboratory that the following tests are required for each sample:

- Wet weight (gm).
- Dry weight (gm).
- Moisture content (%) (Calculated from the above measurements and enabling a comparison against your processor's crack out results. Of course, this comparison needs to be made in reference to stockpiling duration, moisture loss, etc).
- Dry matter production (%) is consequently calculated.
- Full analysis of the sample to include Nitrogen (N%), Phosphorus (P%), Potassium (K%), Sulphur (S%), Calcium (Ca%), Magnesium (Mg%), Sodium (Na%), Chloride (Cl%), Zinc (Zn mg/kg), Manganese (Mn mg/kg), Iron (Fe mg/kg), Copper (Cu mg/kg), Boron (B mg/kg).

Once the data has been received from the laboratory, it is possible to calculate nutrient removal using the sample patch yield result (kg/ha of kernel). It can be entered into the crop nutrient removal section of the "Almond Water Use, Irrigation, Fertiliser and Foliar Spreadsheet" located in the login section of the Almond industry website: www. australianalmonds.com.au. The result will provide an indication of the partitioning of the nutrients within the fruit and the amount of nutrients removed at harvest.

For those who prefer to do their own calculations, the formula for each fruit compartment (i.e. husk, shell and kernel) which are then summed together to provide whole fruit, is simply:

- (Wet weight yield (kg/ha) x % element (wet weight basis)) = kg/ha element removed

Or

- (Wet weight yield (kg/ha) x mg/kg element (wet weight basis))/1,000,000 = kg/ha element removed

Results and Interpretation

There are no conclusive standards for the nutrient analysis of almonds in the literature, however the nutrient analysis data collected over the last few years from the ABA's commercial demonstration sites and from the CT Trial is provided in Table 1~~Table 1~~ as a guide.

Table 1. 2007/08 and 2008/09 Nonpareil nutrient analysis.

		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe^ (mg/kg)	Cu (mg/kg)	B (mg/kg)	S (%)
Keane	**Husk**	0.62	0.11	2.40	0.15	0.08	0.10	0.22	25.50	14.00	161.00	5.95	54.00	0.02
	Shell	0.54	0.03	0.82	0.16	0.03	0.07	0.09	4.00	5.40	55.50	4.70	23.00	0.02
	Kernel	3.85	0.50	0.82	0.25	0.30	0.01	0.05	41.50	27.50	71.00	13.50	20.00	0.15
Jubilee	**Husk**	0.81	0.09	2.75	0.14	0.08	0.01	0.07	20.00	14.50	62.00	4.75	54.00	0.04
	Shell	0.43	0.03	1.40	0.11	0.03	0.01	0.06	5.20	6.35	15.00	4.10	21.00	0.02
	Kernel	3.95	0.54	0.89	0.19	0.28	0.01	0.05	38.00	27.00	50.00	11.50	15.50	0.15
Pearce	**Husk**	1.30	0.14	3.15	0.15	0.07	0.02	0.20	27.00	51.00	232.00	5.10	45.50	0.04
	Shell	0.60	0.03	1.25	0.14	0.03	0.02	0.08	4.10	15.50	83.00	4.40	25.50	0.02
	Kernel	4.10	0.54	0.83	0.23	0.31	0.01	0.05	42.00	42.00	72.50	12.00	19.00	0.17
CT Trial#	**Husk**	0.3-0.5	0.02-0.05	1.4-2.6	0.06-0.08	0.02-0.03	0.01	0.03-0.07	30-82	3.2-7.5	29-42	0.8-2.2	28-56	0.01
	Shell	0.3-0.5	0.01-0.02	0.5-1.8	0.05-0.1	0.01-0.03	0.01	0.05-0.07	7.3-15	2.4-8.7	5.1-27	0.9-2.7	11-28	0.01-0.02
	Kernel	1.7-3.4	0.19-0.39	0.34-0.756	0.09-0.2	0.11-0.24	0.01	0.07	19-51	11-37	20-50	3.1-7.9	11-31	0.01-0.13

#Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Using the data in Table 1~~Table 1~~ and the kernel yield results, crop nutrient removal, crop nutrient removal plus 20% and an approximate nutrient balance is provided in Table 2~~Table 2~~, Table 3~~Table 3~~ and, Table 4~~Table 4~~ respectively.

Table 2. 2007/08 and 2008/09 Nonpareil whole fruit nutrient removal (kg/ha).

	Kernel Yield (kg/ha)	Water (ML/ha)	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Fe^	Cu	B	S
Keane	2,625	9.37	145.82	20.10	179.93	17.64	12.69	7.01	15.83	0.27	0.17	1.25	0.08	0.41	5.42
Jubilee	4,510	16.09	266.32	33.74	340.00	23.81	20.64	1.64	10.16	0.38	0.28	0.87	0.11	0.65	10.52
Pearce	3,977	10.87	247.64	29.28	231.46	20.56	16.36	1.63	14.16	0.32	0.47	1.72	0.09	0.39	9.41
CT Trial[#]	3,785-4,138	11.10-17.70	95-291	10-27	136-357	8-21	7-17	1-3	5-18	0.5-1.0	0.1-0.3	0.3-1.1	0.02-0.07	0.3-1.3	2-7

[#]Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.
^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Table 3. 2007/08 and 2008/09 Nonpareil whole fruit nutrient removal plus 20%.

	Kernel Yield (kg/ha)	Water (ML/ha)	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Fe^	Cu	B	S
Keane	NA	9.37	174.98	24.12	215.92	21.17	15.23	8.41	19.00	0.32	0.20	1.50	0.10	0.49	6.50
Jubilee	NA	16.09	319.58	40.49	408.00	28.57	24.77	1.97	12.19	0.46	0.34	1.04	0.13	0.78	12.62
Pearce	NA	10.87	297.17	35.14	277.75	24.67	19.63	1.96	16.99	0.38	0.56	2.06	0.11	0.47	11.29
CT Trial[#]	NA	11.10-17.70	114-349	12-32	163-428	10-25	8-20	1.2-3.6	6-22	0.6-1.2	0.1-0.4	0.4-1.3	0.02-0.08	0.4-1.6	2-8

[#]Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.
^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Table 4. Nonpareil 2007/08 and 2008/09 whole fruit nutrient balance.

	N (kg/ha)			P (kg/ha)			K (kg/ha)		
	Actual Applied (IN)	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**	**Actual Applied (IN)**	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**	**Actual Applied (IN)**	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**
Keane	240	175	+65	25	24	+1	400	216	+184
Jubilee	320	320	0	50	41	+9	600	408	+192
Pearce	320	297	+23	38	35	+3	500	278	+222
CT Trial[#]	240-320	114-349	+206 to -109	54	12-32	+22 to -42	400-600	163-428	+237 to +172

[#]Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

Analysis of the above tables very simply suggests:

- Keane - More nitrogen applied than removed, good balance of phosphorus, more potassium applied than removed
- Jubilee Almonds - Good balance of nitrogen, good balance of phosphorus, more potassium applied than removed
- Pearce - Good balance of nitrogen, good balance of phosphorus, more potassium applied than removed
- CT Trial - Variable.

The variable nutrient removal from the CT Trial compared to the other orchards is difficult to explain and will require further seasons data and investigation. Quite simply, it could be seasonal or sampling variability across the orchard. For example, the three commercial orchards sampling is a result of a bulk sampling procedure and consequently an average of the patch where as the CT Trial results are the range from individual trees with no bulk sampling and averaging.

Each grower's orchard may also have different results due to sampling rigour, a lighter yield, a lower analysis fruit caused by a lighter fertiliser program or different crackout percentages and weights. At this stage we are all feeling our way on how the data should be interpreted, but if all almond orchards included measurements of crop nutrient removal in their yearly monitoring program (for example from one or more representative patches of Nonpareil) it is expect that the usefulness of the data will become evident. The data may slightly vary from one patch to the next but this tool will provide a good basis on which to formulate a strategic fertiliser program from one year to the next. Further analysis of future crops, including traditional leaf analysis, and the use of other tools such as soil sampling and soil solution extractors will not only fine tune the total nutrient requirements of an almond orchard but also the timing of nutrient applications and in what ratios.

For further information contact Ben Brown, Industry Liaison Manager

Published by Almond Board of Australia, *Po Box 2246, Berri, South Australia 5343*
Telephone (08) 8582 2055 Facsimile (08) 8582 3503

ACKNOWLEDGEMENTS
The input and suggestions made by Dr Ben Robinson and Brett Rosenzweig.

©Almond Board of Australia
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER
Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.4 – Fact Sheet: Almond Orchards and Soil Acidification

Fact Sheet 09
Almond Orchards and Soil Acidification

Richard Merry
CSIRO – Land and Water

Ben Brown
Almond Board of Australia

Welcome to the ninth edition of "All About Almonds", Almond Orchards and Soil Acidification. Fact sheets are distributed to almond growers via email, in addition to being made available for download from the ABA website: www.australianalmonds.com.au (follow links to the login section of the growing page).

1. Background

The formation of acid in soil is a side effect of most forms of modern agriculture and can be particularly important in intensive systems. Many of the soils used in Australian agriculture initially had pH values suitable for growth of most plants or have residual calcium carbonate (lime) that counteracts the effects of any acidity formed. This means that low input agriculture can proceed for some time before the undesirable effects of acidification become evident. The changes in the soil are usually slow and may not be noticed until there are severe production decreases.

However, intensification of agriculture (increased fertiliser use, increased production, etc.) can speed up acidification processes and their undesirable effects. Consequently, there is a need to monitor practices, soil condition (usually with a pH measurement) and when necessary, remediate the soil by liming.

It is important to be aware of the processes leading to acidification and what should be done to protect soil and its capacity to support root growth.

Soil types vary in their capacity to cope with acidification. The main difference is in the time taken to reach a critical point where productivity is affected. This is because soils differ in their pH buffering capacity which is the capacity of a soil to resist pH change. Sandy soils have a lower buffering capacity than clayey soils and if lime is present in the soil, the buffer capacity can be very large. If the plant production system produces acid, in the long term it does not matter what the properties of the soil are as the soil is being acidified – poorly buffered soils reach a critical pH sooner than well buffered soils. Although a pH measurement will indicate the condition of the soil that is critical for plant growth, a buffer capacity or lime requirement measurement is needed to estimate the amount of lime needed to raise soil pH to a target level.

Depending on the pH buffering capacity of the soil and its starting pH, it may take decades to reach a situation where plant production is affected and as the process is often slow, it is usually difficult to separate yield decline from normal seasonal variation. For this reason it is important to maintain a satisfactory soil pH condition to avoid potential productivity losses.

Modern almond production systems in Australia produce acidity when yields increase and particular fertilisers are used, especially those ammonium-containing forms of nitrogen (e.g. sulfate of ammonia, urea, UAN, ammonium nitrate, etc). In drip irrigated orchards, the production system concentrates fertiliser placement, water delivery and nutrient uptake into a relatively small proportion of the total soil volume and this zone has a high potential for rapid acidification – significantly more than sprinkler irrigated orchards. This situation has also been observed in many other drip irrigated crops such as citrus orchards and vineyards.

2. Measuring Soil Acidity

Soil acidity (or alkalinity) is measured by a pH test and is a measure of the concentration of hydrogen ions (H^+) in the soil solution. pH is measured on a negative logarithmic scale between 1 and 14 with 7 being neutral (Figure 1).

Soil pH is often measured using two laboratory techniques; 1) 1:5 solution of soil and water (pH_w), or 2) 1:5 solution of soil and a weak solution of calcium chloride (pH_{ca}). The calcium chloride method which is the more commonly used and reliable method, will produce results that are approximately 0.8 of a pH unit lower than water tests and is less subject to seasonal variation.

Due to the logarithmic scale, a change in soil pH of one pH unit represents a tenfold change in hydrogen ion activity. That is, a small decrease in soil pH results in a large increase in acidity. For example, soil with a pH of 4 is ten times more acidic than a soil with a pH of 5 and 100 more times acidic than a soil with a pH of 6.

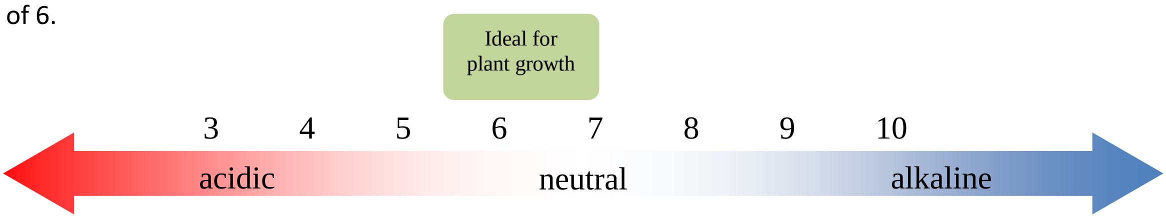


Figure 1 pH Scale

A less common measurement is soil pH buffering capacity. This measurement is more difficult to make and not often carried out. It is the rate of change of soil pH as acid is added. Clays and soils with increased organic matter have a higher pH buffer capacity than sandy soils.

3. Causes of Soil Acidification in Almond Orchards

There are several important causes of soil acidification and the interactions of the acidification processes can be complex (Figure 2). They have been known and studied for a long period of time – even the early farmers (Etruscans, Romans) knew that lime was needed to offset acidity – and liming practices have long been in place in other parts of the world.

The processes of acidification outlined below are known to be the principle causes of soil acidification in agricultural systems and much more significant than external causes of acidification such as acid rain. The two major causes of soil acidification in almond orchards are the use of some nitrogen fertilisers and product (fruit) removal.

AUSTRALIAN ALMONDS
www.australianalmonds.com.au

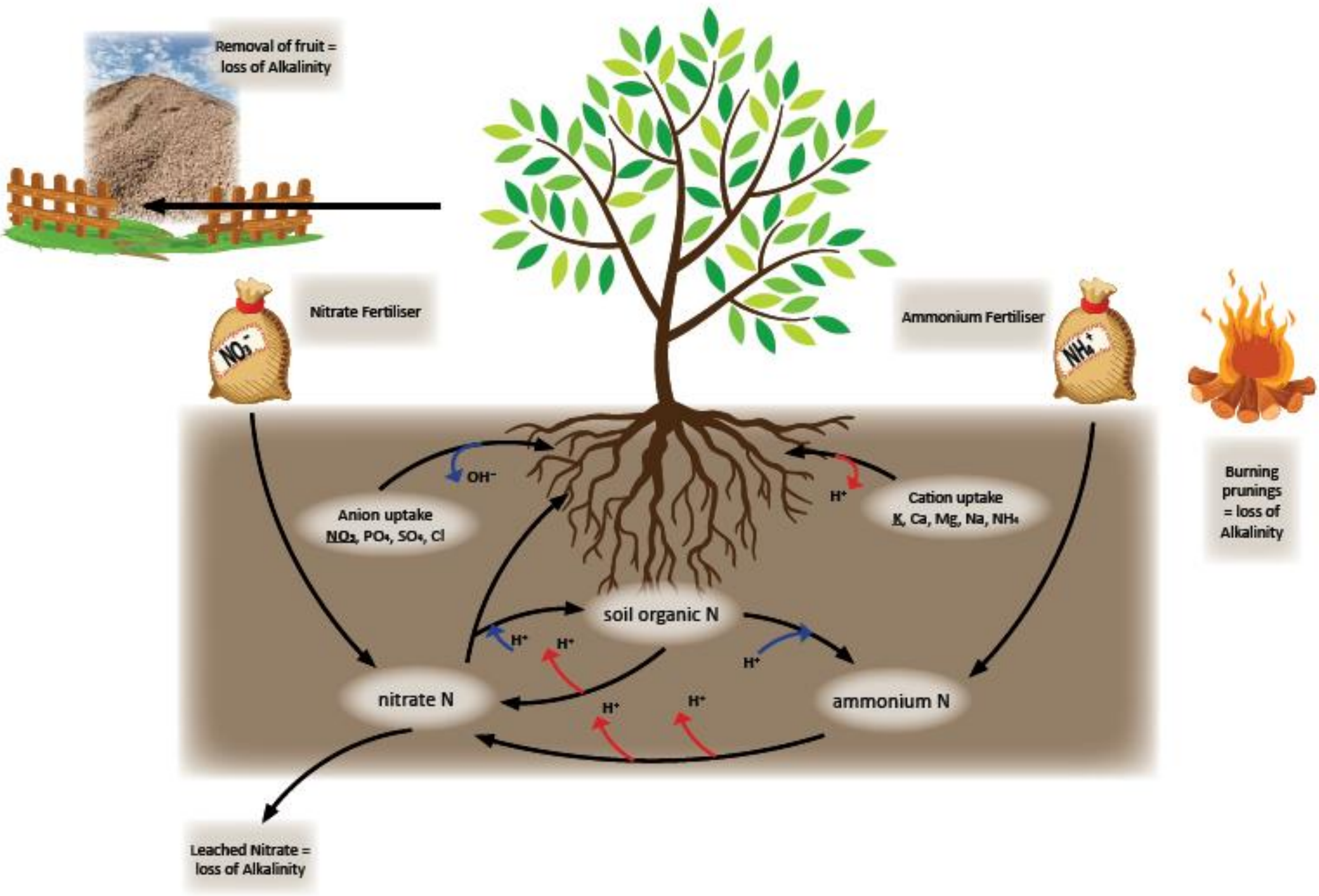


Figure 2 Processes of Soil Acidification in Almond Orchards

3.1 Nitrogen Fertilisers

Nitrogen fertilisers are a major cause of soil acidification when fertilisers containing ammonia are used. Although not exactly the same, urea behaves in a similar way. The processes that are involved are complex and include reactions in the soil, exchanges with the plant root, leaching and volatilisation.

Each ammonium ion (NH_4^+) in the fertiliser is usually transformed to nitrate (NO_3^-) in the soil by bacteria. This process releases two acidifying protons (H^+) for each ammonium ion and one acidifying proton for each amino group (NH_2). The amino group usually comes from the natural decomposition of organic matter.

There is a further process that will determine the severity of the acidification; that is, the fate of the nitrate ion. If the nitrate ion is taken up by the plant, the acidification effect is less than if the nitrate ion were to be leached beyond the root zone. (See the nutrient uptake section below for further explanation of this process).

In practice, scientists mostly use average values for acidification by fertilisers as these values are usually able to account for measured changes in soil acidity (see Table 1).

Australian Almonds
www.australianalmonds.com.au

Fertiliser	Equivalent Lime ($CaCO_3$) Needed to Neutralise Acidity (kg $CaCO_3$ / kg N or S)[b]
Urea	1.8
Ammonium Nitrate	1.8
Ammonium Sulfate	5.4
MAP	5.4
DAP	3.6
Sulfur (elemental)	3.1[c]
N as Nitrate	-3.2[d]

Table 1 The acidity resulting from the use of nitrogen or sulfur in fertilisers. The values presented are the average amount of lime ($CaCO_3$) needed to neutralise the acidity.

Adapted from Adams (1984)
[b] These are average values for nitrogen and can vary ± 1.8 kg.
[c] This assumes complete conversion to acid; for thiosulfates, the value is about 1.6 per unit of S.
[d] This is negative because nitrate uptake by plants increases the alkalinity of soil. This value assumes 10% of the nitrate is leached.

For reasons outlined below, nitrate fertilisers are not acidifying and can make the soil more alkaline. Ammonium nitrate contains two forms of nitrogen, but the acidification from the ammonium component is greater than the alkalinity that results from the nitrate component.

3.2 Other Fertilisers

Whilst most attention is given to the acidification risk from nitrogen fertilisers, some other fertilisers can also cause acidification. They are mainly fertilisers that contain sulfur – elemental or dusting sulfur, and thiosulfates. In these sulfur-containing materials, some or all of the sulfur is acted on by soil bacteria producing sulfuric acid.

Sulfate fertilisers (such as potassium sulfate, magnesium sulfate, zinc sulfate, etc) do not acidify soils. The only obvious exception is ammonium sulfate which acidifies soil due to its ammonium component, not the sulfate component.

It is a common misconception that superphosphate has caused soil acidification. This is untrue. Using superphosphate has enabled legumes and other plants to grow well and it is the consequences of nitrogen fixation, product removal and associated acidification that is really contributing to acidification.

3.3 Nutrient Uptake and Fruit Removal

When plants grow, they usually take up nutrients such as nitrogen (as nitrate, NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), phosphorus (as phosphate, $H_2PO_4^{2-}$), sulfur (as sulfate, SO_4^{2-}), and others. You will notice these nutrients have a positive (+) or negative (-) charge. In the process where these charged elements are taken up through plant roots, the plant needs to release an element with equivalent charge. This is achieved in one of two ways:

1. When a positively charged ‘cation’ (eg K^+) is taken up, the plant exchanges an equivalent positive charge by releasing an acidifying proton (H^+).
2. When a negative charged ‘anion’ (eg NO_3^-)is taken up, the plant exchanges an equivalent negative charge by releasing an alkaline hydroxyl (OH^-).

AUSTRALIAN ALMONDS
www.australianalmonds.com.au

Most plants take up more positively charged than negatively charged ions and the net effect is soil acidification. In a closed system where all plant matter is recycled on-site, the uptake of more positive charged ions may not be a problem. However, when plant products (e.g. fruit) are removed, the 'alkalinity' developed in the plant material is lost and the soil is left in a more acidic condition. This is made worse in high yielding agricultural systems (e.g. almond orchards) that produce large quantities of removable plant material, such as almond husks, shells, kernels and prunings.

	Ash Alkalinity of Material (kg $CaCO_3$ / kg, dry)	Indicative Dry Yield (kg/ha)	Equivalent Alkalinity Lost (kg $CaCO_3$ / ha)
Husk	0.043	4,980 6,640	215 285
Shell	0.025	1,250 1,660	31 42
Kernel	0.008	3,000 4,000	24 32
TOTAL		**9,230** **12,300**	**270** **360**

Table 2 Annual plant ash alkalinity, yield of product, percentage dry weight and alkalinity (expressed as calcium carbonate equivalent) of almond husk, shell and kernel.

There are ways of estimating the amount of alkalinity removed and some values expected for almonds can be made using an acidification calculator (Thomas, 2009) and are shown in Table 2. The table is based on limited data but shows estimates of the potential alkalinity lost when almond husks, shells and kernels are removed, per kilogram of these materials, and on a per hectare basis. As all of this plant material is lost, soil acidification equivalent to about 300-400 kg of lime ($CaCO_3$) per hectare is lost by product removal alone each year.

In loamy soils without any natural lime, acidification of 300 kg $CaCO_3$ equivalent each year may result in a soil pH decrease of one unit in:

- Sprinkler Orchards (100% wetted area) – approximately 6 to 8 years, or
- Drip Irrigated Orchards (approx 30% wetted area) – approximately 2 to 2.5 years

In sandy soils, which are traditionally the soils selected for almond orchards, this will occur even faster due to the lower buffering capacity of sand. The use of ammonium-containing fertilisers will also quicken this process.

The almond industry's Optimisation Trial (aka CT Trial) has provided an illustration of how quickly and severely soil acidification can occur on an almond orchard which is planted on sandy textured soil, drip irrigated, receives high amounts of ammonium containing fertilisers, achieves high yield, and doesn't have all of its cations replaced by fertigation (e.g. calcium, magnesium).

A statistical analysis of the CT Trial soil data indicates there has been a statistical effect of the scientific treatments on soil pH, with an approximate decrease in pH_{ca} of 0.25 to 0.65 pH unit/year. The result has seen soil pH_{ca} that began at approximately 8.0 in 2001, decrease to 5.5 at 0 to 20 cm (Figure 3).

AUSTRALIAN ALMONDS
www.australianalmonds.com.au

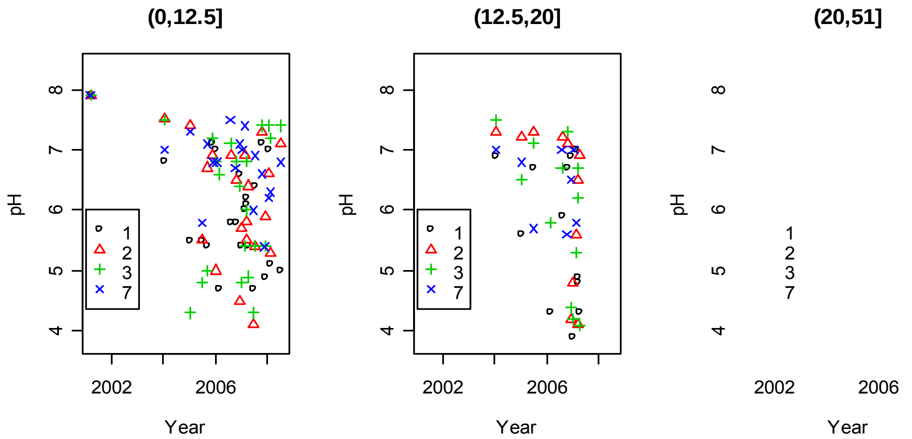


Figure 3 Optimisation Trial, Soil pH at 0-12.5cm and 12.5-20cm

Almonds are deciduous plants, shedding their leaves annually. It is usually assumed that leaves are recycled within the orchard, conserving any of the elements mentioned above. If the leaves, or prunings, are removed or lost from the vicinity of the tree, there will be an additional acidification, but this is thought to be small in comparison to fruit removal at harvest.

3.4 Leaching

As mentioned above, when plants take up nitrate (NO_3^-) - the usual form that plants take up nitrogen from soils - alkalinity is left behind in the soil at the site of uptake. Nitrate usually comes from the nitrification process mentioned above, which is acidifying, or from nitrate-containing fertilisers. Either way uptake of nitrate ions usually assists in making soil more alkaline.

However, there is an exception in situations where there is a high incidence of flushing events due to rainfall or poorly managed irrigation. In these conditions the nitrate in the soil can be leached to a lower point in the soil profile, or even below the rooting zone, and in the process take with it a companion ion. This results in the upper part of the soil profile becoming more acidic and the subsoil more alkaline when more nitrate is taken up from deeper in the soil.

4. Effects of Soil Acidification

Progressive acidification alters soil properties, usually detrimentally unless the soil is very alkaline. In alkaline soils, where pH_w values are higher than 8.5, some acidification may be beneficial and help increase the availability of some nutrients, such as iron (Fe), manganese (Mn) and zinc (Zn). Lowering the pH_w below 8.5 may also improve the efficiency of the nitrification process. As soil acidifies and reaches pH_w values less than 5 to 5.5, significant detrimental changes begin to occur. These effects are outlined below.

4.1 Acidification Effects on Plant Toxicities and Nutrient Availability

When a soil acidifies and the pH_w decreases to below 5, detrimental changes start to occur in the soil. They may not become visually apparent in the plant or its yield loss until the pH_w is much lower, below 4.5. As the soil acidifies, the acidic protons (H^+), which are very reactive, quickly attack minerals in the soil. Firstly, alkaline materials such as lime are used up as it reacts and neutralises the acid. Once the lime has reacted with the acid, it is removed from the soil permanently. Secondly, when most of the lime has been 'used', the acid starts to attack the clay minerals.

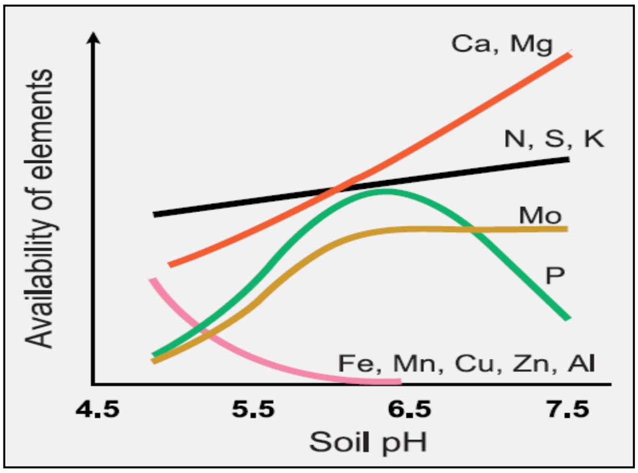


Figure 4 Relationship between soil pH and nutrient availability
(Source: Soil acidity: a guide for WA farmers and consultants)

With increasing acidity (Figure 4), clay mineral decomposition can release elements such as aluminium (Al) and manganese (Mn). Both elements are toxic to plant roots, especially aluminium. Aluminium causes young, growing root tips to become stunted (Figure 5) and roots are often described as 'stubby'. For a plant to be productive its roots must continually grow, so if this is retarded, plant productivity decreases.

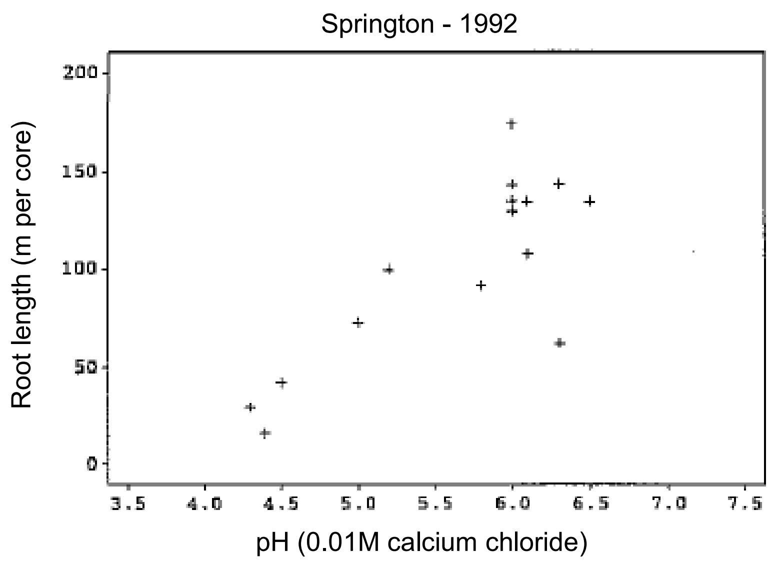


Figure 5 Effect of pH on grapevine root growth (aluminium toxicity), Robinson (2000)

AUSTRALIAN ALMONDS
www.australianalmonds.com.au

Increased aluminium availability in acidified soils also interferes with the ability of the plant root to take up other elements that are essential for growth, including iron (Fe), calcium (Ca) and magnesium (Mg). Acidification actually increases the solubility and availability of elements like calcium and magnesium, but the low pH and effects of high aluminium prevent uptake. These nutrient elements are then vulnerable to leaching from the soil, so over long periods of time, even mildly acidified soils become impoverished in many nutrients.

Other elements, including many of the trace elements (copper, zinc and manganese) become more readily available to plants. Molybdenum (Mo) does not become more available in acidic soils. It is more available in alkaline soils.

4.2 Urea and Ammonium Conversion to Nitrate

The soil processes that convert urea and ammonium-containing fertilisers to nitrate (nitrification) are enabled by soil microorganisms. The same processes are involved in the conversion of amine nitrogen (from the amino acids in proteins that are part of the soil organic matter) to nitrate. Soil pH_w values below 6 are sufficient to start having a detrimental effect on the efficiency of nitrification and the rates decrease progressively below this pH and become negligible by about pH_w 4.5. Consequently, nitrate availability from ammonium-containing fertilisers and organic matter is reduced in acidic soils.

5. Managing Soil Acidification

Managing almond orchards starts with soil preparation. If a soil is already acidic at the time of orchard establishment, lime should be applied to increase soil pH_w to a value greater than 6.

Orchard fertiliser practices and the rate of product removal can be used as a guide to the likely acidification rate and amount of lime needed to remediate it.

It is very important to manage acidifying fertiliser use to ensure that applications are not excessive. If the soil is likely to acidify, it is important to make an allowance for the purchase of liming materials as part of the orchard fertiliser management plan.

Product removal (husks, shells, kernels) is an important cause of acidification. Since they are removed from the orchard, conservation of their alkalinity is not possible and there is little choice but to:

a) replace all nutrient uptake (that is, more than just nitrogen, phosphorus and potassium) with fertiliser applications, and/or
b) replace the alkalinity lost by using a program of liming.

Soils with naturally occurring lime in surface layers may not show effects of acidification for many years. A soil with 1% $CaCO_3$ has approximately 10,000 kg of lime per hectare 10 centimetres deep. However, soil pH should be monitored annually in high yielding orchards with high fertiliser use, particularly in drip irrigated orchards.

In drip irrigated orchards, most acidification is concentrated in the wetted volume of soil as this is where most nitrification and nutrient uptake occurs, not in the inter-row. This concentration of processes can greatly increase the rate of soil acidification. Work in drip irrigated orchards and vineyards have confirmed this, and this volume of soil should be targeted for pH monitoring and lime application. However, managers should not ignore the inter-row where acidification is usually less or minimal.

6. Remediation of Soil Acidification

Once a soil is acidified, the application of liming materials (lime, dolomite, etc.) is the principal way acidification can be managed. The amount required can be minimised by putting in place management practices outlined above.

Lime application rate is usually based on a pH measurement, identification of a 'target' pH and an estimate of the soil pH buffer capacity. It will also vary depending on the type of lime being used.

Robinson (2000) developed a quick method to estimate buffering capacity by estimating soil texture and using 'rule of thumb' data. The research indicated to raise soil pH by one unit to a depth of approximately 15 cm, the following rates of lime (t/ha) may be required:

- sands, loamy sands 1.0 – 2.0
- sandy loams 2.5 – 3.5
- loams, sandy clay loams 3.5 – 4.0
- loamy clays 4.5 – 5.0

Alternatively, laboratory tests are available.

There can be difficulties in physical application and incorporation of lime in drip irrigated orchards. The soil needs to be moist and the lime 'watered' in. Lime also takes a few months to equilibrate with the soil following application. Consequently, lime application should be followed up with soil pH testing to ascertain is effect.

There can also be difficulties in all orchards if sub-soil layers are allowed to acidify. For these reasons, it is very important to manage acidity before soil deeper than 20 or 30 cm becomes acidified.

Some reversal of acidification can be expected if nitrate fertilisers (for example, calcium or potassium nitrate) are used. There may be cost constraints in using them, but this should be balanced against the cost of applying lime if acidifying fertilisers are used. It should also be noted that fertiliser programs solely based on nitrate-containing fertilisers are not 'healthy' for the plant or fruit.

The chemical properties of irrigation water may also need to be taken into account, depending on its source. Most dam water in high rainfall areas has very low alkalinity. Water from the Murray River has a low and seasonally variable alkalinity. Work assessing dripper irrigated vineyards suggests that it has little beneficial effect in neutralising acidity. However, groundwater from aquifers in limestone which becomes saturated with calcium carbonate can be effective and may significantly raise soil pH. Reclaimed water needs to be analysed on an individual source basis and used with extreme care as some sources have high potassium, sodium and alkalinity, and have potential to cause detrimental changes to the subsoil drainage characteristics.

7. Key Points

- Soil acidification can be a naturally occurring process.
- Horticulture rapidly accelerates the soil acidification process.
- If unmanaged, soil acidification in drip irrigated orchards may occur at approximately three to four times the rate in comparison to sprinkler irrigated orchards due to the rapid exhaustion of such a small, concentrated soil volume.

- Current almond fertiliser programs in drip irrigated orchards are resulting in soil pH values decreasing by approximately of 0.25 to 0.65 pH_{ca} unit/year. The result has seen soil pH_{ca} that began at approximately 8.0 in the year 2001, decrease to 5.5 at 0 to 20 cm by 2008.
- Almond trees take up more positive ions than negative ions, resulting in a potential net soil acidification effect.
- The removal of fruit at harvest exports alkalinity which is not returned to the soil, causing acidification.
- Biggest causes of soil acidification in almonds are fruit removal at harvest and ammonium based fertilisers.
- Other potential causes of soil acidification in almonds are nitrate leaching and removal of prunings.
- Nitrogen fertiliser programs should be more biased towards nitrates (alkaline effect) rather than ammonium (acidifying effect) sources. However, be mindful that nitrate toxicity may be detrimental to fruit quality and nitrate is more readily mobile and susceptible to leaching.
- Fertiliser and acidity management programs should aim to balance nutrients lost, and not just consider nitrogen, phosphorus and potassium. A survey of industry leaf analysis has shown decreasing calcium and magnesium concentrations. Use of dolomitic limestone and calcium nitrate for acidity management will help replace lost calcium and magnesium.
- Monitor soil pH annually.
- Remediate soil acidification with lime applications. Lime applications are to be calculated on current soil pH values, a target soil pH value and an estimate of the soil pH buffering capacity. Re-monitor soil pH.

References

Adams, F (1984) Crop responses to lime in the Southern United States. In 'Soil Acidity and Liming' 2nd Edition. F Adams (editor) pages 211-259, Agronomy No 12, American Society of Agronomy, Madison, Wisconsin.
Helyar, KR, and Porter, WM (1989) Soil acidification, its measurement and the processes involved. In 'Soil Acidity and Plant Growth", AD Robson. (editor), pp 61-101, Academic Press, Sydney, Australia.
Kennedy, IR (1992) Acid Soil and Acid Rain. 2nd Edition. Research Studies Press Ltd., Taunton, Somerset. (Technical, requiring knowledge of chemistry).
Robinson, JB (2000) Managing Soil Acidification. Proceedings: Eight Australian Wine Industry Technical Conference, pp45-48
Thomas, B (2009) Calculators of Soil pH Change – Almond Orchards. In: Managing Soil Degradation in Orchards Which Utilise High Fertiliser Inputs. National Landcare Programme – Community Support Component, Project No. 64264. (calculator available for download at http://australianalmonds.com.au/industry/resources_reports_fact_sheets)

For further information contact Ben Brown, Industry Liaison Manager

Published by Almond Board of Australia, *PO Box 2246, Berri, South Australia 5343*
Telephone (08) 8582 2055 Facsimile (08) 8582 3503

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.
This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia

All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

AUSTRALIAN ALMONDS
www.australianalmonds.com.au

Appendix 1.5 – Fact Sheet: Balancing Nutrient Inputs and Outputs – CT Trial Results

Balancing Nutrient Input and Output: CT Trial Results

Mark Skewes[A], Mahalakshmi Mahadevan[A],
Brett Rosenzweig[B], and Ben Brown[B]

[A]South Australian Research & Development Institute
[B]Almond Board of Australia

Summary

Soil solution monitoring beneath an Almond irrigation and nutrition trial identified key considerations for managing fertigation in high input/high yield almond production systems. This factsheet reports issues relating to the balance between nutrient applications, irrigation and crop requirements.

A key finding is that applied potassium can accumulate in the soil when soils are naturally high in potassium. As a result, it is important to understand the potassium requirements of the crop relative to the natural abundance of potassium in soils, before commencing a fertigation program.

The trial further illustrated a link between crop water use and nutrient uptake, identifying the need to reduce nutrient applications when irrigation volumes are limited, to avoid accumulation of ions in the rootzone, leading to elevated soil salinity.

Finally, the trial demonstrated that application of nutrients above crop requirements leads to leaching of nutrient beyond the rootzone, reducing the economic and environmental sustainability of the production system.

Areas of study which would benefit from further work were identified.

Introduction

The Almond Board of Australia, with assistance from Horticulture Australia Limited (HAL), established a trial titled "Sustainable Optimisation of Australian Almond Production" at CT Farms near Berri, South Australia. The aim of the trial was to investigate the impact of different levels of water and fertiliser inputs on Almond growth and productivity.

A number of questions were raised by the results of the trial:

- Yield increased between the low (60%) and medium (100%) irrigation treatments, but the difference was not significant.
- There were no significant yield differences between fertiliser treatments over seven growing seasons, in spite of large differences in the amount of nutrients (i.e. nitrogen and potassium) applied.
- Soil analysis indicated nitrogen and potassium were accumulating within deeper layers of the soil profile over the course of the trial.
- Leaf tissue levels of nitrogen and potassium increased over the life of the trial, and were well above levels generally seen across the Almond industry, and above the recommendations of Robinson, Treeby, and Stephenson (1997).
- Nutrient analysis of harvested fruit indicated exported nitrogen levels were 12% greater than the amount of nitrogen fertiliser applied in Treatment 1 (240 kg/ha N).
- Nutrient analysis of harvested fruit indicated exported nitrogen levels were less than the amount of nitrogen fertiliser applied in Treatment 2 (320 kg/ha N).
- Exported potassium levels were consistently lower than the amount of potassium fertiliser applied across all treatments.
- Environmental (i.e. leaching beyond the root zone) and economic (i.e. money spent on fertiliser) considerations highlighted the need to further understand the fate of applied nutrients.

All of these considerations suggested better understanding of nutrient movement and uptake were needed in order for Almond growers to make better decisions about fertiliser applications and irrigation management.

In response, the South Australian Research and Development Institute (SARDI) were invited to establish a monitoring program within the trial site, using SoluSamplers® to monitor the movement of solutes within and beyond the root zone of specific treatments (Table 1 and Table 2, and Figure 1).

Table 1: Irrigation and Nutrient Treatments

Treatment	Irrigation (% of Target)	Nutrient (N:K) (kg/ha/yr)
T1	100	240:400
T2	100	320:600
T3	100	480:800
T6	60	320:600
T7a (2001/02 to 2007/08)	Irregular	180:87
T7 (from 2008/09)	100	240:400

Table 2: Nutrient Treatment Details

Nutrient Application	Timing	Target N : K Application (kg/ha)							
		T1 & T7*		T2 & T6		T3		T7a*	
		N	K	N	K	N	K	N	K
Postharvest	21/4/09 – 15/5/09	75	132	75	132	75	132	-	-
Profile Establishment	5/8/09 – 12/8/09	32.5	95	32.5	95	32.5	95	-	-
Growing Season	1/9/09 – 6/11/09	132.5	173	132.5	173	132.5	173	102	57
	7/11/09 – 8/1/10	-	-	80	200	80	200	50	30
	9/1/10 – 19/2/10	-	-	-	-	160	200	28	-
	Sub Total	132.5	173	212.5	373	372.5	573	180	87
Annual Total		240	400	320	600	480	800	180	87

** From 2008/09, T7 was modified from irregular watering and 180:87 to consider more current best practice, i.e. Treatment 1 (100% ETc, 240:400). Application dates do not always correspond; see Figure 1 for actual timing.*

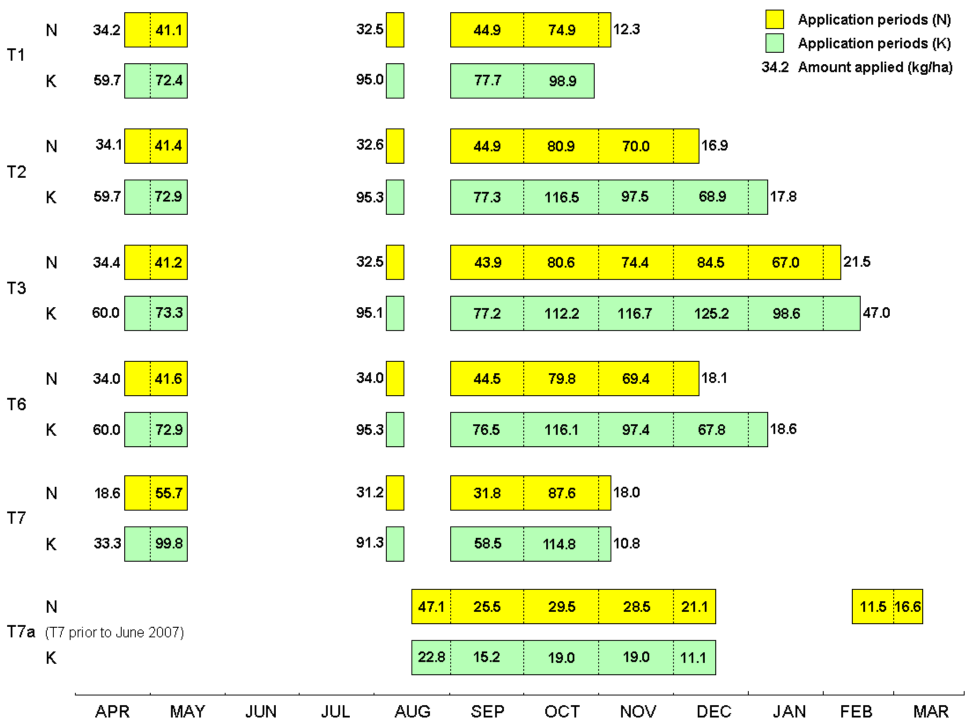


Figure 1: Monthly nutrient applications (kg/ha) by treatment

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343
P + 61 8 8582 2055 | F + 61 8 8582 3503
E admin@australianalmonds.com.au | W www.australianalmonds.com.au

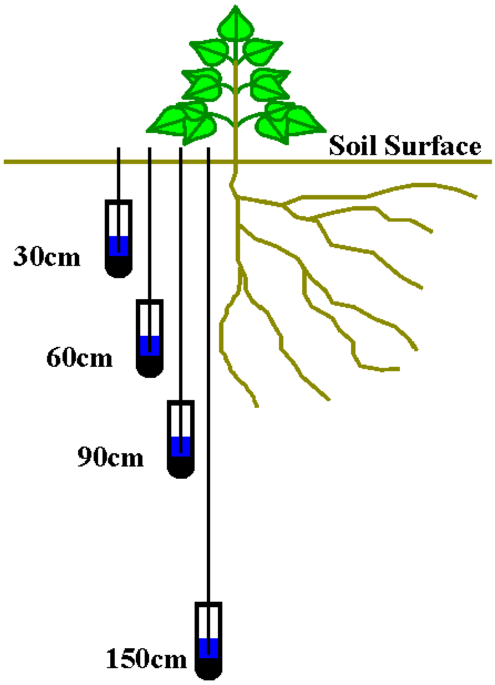


Figure 2: Layout of SoluSamplers within the trial site

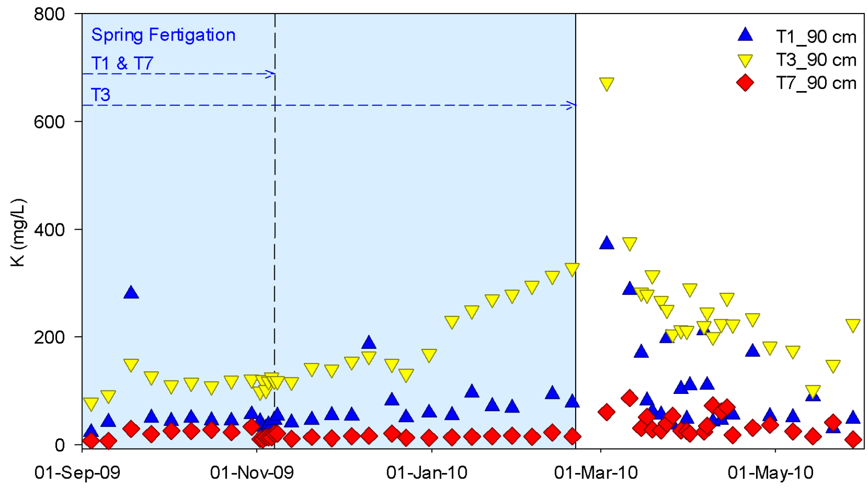


Figure 3: Potassium concentration at 90 cm depth in T1 (400kg/ha K), T3 (800kg/ha K) and T7 (87-200kg/ha K)

SoluSamplers® were installed at depths of 30 and 60 cm within the active root zone, and at 90 and 150 cm beyond the rootzone (Figure 2), and sampled weekly throughout the season. Samples were unable to be taken when soil water content fell too low (i.e. <60kPa), as happened during the dry winter of 2009.

Concentration of specific ions were analysed in the samples collected, and used to evaluate a number of hypotheses regarding the movement and fate of nutrients at the trial site.

This Factsheet discusses the results of soil solution analysis as they relate to issues of nutrient balance at the trial site. The hypotheses proposed address the balance between fertiliser applications, crop nutrient requirements, naturally occurring nutrients, and water availability.

All About Almonds – Timing Nutrient Inputs for Best Effect: CT Trial Results discusses soil solution results as they relate to the timing of nutrient applications.

Hypothesis 1

If soils naturally high in potassium receive additional potassium from fertilisers, then potassium will accumulate within the soil profile.

Findings and Lessons Learnt

Potassium concentration at 90 cm (below the root zone) varied throughout the season, but the concentration in T3 was higher than T1 on almost every sampling date, and T7 was consistently lower than all other treatments (Figure 3).

Annual potassium applications were 400 kg/ha for T1, and 800 kg/ha for T3, whilst T7 received only 87 kg/ha from 2001/02 to 2007/08, and 400 kg/ha from 2008/09 (Table 2). Annual removal of potassium via harvested fruit was estimated at 330 to 360 kg/ha (Brown, 2011).

The higher soil solution potassium concentrations correspond to greater potassium applications. The results suggest unutilised potassium is accumulating lower in the soil profile, particularly when potassium applications exceed 400kg/ha.

Further Work

Further work should focus on the quantity of potassium required and the rate of potassium uptake (thus supply) required by high yielding almond orchards. This will provide insight into whether the potassium requirements may be met by natural abundance, or whether applications of potassium containing fertilisers are required, and if so how much and at what time.

In addition, further research is required to determine the impact of potassium applications on other soil cations (e.g. calcium, magnesium, and sodium), and general soil health.

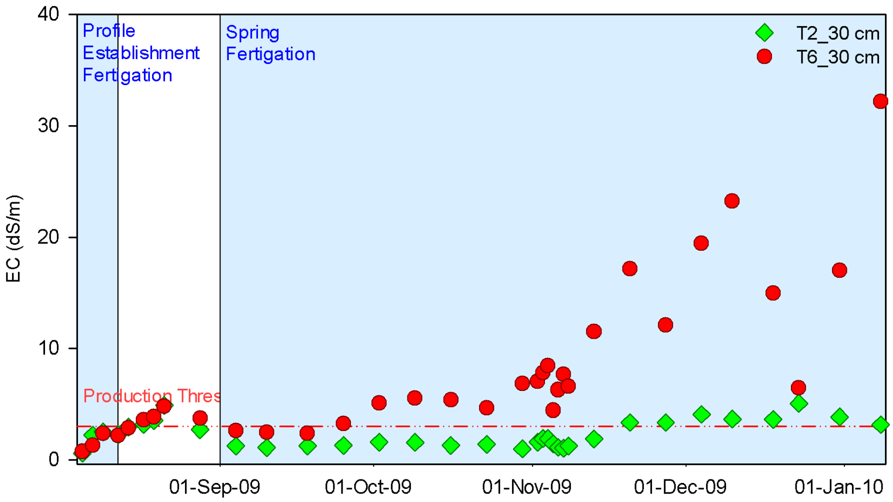


Figure 4: Electrical conductivity at 30 cm depth in T2 (320:600, 100% ETc) and T6 (320:600, 60% ETc)

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343
P + 61 8 8582 2055 | **F** + 61 8 8582 3503
E admin@australianalmonds.com.au | **W** www.australianalmonds.com.au

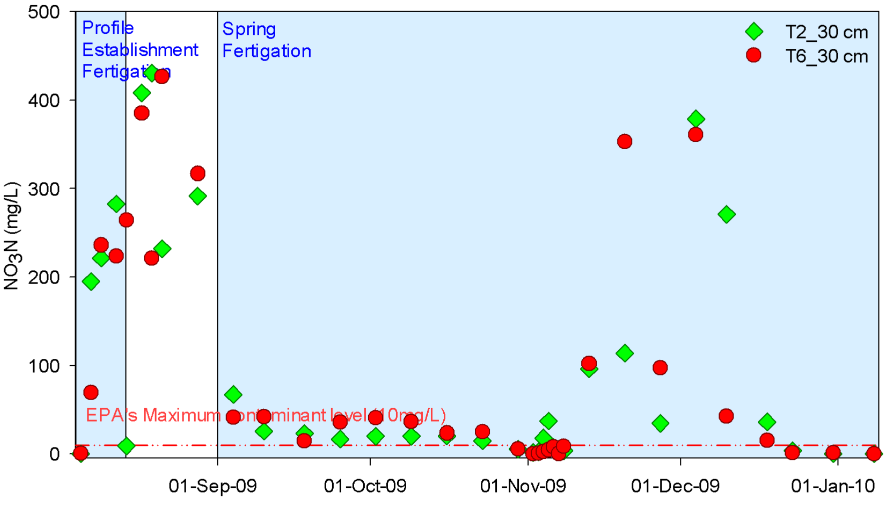


Figure 5: Nitrate concentration at 30 cm depth in T2 (320:600, 100% ETc) and T6 (320:600, 60% ETc)

Hypothesis 2

If fertiliser is applied to an almond orchard receiving irrigation volumes less than the plant requirement (i.e. Treatment 6), then ion concentrations and soil salinity will increase, and reduce plant water and nutrient uptake.

Findings and Lessons Learnt

The electrical conductivity (EC) of soil solution at 30 cm depth in T2 and T6 during profile establishment and spring/summer fertigation is shown in Figure 4. The increase in electrical conductivity corresponded to decreasing water applications, with T6 considerably higher in electrical conductivity, particularly from the beginning of October.

Treatments 2 and 6 received equal quantities of fertiliser throughout the trial and the same quantity of water during profile establishment; the only difference was T6 received 40% less water from approximately September onwards.

The increase in T6 EC from October was likely a result of crop water requirements exceeding water applications, leading to lower soil water content, resulting in concentration of nutrients (i.e. salts).

The threshold value for soil saturation extract salinity (ECse) in almonds is 1.5 dS/m (Ayers and Westcot, 1989), after which yield declines. Data published by Biswas et al (2007) indicates this equates to a soil solution salinity of approximately 3.0 dS/m.

Figure 4 indicates T2 EC increased to 5.1 dS/m in late December, but was below 3.0 dS/m for most of the season. In contrast, T6 was above 3.0 dS/m from October until April (not all data is shown), and recorded a peak reading of 33.9 dS/m in early January, ten times the threshold value.

T2 and T6 nitrate concentration at 30 cm depth during profile establishment and spring/summer fertigation is displayed in Figure 5. The data indicate nitrate concentrations were generally similar throughout both periods, despite 40% less water in T6 from September. Both T2 and T6 recorded peak nitrate concentrations from mid November to mid December.

The trend of increasing nitrate concentrations from early November is similar to the electrical conductivity readings (Figure 4) for both treatments, but the consistently higher EC readings of T6 in relation to T2 was less evident in the nitrate data. This rise in concentration corresponds to a change in the applied nitrogen from Ammonium Nitrate to Urea, and also a drop in pH, but pH in T6 remains higher than in T2. It is possible that this difference in pH leads to greater volatilisation of the Ammonia derived from the breakdown of Urea, and therefore less production of Nitrate in T6 than in T2, resulting in similar concentration of Nitrate given the different volumes of soil water.

The data in Figure 6 indicates the potassium concentration at 30 cm depth was higher in T6 relative to T2 from mid September to January.

This data is consistent with the electrical conductivity readings (Figure 4), and further suggests the higher readings in T6 from mid September were likely a result of crop water requirements exceeding water applications, leading to lower soil water content, leading to concentration of nutrients (i.e. salts).

Further Work

Electrical conductivity, potassium and to a lesser degree nitrate, show increases in concentrations of ions which correspond to lower water applications. Although it is difficult to correlate this data with the quantity of nutrient uptake by the plant, the data would suggest the osmotic potential of the 30cm soil depth would be high and the conditions more difficult for water and nutrient uptake.

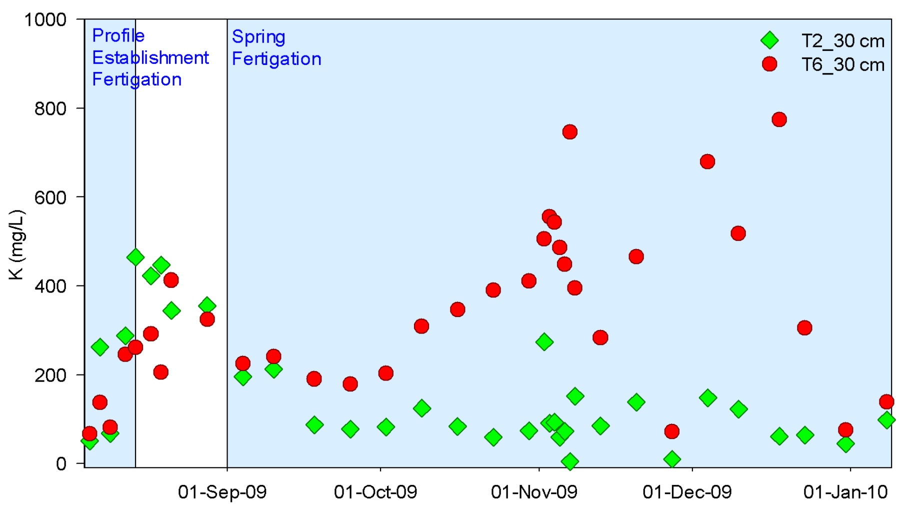


Figure 6: Potassium concentration at 30 cm depth in T2 (320:600, 100% ETc) and T6 (320:600, 60% ETc)

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343
P + 61 8 8582 2055 | **F** + 61 8 8582 3503
E admin@australianalmonds.com.au | **W** www.australianalmonds.com.au

Further investigation of this question could lead to a better understanding of the interactions between the soil, water, nutrients and plant, and a management system that: manages fertigation via concentration; is adaptable to lower water use orchards or regions; is adaptable to recycled water sources; and is responsive to seasonal yield variations and not just area based (i.e. kg/ha) calculations.

Hypothesis 3

If applications of fertiliser are applied above crop requirements, then fertiliser will accumulate within the soil profile and reduce economic and environmental sustainability.

Findings and Lessons Learnt

Figure 7 details Almond fruit development, and Figure 8 and Figure 9 illustrate nitrate and potassium concentrations in relation to almond fruit development.

The data indicates both nitrate and potassium concentrations are relatively stable from the end of fruit/pericarp growth (i.e. early October) to hull split (i.e. early January), after which concentrations increase at all depths until mid February.

The increase in nitrate and potassium concentration from mid December within T3 corresponds to extended fertiliser applications. T2 and T3 received the same quantity of fertiliser until the end of December, after which T2 applications ceased and T3 fertiliser applications continued until mid February. It is apparent that crop nutrient demand is greatest prior to the completion of kernel (embryo) growth and declines considerably following hull split.

It is therefore evident fertiliser applications following kernel (embryo) growth, and in particular following hull split, result in an accumulation of nutrients throughout the soil which does not achieve a return on investment, and has the potential to leach and cause off-site environmental impacts. It is clear both these outcomes reduce the sustainability of almond production.

Further Work

Further research into the nutritional requirements of Almonds at different growth stages and monitoring of soil solution will obtain optimum return on investment with minimal impact on the environment.

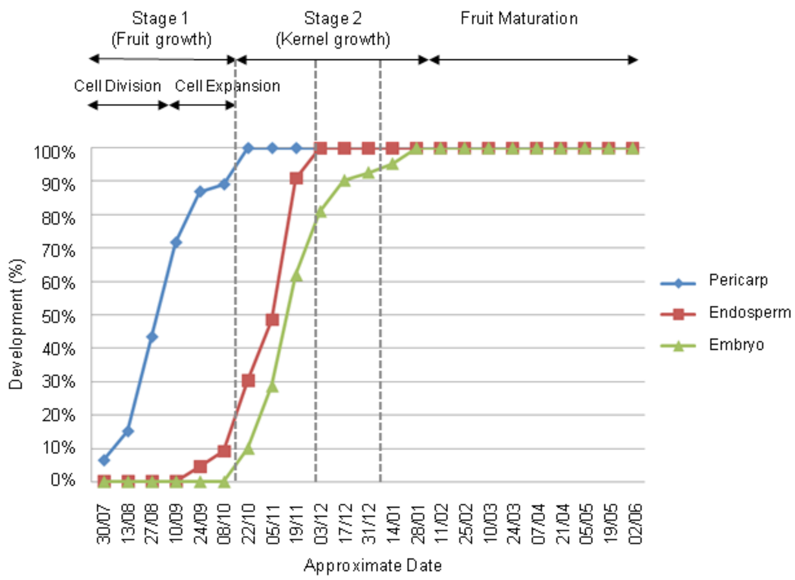


Figure 7: Almond fruit development (adapted from Hawker & Buttrose, 1980)

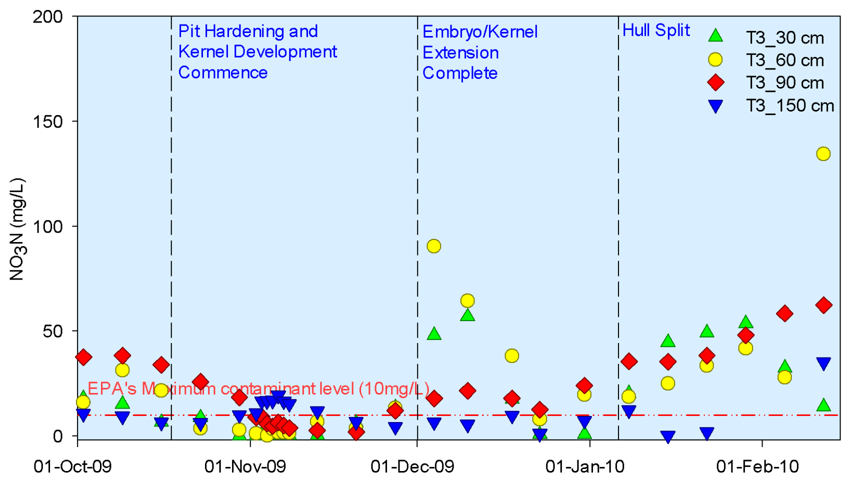


Figure 8: Nitrate concentration in treatment 3 (480:800) associated with spring and summer fertigation

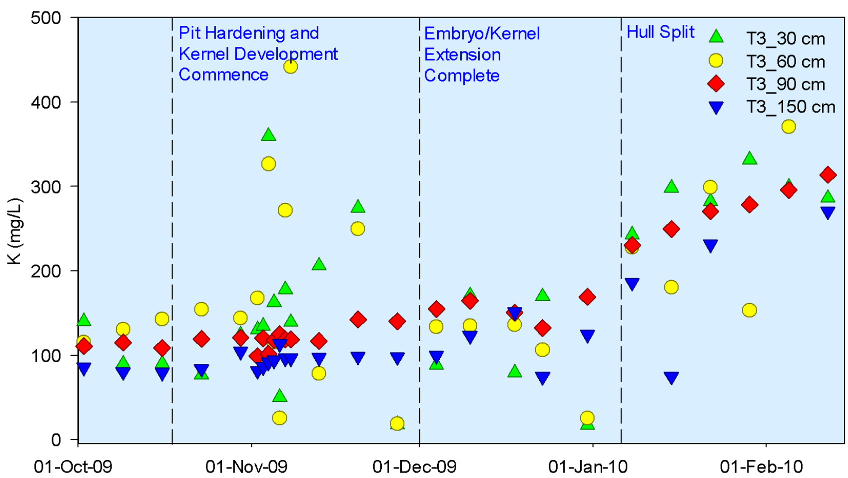


Figure 9: Potassium concentration in treatment 3 (480:800) associated with spring and summer fertigation

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343

P + 61 8 8582 2055 | **F** + 61 8 8582 3503
E admin@australianalmonds.com.au | **W** www.australianalmonds.com.au

References

Ayers, R.S. and D.W. Westcot, 1989. Water Quality for Agriculture, FAO Irrigation and Drainage Paper, 29 (Rev. 1), Food and Agriculture Organization of the United Nations, Rome.

Biswas, T.K., M. Dalton, P. Buss, and G. Schrale, 2007. "Evaluation of Salinity-Capacity Probe and Suction Cup Device for Real Time Soil Salinity Monitoring in South Australian Irrigated Horticulture." Proceedings of the 2nd International Symposium on Soil Water Measurement (Beltsville, Maryland, USA.

Brown, B., 2011. Sustainable Optimisation of Australian Almond Production. Horticulture Australia Limited Project AL07005, Final Report.

Hawker, J.S. and M.S. Buttrose, 1980. "Development of the Almond Nut (Prunus Dulcis (Mill.) D. A. Webb). Anatomy and Chemical Composition of Fruit Parts From Anthesis to Maturity", Annals of Botany 46:313-21.

Robinson, J. B., M.T. Treeby, and R. A. Stephenson. 1997. "Fruits, Vines and Nuts." Pp. 349-82 in Plant Analysis: An Interpretation Manual, 2nd ed. Douglas J. Reuter and J. B. E. Robinson. Collingwood, Victoria: CSIRO Publishing.

United States Environmental Protection Agency, National Primary Drinking Water Regulations, 2009. EPA 816 – F–9-004.

For further information contact Ben Brown, Industry Development Manager

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia December 2010
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.6 – Fact Sheet: Timing Nutrient Inputs for the Best Effect

Timing Nutrient Inputs for Best Effect

Mark Skewes[A], Mahalakshmi Mahadevan[A],
Brett Rosenzweig[B], and Ben Brown[B]

[A]South Australian Research & Development Institute
[B]Almond Board of Australia

Summary

Soil solution monitoring beneath an Almond irrigation and nutrition trial identified key considerations for managing fertigation in high input/high yield almond production systems. This factsheet reports issues relating to the timing of nutrient applications.

It was found that nutrient applications in late winter, following profile establishment irrigations, are susceptible to leaching due to rainfall and irrigation, as a result of very low uptake of nutrients at this time.

Crop nutrient demand was high during spring and early summer, up until hull split, corresponding to the peak growth stages of the almond nut. Fertigation applications during this period that are well matched to crop requirements result in good crop uptake and minimal leaching losses.

Crop nutrient demand declined after hull split, and applications of fertiliser after this time are susceptible to leaching from rainfall and irrigation.

Post-harvest fertiliser applications in April and May are susceptible to leaching due to very low uptake of nutrients at this time, and throughout winter. Applications may be best applied in March.

Introduction

The Almond Board of Australia, with assistance from Horticulture Australia Limited (HAL), established a trial, "Sustainable Optimisation of Australian Almond Production" at CT Farms near Berri, South Australia. The aim of the trial was to investigate the impact of different rates of water and fertiliser on Almond growth and productivity.

A number of questions were raised by the results of the trial:

- Yield increased from the low (60% Etc) to medium (100% Etc) irrigation treatments, but the difference was not significant.
- There were no significant yield differences between fertiliser treatments, in spite of large differences in the amount of nutrients (i.e. nitrogen and potassium) applied.
- Soil analysis indicated nitrogen and potassium were accumulating within the deeper layers of the soil profile between seasons.
- Nitrogen and potassium increased over the life of the trial, and were well above levels generally seen across the Almond industry, and above the recommendations of Robinson, Treeby, and Stephenson (1997).
- Nutrient analysis of harvested fruit indicated exported nitrogen levels were 12% greater than the amount of nitrogen fertiliser applied in Treatment 1 (240 kg/ha N).
- Nutrient analysis of harvested fruit indicated exported nitrogen levels were less than the amount of nitrogen fertiliser applied in Treatment 2 (320 kg/ha N).
- Exported potassium levels were consistently lower than the amount of potassium fertiliser applied across all treatments.
- Environmental (i.e. leaching beyond the root zone) and economic (i.e. money spent on fertiliser) considerations highlighted the need to further understand the fate of applied nutrients.

All of these considerations suggested better understanding of nutrient movement and uptake were needed in order for Almond growers to make better decisions about fertiliser applications and irrigation management.

In response, the South Australian Research and Development Institute (SARDI) were invited to establish a

Table 1: Irrigation and Nutrient Treatments

Treatment	Irrigation (% of Target)	Nutrient (N:K) (kg/ha/yr)
T1	100	240:400
T2	100	320:600
T3	100	480:800
T6	60	320:600
T7 (2001/02 to 2007/08)	Irregular	180:87
T7 (from 2008/09)	100	240:400

Table 2: Nutrient Treatment Details

Fertiliser Application	Timing	Amount of N : K Applied (kg/ha)					
		T1		T2 & T6		T3	
		N	K	N	K	N	K
Postharvest	21/4/09 – 15/5/09	75	132	75	132	75	132
Profile Establishment	5/8/09 – 12/8/09	32.5	95	32.5	95	32.5	95
Growing Season	1/9/09 – 6/11/09	132.5	173	132.5	173	132.5	173
	7/11/09 – 8/1/10	-	-	80	200	80	200
	9/1/10 – 19/2/10	-	-	-	-	160	200
	Sub Total	132.5	173	212.5	373	372.5	573
Annual Total		240	400	320	600	480	800

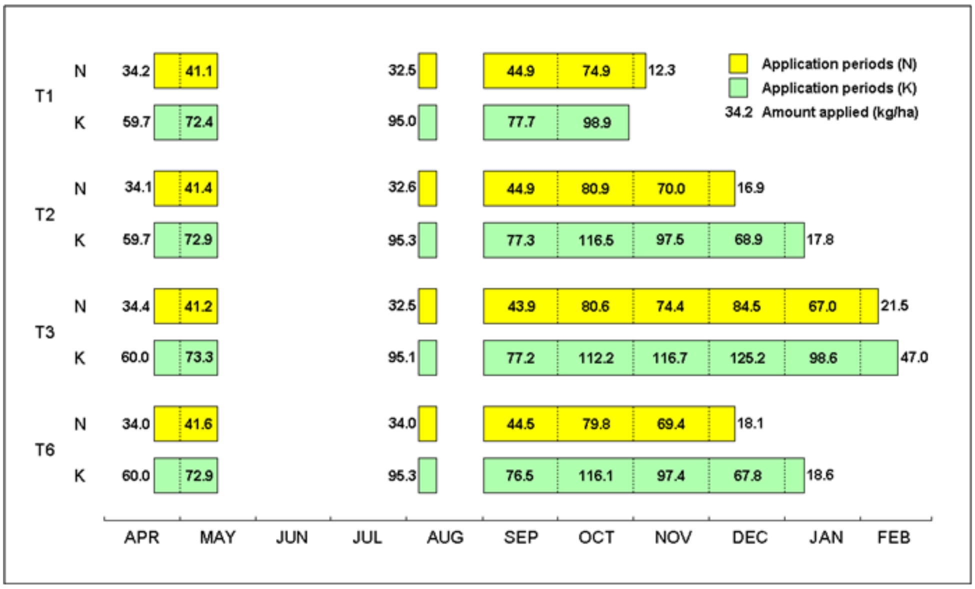


Figure 1: Monthly nutrient applications (kg/ha) by treatment

SoluSamplers® were installed at depths of 30 and 60 cm within the active root zone, and at 90 and 150 cm beyond the root zone (Figure 2), and sampled weekly throughout the season. Samples were unable to be taken when soil water content fell too low (i.e. <60kPa), as happened during the dry winter of 2009.

Concentration of specific ions were analysed in the samples collected, and used to evaluate a number of hypotheses regarding the movement and fate of nutrients at the trial site.

This Factsheet discusses the results of soil solution analysis as they relate to issues of timing of fertiliser applications. The hypotheses proposed address the efficacy of fertigation applied at various stages of the growing season.

All About Almonds –Balancing Nutrient Input and Output: CT Trial Results discusses soil solution results as they relate to nutrient balance within the soil/ water/plant system.

Hypothesis 1

If 250 kg/ha of potassium nitrate is applied in late winter following the profile establishment irrigation, then nitrogen and potassium will remain in the root zone for early season uptake.

Findings and Lessons Learnt

Immediately following the beginning of the potassium nitrate applications on 5th August 2009, the nitrate concentration increased rapidly at 30cm and continued to increase until the completion of the applications on 12th August (Figure 3).

The increase in nitrate concentration at 30cm during profile establishment was expected, due to the large application of fertiliser. The continued rise in nitrate concentration between profile establishment and the beginning of spring irrigations corresponds to a slow decline in soil water content, leading to an increase in nitrogen per volume of stored water (i.e. mg/L).

Once spring irrigations began on 21st August, the nitrate concentration at 30cm progressively declined, but simultaneously began to rise at 60 and to a lesser extent 90cm (Figure 3).

The large rise in nitrate concentration at 60 cm suggests some of the decline at 30 cm was due to movement of fertiliser through the profile. It is not clear how much nitrate was actually taken up by the trees during and following profile establishment, but it was clear that not all the nitrate applied was taken up, and as a result it was vulnerable to leaching from the root zone by rainfall or irrigation.

Potassium levels were elevated prior to the application of the profile establishment fertigation, and subsequently declined during application (Figure 4).

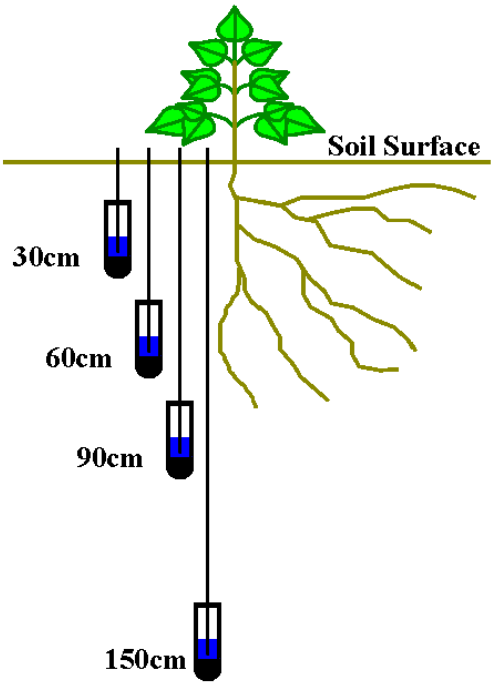


Figure 2: Layout of SoluSamplers within the trial site

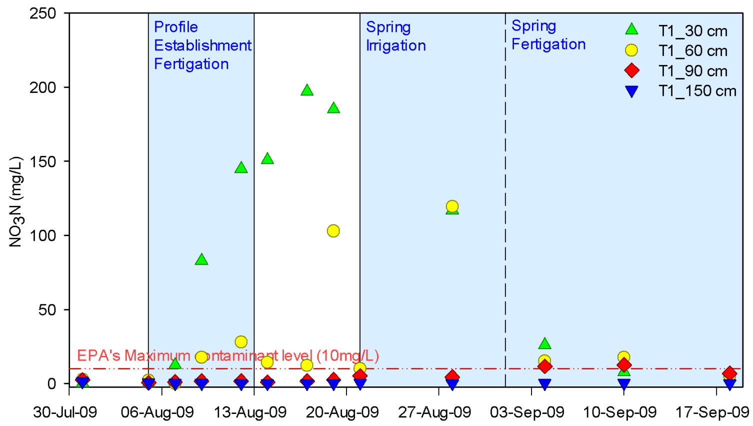


Figure 3: Nitrate concentration in Treatment 1 (240:400) associated with profile establishment

The soil at the trial site was naturally high in potassium. In addition, the trial received spring and post harvest fertiliser applications of potassium over a number of seasons. As a result, natural abundance and prior applications of potassium combined with the low mobility of potassium resulted in relatively high concentrations of potassium in the soil throughout the season. The decline in concentration during profile establishment fertigation was likely due to increased soil water content and a reduction in concentration, and leaching to 90cm where concentrations increased.

Although slightly delayed, there was a rise in potassium concentration at all soil depths following application of potassium nitrate in August 2009 (Figure 4), followed by a decline in concentration once spring irrigations commenced.

The rise in potassium concentration at 60 cm depth during and following profile establishment indicates that potassium initially moved through the soil profile. Results indicate potassium reached 90 cm and 150 cm.

Further Work

Further work should focus on the nutritional requirements of almond trees at profile establishment, to identify the most appropriate timing of fertiliser applications and the amount of fertiliser required.

Hypothesis 2

If the concentration of nitrogen and potassium did not increase at depth prior to hull split, then spring and early summer fertiliser applications were well matched to crop requirements and efficiently utilised by the crop.

Findings and Lessons Learnt

Nitrate concentration declined at 30 and 60cm in late August and early September, and remained relatively low and stable during September and October (Figure 5). Nitrate concentrations remained relatively low and stable at 90 and 150cm during late August, September and October.

Given nitrate concentrations slightly increased at 60cm in early September and concentrations subsequently remained relatively constant at all depths, nitrate was likely to have been partially leached beyond 60cm and removed from solution by plant uptake.

Low nitrate concentrations in deeper soil layers suggest minimal leaching occurred, which combined with the observations above, suggests the majority of nitrate applied between August and the end of November was taken up by plant roots.

Nitrate concentrations increased in late November and early December at 30cm and 60cm. However, nitrate concentrations remained relatively low at 90 and 150cm through November, December and early January (i.e. hull split).

The high nitrate concentrations at 30 cm soil depth were likely a result of high crop water use, soil surface evaporation, and reduced soil water content, leading to increased nitrate concentration.

Potassium concentrations remained relatively stable in September and October at all depths (Figure 6). Concentrations rose briefly at 30 and 60cm in the beginning of November, then returned to pre November levels and remained relatively stable until early January.

Potassium concentrations were generally higher than nitrate, reflecting the greater soil content of potassium. High concentrations at 30 and 60 cm in early November may have been due to concentration as a result of crop water use and surface evaporation, as described previously. Potassium concentrations increased at 90cm from early November, suggesting some leaching. The absence of large changes at 90 and 150 cm suggested minimal leaching.

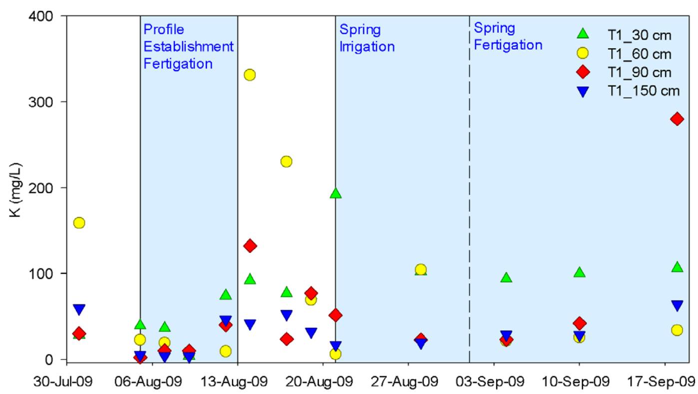
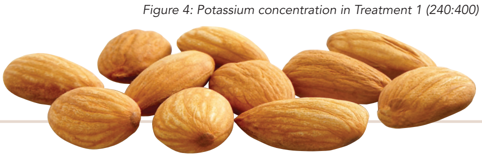


Figure 4: Potassium concentration in Treatment 1 (240:400) associated with profile establishment



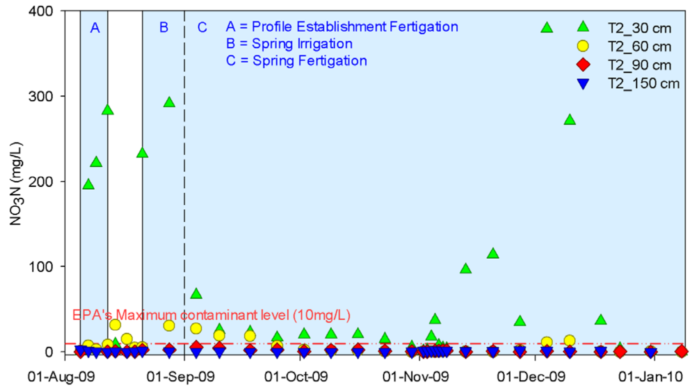


Figure 5: Nitrate concentration in Treatment 2 (320:600) associated with spring and summer fertigation

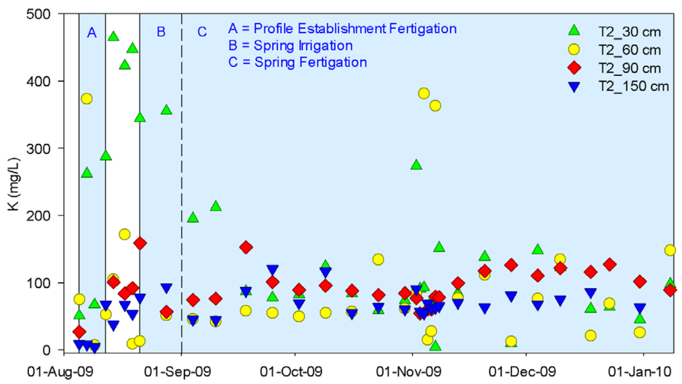


Figure 6: Potassium concentration in Treatment 2 (320:600) associated with spring and summer fertigation

Further Work

Further work should focus on the water and nutrient requirements of almonds during spring and early summer. The results suggest nitrogen and potassium applications in spring and summer were well matched and water was limiting in November, a conclusion supported by soil water data.

Hypothesis 3

If fertiliser applications continue after kernel development and hull split (e.g. Treatment 3), then fertiliser will be unutilised and accumulate in the profile.

Findings and Lessons Learnt

Figure 7 illustrates the development of Almond fruit over the course of the season, as determined by Hawker and Buttrose (1980). Approximate dates were transferred to Figure 8 and Figure 9 to assist in comparison with soil solution data.

When fertigation was extended beyond embryo/kernel extension (early December), nitrate concentration increased briefly at all depths, and then declined (Figure 8).

The sudden increase in T3 nitrate concentration in early December (Figure 8) coincided with the end of Endosperm growth (Figure 7), and could either suggest a concentration effect caused by high crop water use and poorly matched water applications, or a decline in crop nutrient requirements at this point, allowing accumulation of nitrate throughout the soil profile.

The subsequent decrease in concentration at 30 and 60cm, and increase at 90cm suggests nitrate leached out of the root zone. This does not correlate well to the pattern seen in T2 (Figure 5), where the increase in early December was only seen at 30 cm, with no suggestion of leaching beyond that depth.

When fertigation was applied beyond hull split (early January), nitrate concentration increased at all depths (Figure 8).

Following the completion of kernel growth and beginning of hull split, (Figure 7), nitrate concentration increased at all depths. The gradual increase in concentration at all depths, particularly at 90 and 150 cm, suggests leaching through the soil profile. This strongly suggests the nitrate requirement of Almond trees is considerably less following hull split, a conclusion supported by the decline in active fruit growth shown in Figure 7.

Following the completion of embryo/kernel growth (early December), the concentration of potassium was variable with no clear trend (Figure 9).

Potassium concentration increased at all depths following hull split in late January (Figure 9), a pattern remarkably similar to nitrate (Figure 8).

The rise in potassium concentration at all depths following hull split, particularly at 90 and 150 cm, suggest potassium applications were above crop requirements and leached through the profile. Soil water data indicates the increased concentration was not due to drying of soil.

Hypothesis 4

If fertiliser is applied immediately following harvest and prior to defoliation, then the fertiliser will be utilised by the crop.

Findings and Lessons Learnt

T6 Nitrate concentration during postharvest and profile establishment are shown in Figure 10. Nitrate concentration increased considerably at all depths during postharvest fertigation.

Although T6 was the reduced irrigation treatment, all treatments received similar irrigation and fertigation programs during postharvest and profile establishment (Table 2). The increase in concentration at all depths (no data available for 150 cm) indicates some of the nitrate applied during postharvest fertigation leached beyond the active root zone, to at least 90cm. This suggests irrigation applications at this time were higher than crop water use. The quantity of leached nitrate is unable to be determined from this data.

Following the completion of fertigation in May 2009, nitrate concentration decreased at 30 and 60cm depth, and remained relatively unchanged and high at 90 cm. When irrigation resumed in late July 2009, nitrate concentrations at all depths decreased rapidly.

The decrease at 30 and 60cm suggests nitrate was either taken up by roots or leached by irrigation and rainfall. The slower decline at 60 cm and the high concentration at 90 cm for a month after fertiliser applications ceased, combined with relatively static soil water data, suggest that there may have been some uptake during this period, combined with slow leaching due to rainfall.

The decline in nitrate concentration at all depths in July indicates a portion of the fertiliser applied in May was leached through the profile and not taken up by the tree. The higher concentrations at 150 cm further indicate leaching of residual fertiliser occurred rather than uptake.

Further Work

The focus of further work should be on changes in crop nutritional requirements across the course of the growing season. It would appear that nutritional requirements reduce following embryo/kernel growth, and decline further following hull split, but it is not clear by how much. A clear understanding of requirements relative to the physiological growth stages of almonds would be a most useful tool for growers in managing nutrient applications.

Following the completion of fertigation in May 2009, potassium concentration decreased at 30 cm depth, and remained relatively unchanged and high at 60 and 90 cm depth. When irrigation resumed in late July 2009, potassium concentrations at all depths decreased rapidly.(Figure 11)

The data appears to be similar to nitrate, with a portion of potassium applications being leached through the profile and not taken up by the plant in May, and further leached beyond the active rootzone following profile establishment irrigations in July and August.

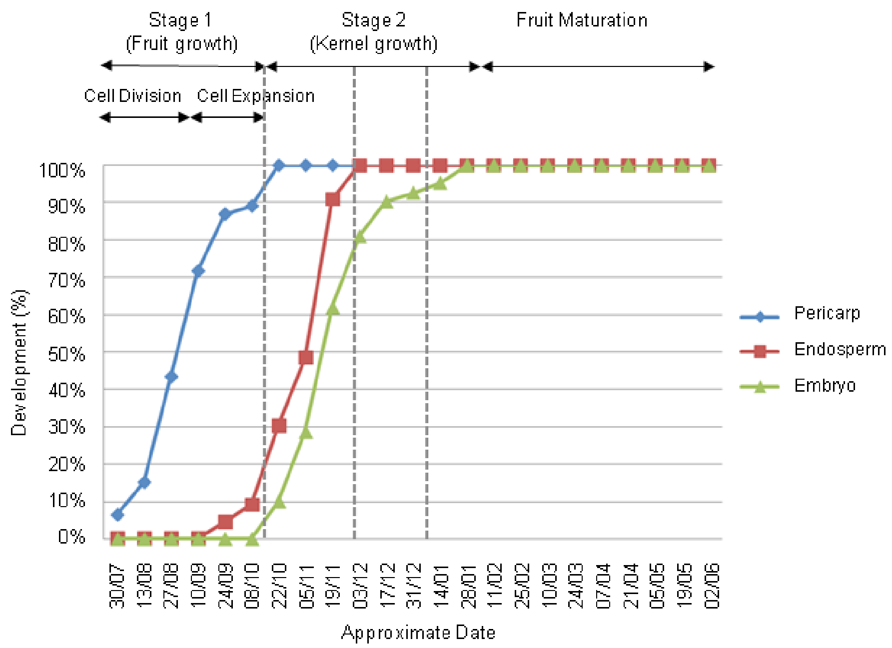


Figure 7: Almond fruit development (adapted from Hawker & Buttrose, 1980)

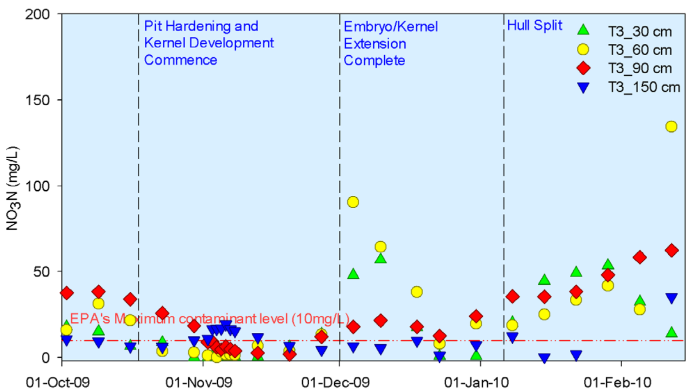


Figure 8: Nitrate concentration in Treatment 3 (480:800) associated with spring and summer fertigation

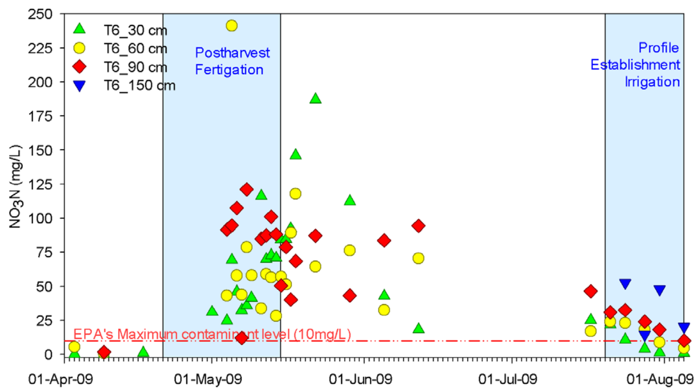


Figure 10: Nitrate concentration in Treatment 6 (60%ETc, 320:600) associated with postharvest fertigation

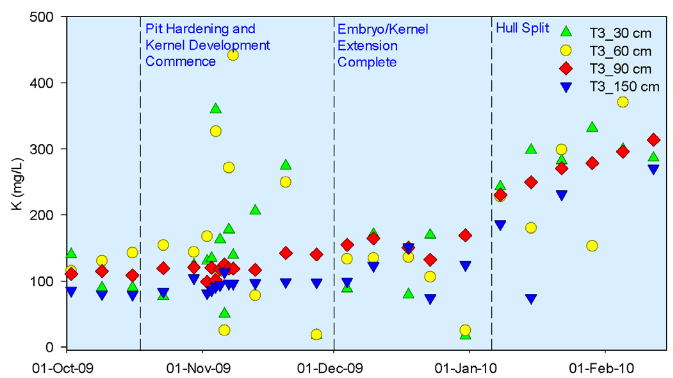


Figure 9: Potassium concentration in Treatment 3 (480:800) associated with spring and summer fertigation

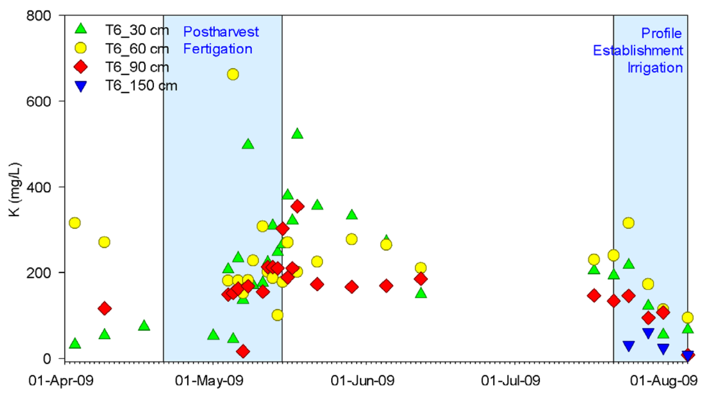


Figure 11: Potassium concentration in Treatment 6 (60%ETc, 320:600) associated with postharvest fertigation

References

Hawker, J.S. and M.S. Buttrose, 1980. "Development of the Almond Nut (Prunus Dulcis (Mill.) D. A. Webb). Anatomy and Chemical Composition of Fruit Parts From Anthesis to Maturity", Annals of Botany 46:313-21.

Robinson, J. B., M.T. Treeby, and R. A. Stephenson. 1997. "Fruits, Vines and Nuts." Pp. 349-82 in Plant Analysis: An Interpretation Manual, 2nd ed. Douglas J. Reuter and J. B. E. Robinson. Collingwood, Victoria: CSIRO Publishing.

United States Environmental Protection Agency, National Primary Drinking Water Regulations, 2009. EPA 816 – F–9-004.

For further information contact Ben Brown, Industry Development Manager

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

Government of South Australia

ALMOND BOARD OF AUSTRALIA

HAL Horticulture Australia

SARDI South Australian Research and Development Institute

ACKNOWLEDGEMENTS
The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER
Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.7 – Fact Sheet: Leaf Tissue Analysis Review

Background Paper
Leaf Tissue Analysis Review

Brett Rosenzweig, Almond Board of Australia

Background

Plant analysis as a method to diagnose plant health, dates back to the early 1900's (Reuter & Robinson 1997). Plant analysis has been developed to provide information on the nutrient status of plants as a guide to nutrient management for optimal plant production whilst also minimising the risk of environmental and economic cost of over-fertilisation (Reuter & Robinson 1997).

There have been two approaches to using plant analysis. One is as a diagnostic tool where critical values are defined which allow the user to show whether the plant is deficient in a particular micro- or macro- nutrient, or affected by a toxic concentration of something like chloride or boron. The second method is as a monitoring tool where the nutrient concentrations in the leaves are compared with standard ranges and growers can assess the nutrient status of their crop and make informed decisions on how appropriate their fertiliser program might be. Critical values have most commonly been derived from experimentally determined relationships between plant yield and associated nutrient concentration. The relationship tends to form a curve of the kind shown in Figure 1 with increasing yields occurring with increasing nutrient levels (i.e. deficient to marginal levels), with a short or long plateau where yields don't change with increasing nutrient levels (i.e. adequate levels) and finally yields decreasing with increasing nutrient levels (i.e. toxicity). The commonly used standard nutrient ranges are more usually determined from a mixture of experiments and field surveys which allow the agronomist to sketch in parts of the curve. (It is usually easy to see when a crop is severely deficient or showing toxicity. The uncertain areas are often described as "low" or "high", or "marginal" as shown in the diagram.

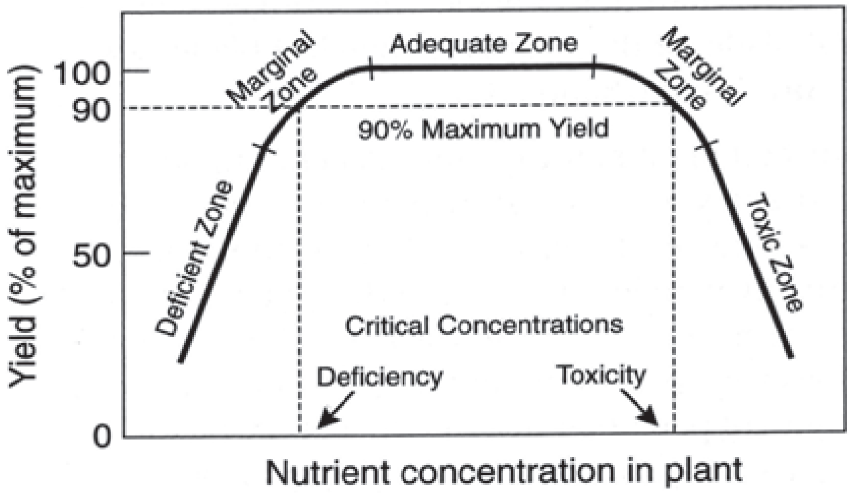


Figure 1: Derivation of critical concentrations for diagnosing nutrient deficiency and toxicity in plants (Reuter & Robinson 1997).

To be useful, leaf analysis is dependent on proper sampling both in terms of leaf choice and timing. If a diagnostic sample is taken it often represents only a few trees. If a monitoring sample is taken it often represents a complete block. Either way, the sampling program should be repeatable so results can be objectively compared from one year to the next. For monitoring, samples should be collected from all four quadrants of the tree and in a pattern that best reflects the variability of the orchard. Leaf sampling should also occur at the correct time during the growing cycle to allow valid comparison with the standards. In the CT Trial, leaf samples were taken during October, November, and December as well as the traditional January timing.

Leaf analysis values over a few seasons can show a trend of plant nutrient levels from one sampling event to another. Results can't be used to determine actual rates of nutrient to apply in a fertigation program because of the uncertainties that exist within any one orchard. Soil type can influence nutrient availability. Some nutrients are easily leached away from the roots below the root zone etc.

Calculations of crop nutrient removal can help growers understand the sorts of fertiliser rates that might be required. Leaf analysis can help show if these calculations have been appropriate and help fine tune them.

A leaf analysis will give a rough average of the plant nutrient status in the orchard. This means that when levels for a particular nutrient are at a marginal to adequate level, then it's possible for 50% of the orchard to be below adequate or even deficient.

In a nutrition survey by Brown, 2009 it was found that Californian almond growers were aiming for higher values than those set by the University of California (UC). Infield testing showed when growers achieved a higher level of leaf nutrition, for

Table 1: Almond leaf standards for January sampling – South Australian survey work by Robinson and Glenn (1981) based on the Californian method (e.g. Beutel et al 1976).

NUTRIENT	Deficient (D)	Marginal (M)	Adequate (A)	Toxic / Excessive (T)
N (%)	< 1.8	1.8-1.9	2.0-2.5	
P (%)	< 0.1		>0.1	
K (%)	< 1.0	1.0-1.3	1.4-1.7	
S (%)				
Ca (%)			>2.0	
Mg (%)			>0.25	
Na (%)			<0.25	>0.25
Cl (%)			<0.3	>0.3
Cu (mg/kg)			>4	
Zn (mg/kg)	<15	15-24	25-30	
Mn (mg/kg)			>20	
Fe (mg/kg)				
B (mg/kg)	<12	12-24	25-65	>85

example 2% K compared to the traditional UC recommendation of 1.4% K, yields were maintained at a highly productive level. If the average nutrition level of K was allowed to fall to 1.4%, then 50% of the orchard could be deficient and therefore yields could drop accordingly.

Brown, 2009 has also noted there could be a difference in sampling fruiting spurs compared to the traditional method of non fruiting spurs. If fruiting spurs were sampled, the likely result would be lower nutrient concentrations as fruiting spurs have a greater nutritional demand. In the CT Trial we sampled fruiting spurs.

Average Australian almond industry yields have increased by approximately 30% in the last 8-9 years from 2.5T/Ha to 3.2T/Ha. This increase is largely attributed to increased and more efficient use of inputs (mainly water and fertiliser) as a response to the data collected in the CT Trial. The increase in average yields would suggest the traditional leaf analysis standard ranges which were last reviewed in California and Australia in 1976 and 1981 respectively, may not be appropriate for the sorts of yields now being obtained.

Grower Survey

In early 2010 a survey of past leaf analysis results from a range of growers was undertaken across the Australian almond industry. It aimed to statistically analyse the data and propose new working leaf analysis standards. We hoped the review would provide some insight into the range of levels of leaf nutrient concentrations now being achieved and how they related to the current Australian leaf analysis standards. The growers' results were also compared to the CT Trial leaf analysis records.

The survey collected data from orchards with the following characteristics:

- Mature almond trees, generally greater than 5 year old.
- Predominantly Nemaguard rootstock.
- Nonpareil only.
- Traditional spacings of approximately 280-300 trees/ha.
- Mid to late January leaf samples from non-fruiting spurs.
- Irrigation and yield records from which leaves were sampled.

This Fact Sheet proposes new standards for nutrient concentrations in leaves sampled in October, November, December and the traditional January timing.

Results

Leaf analysis data were collected from 12 participating properties for 2002 to 2009. The data were collated and boxplots[1] were used to present the combined data for all participants. The average and range of values for each nutrient are presented below and compared with data from the CT Trial and the traditional leaf standards of Robinson and Glenn, 1981 (Table 1).

Only a few growers were able to provide data prior to 2003. Beyond 2003, the majority of surveyed growers were able to contribute data which is evident in the greater variability depicted by the boxplots. The range of samples contributed by each grower each year is shown in Table 2 and this sample size needs to be accounted for when analysing the graphs. In addition to this, some variation may occur in results provided by different analytical labs which is why growers are recommended to continue to use one laboratory which allows trends to be followed with more confidence.

Table 2: Breakdown of samples by grower

Samples	G1	G2	G3	G4	G5	CT	G6	G7	G8	G9	G10	G11
1 – 5	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	
5 >							✓					✓
% of total	1.5	1.0	4.1	4.1	0.5	4.6	16.0	1.3	2.1	1.0	0.4	63.4

[1]*Box plot - a box plot or boxplot (also known as a box-and-whisker diagram or plot) is a convenient way of graphically depicting groups of numerical data through their five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). A boxplot may also indicate which observations, if any, might be considered outliers. Wikipedia, The Free Encyclopaedia. Retrieved, January 4, 2010, from* http://en.wikipedia.org/w/index.php?title=Box_plot&oldid=331915126

January leaf tissue analysis

Surveyed growers versus CT Trial

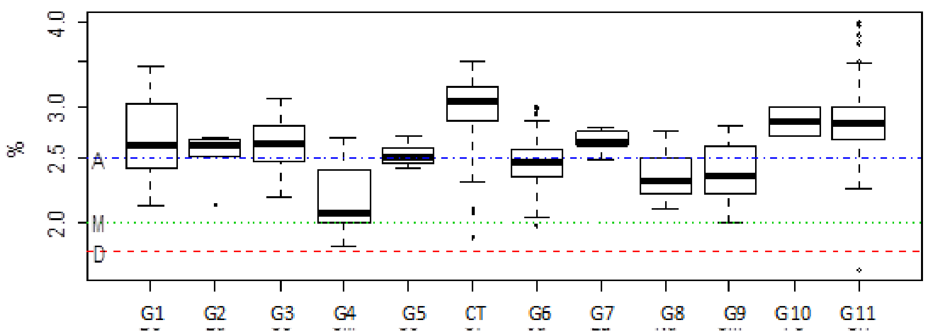


Figure 2: January leaf nitrogen (N) levels – Surveyed Growers vs. CT Trial.

Nitrogen – The majority of the growers had mean nitrogen levels of 2.5% or greater, with none of the nitrogen levels below the traditional deficiency level of 2%. The CT Trial had higher average concentrations of nitrogen compared to the grower's results which may be explained by the higher number of foliar sprays and intensive fertigation program.

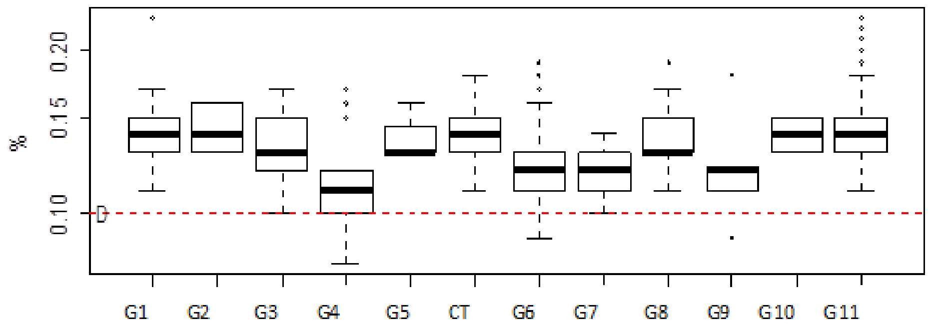


Figure 3: January leaf phosphorus (P) levels – Surveyed Growers vs. CT Trial.

Phosphorus – Most results indicate phosphorus levels of 0.12 to 0.14%, which is 20 to 40% above the traditional standard of 0.10%. The CT Trial had results similar to the growers' which suggest similar levels of phosphorus are being applied during fertigation programs.

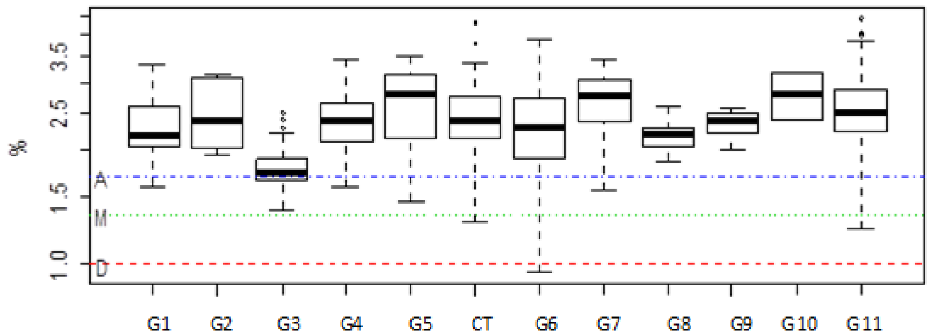


Figure 4: January leaf potassium (K) levels – Surveyed Growers vs. CT Trial.

Potassium - Most levels were considered to be above adequate. Grower 3 had 25-50% of results classified as slightly less than adequate. The range of results amongst the growers was quite varied. There was little difference between the CT Trial mean potassium and the growers' results.

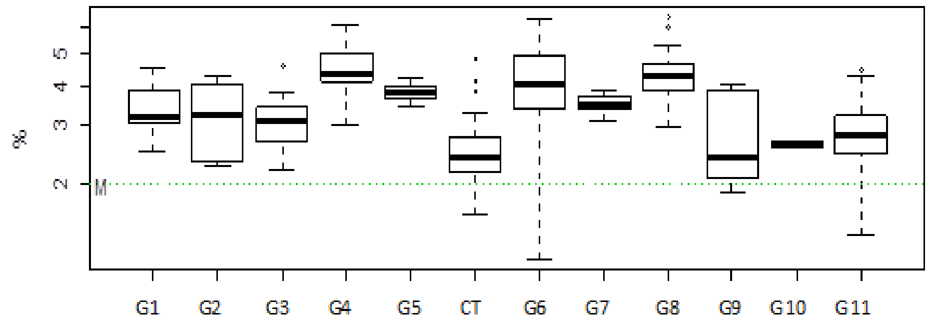


Figure 5: January leaf calcium (Ca) levels – Surveyed Growers vs. CT Trial.

Calcium – Generally levels were adequate. All growers had higher mean calcium levels when compared to the CT Trial where we know that soils were beginning to acidify which might make Ca less available.

Almond Board of Australia Inc.
9 William Street, PO Box 2246 | Berri South Australia 5343

P + 61 8 8582 2055 | **F** + 61 8 8582 3503
E admin@australianalmonds.com.au | **W** www.australianalmonds.com.au

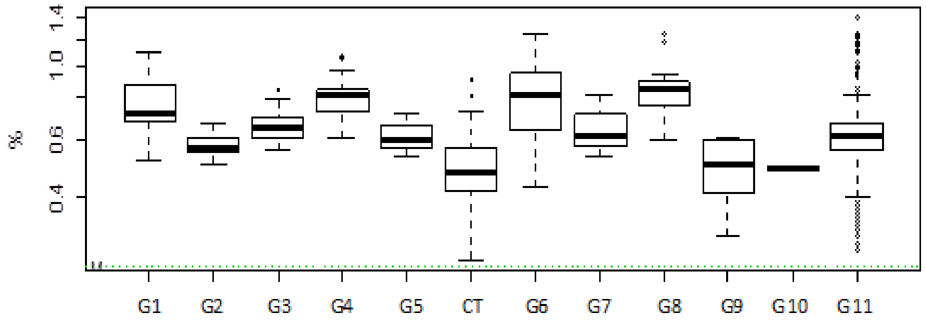


Figure 6: January leaf magnesium (Mg) levels – Surveyed Growers vs. CT Trial.

Magnesium - All levels were adequate and all growers' results had a higher mean than the CT Trial. The CT Trial, Growers 6, 9 and 11 had a wide range of results. The CT Trial results could be lower due to low soil pH which can magnesium availability or higher potassium inputs which can interfere with Mg uptake.

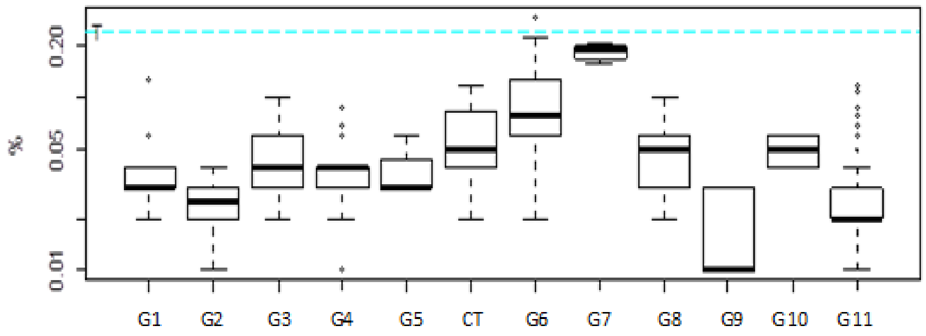


Figure 7: January leaf sodium (Na) levels – Surveyed Growers vs. CT Trial.

Sodium - Most of Grower 7's samples approached Sodium toxicity while Grower 6 had some samples and outliers that reached levels that could be toxic. Grower 9 had the lowest mean sodium levels with the rest of the growers result similar to the CT Trial. Heavy soil types may influence and be the cause of high levels.

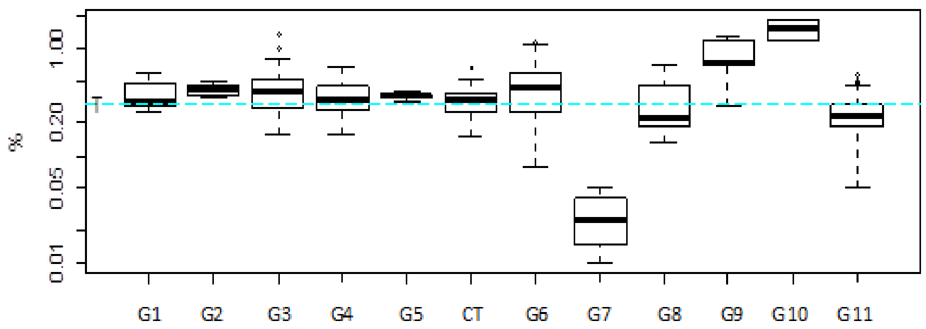


Figure 8: January leaf chloride (Cl) levels – Surveyed Growers vs. CT Trial.

Chloride - Many of the growers samples exceeded the proposed toxic level, in particular all samples from Grower 10 were well above the toxic levels and likely to have resulted in visible leaf burn. With the exception of Growers 7, 9 & 10, all other growers had similar chloride levels to the CT Trial.

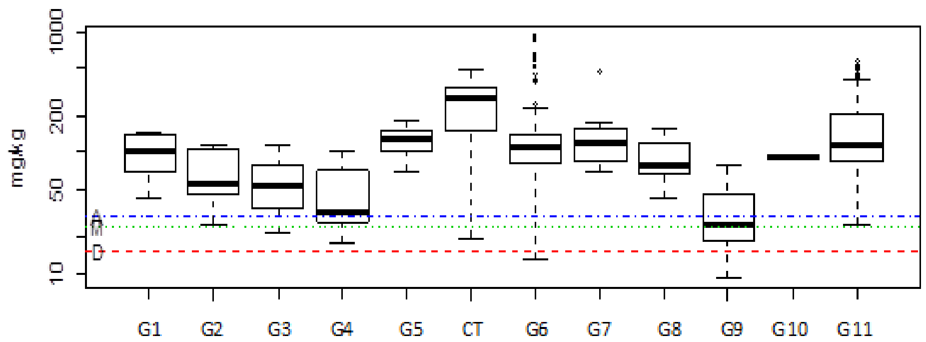


Figure 9: January leaf zinc (Zn) levels – Surveyed Growers vs. CT Trial.

Zinc - With few exceptions, levels were high suggesting contamination of the leaf surfaces with foliar nutrient sprays. Approximately 50% of Grower 9's samples were marginal. The CT Trial zinc levels were higher than the rest of the growers due to the intensive foliar fertiliser program that was not used by the rest of the industry.

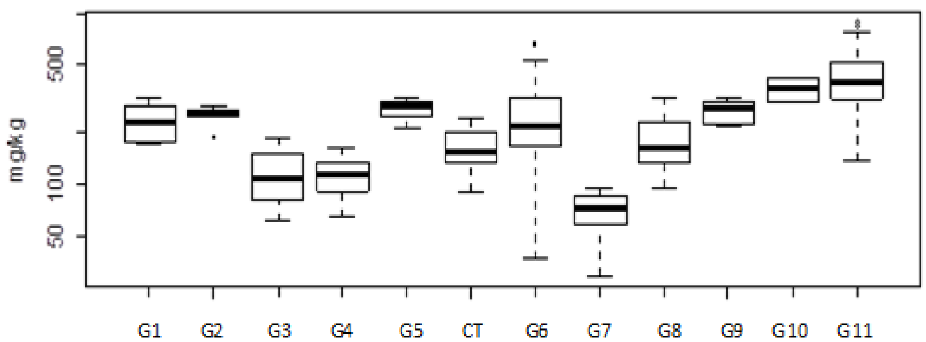


Figure 10: January leaf manganese (Mn) levels – Surveyed Growers vs. CT Trial.

Manganese - All growers were above the adequate value of 20mg/kg and many were very high suggesting contamination of the leaf surfaces with foliar nutrients and/or Mancozeb. Soil acidification can also lead to high leaf manganese concentrations. There were no clear trends of the manganese levels except Grower 7's levels were lower than the other growers. Growers 6 & 11 had a wide spread of results indicating a large number of samples were taken. There was no clear differentiation between the CT Trial and growers results.

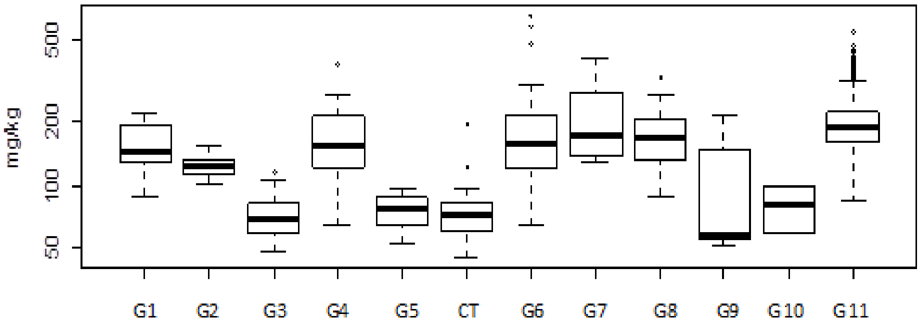


Figure 11: January leaf iron (Fe) levels – Surveyed Growers vs. CT Trial.

Iron - No current guidelines exist for iron. Growers 3, 5, 9 & 10 had similar mean results when compared to the CT Trial while all other growers had higher levels. Dust contamination of leaf surfaces can lead to confusing results.

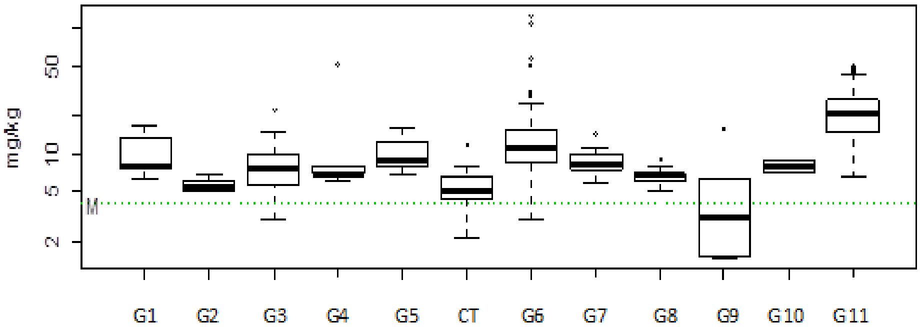


Figure 12: January leaf copper (Cu) levels – Surveyed Growers vs. CT Trial.

Copper - Generally levels were adequate. An exception was Grower 9 where more than 50% of samples had copper levels less than marginal. The growers mean results were similar to the CT Trial mean.

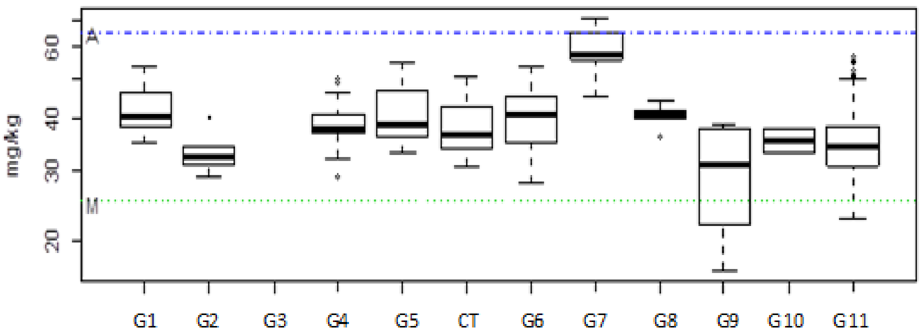


Figure 13: January leaf boron (B) levels – Surveyed Growers vs. CT Trial.

Boron - Most samples were adequate. An exception was Grower 9 where more than 25% of samples were classified as less than marginal. All other growers mean results were similar to the CT Trial mean. Research from California (Brown et al) shows a better correlation between hull boron and tree boron status than leaf boron.

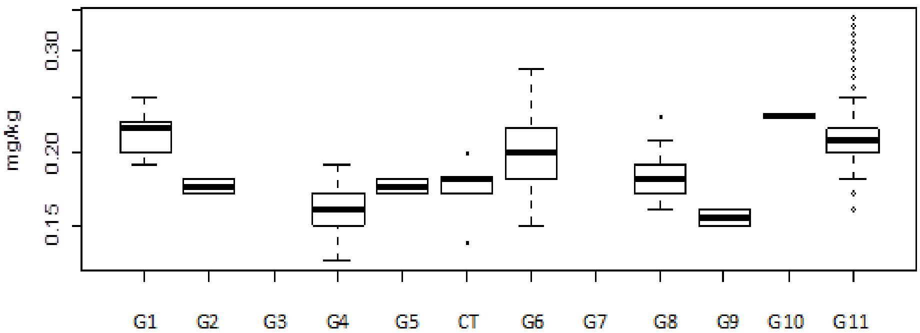


Figure 14: January leaf sulphur (S) levels – Surveyed Growers vs. CT Trial.

Sulphur - No guidelines exist for sulphur and no clear trends can be drawn from the results.

January leaf tissue analysis

Trends in time for all samples

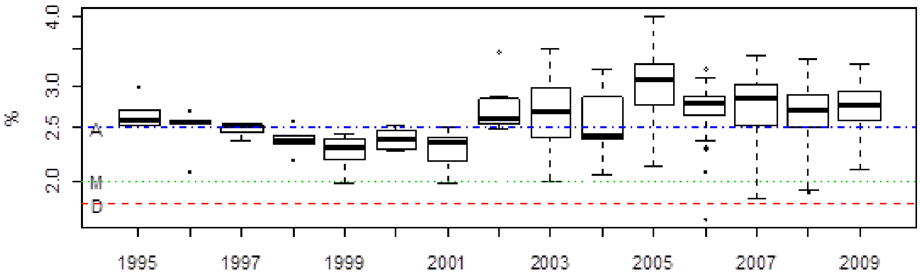


Figure 15: Trends in time of January leaf nitrogen (N) levels for all samples

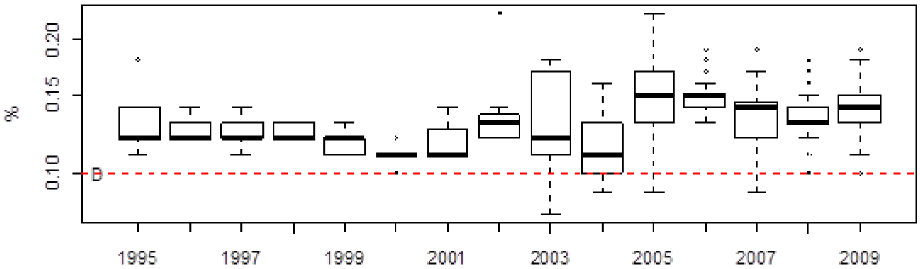


Figure 16: Trends in time of January leaf phosphorus (P) levels for all samples

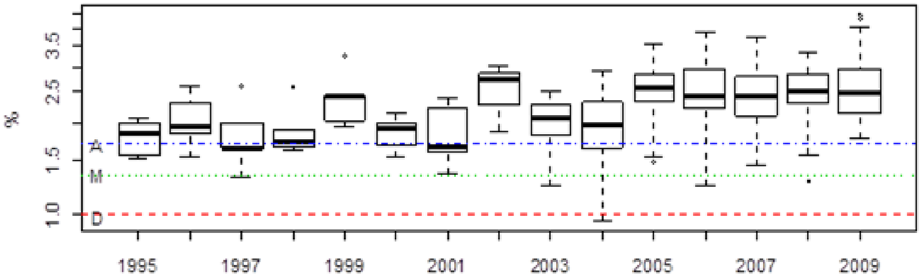


Figure 17: Trends in time of January leaf potassium (K) levels for all samples

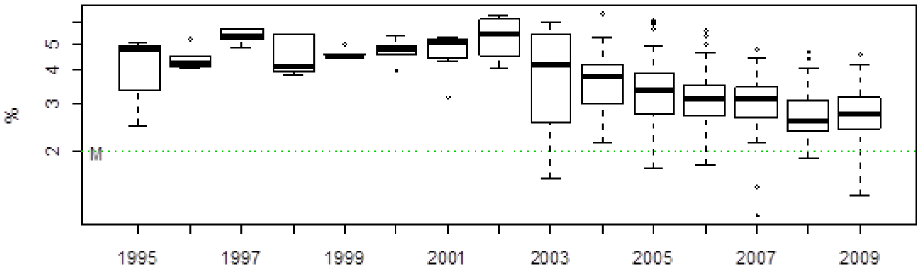


Figure 18: Trends in time of January leaf calcium (Ca) levels for all samples

Nitrogen - Nitrogen levels declined from 1995 to 2001 but then increased and remained relatively stable with mean nitrogen levels of approximately 2.7%. The increase in mean nitrogen levels may be attributed in part to fertigation programs from the CT Trial beginning to be adopted by the wider almond industry. The increase in all three major nutrients from 2003 onwards corresponds with the start of the CT Trial. As results from the CT Trial spread among the industry, daily drip irrigations and higher, more frequent fertigation program became more common. This helped increased the average industry production from 2.5T/Ha to 3.2T/Ha.

Phosphorus - No clear trends, although the data indicated increased levels from 2005. This may be due to younger orchards being included in the survey, and an increasing trend towards ripping in superphosphate when establishing an orchard. The way phosphorus is applied has changed from 2003 onwards with less regular ground applications of superphosphate to more precise applications of MAP through drip fertigation.

Potassium - There was considerable year to year variability up to 2004 and may be a result of seasonal yield variations and little or no potassium applications in many of the grower's traditional fertiliser programs. From 2005, the amount of potassium applied in fertigation programs increased following adoption of the early CT Trial results.

Calcium - Levels were more or less constant from 1995 to 2002, but have steadily declined since. The decline could be a result of increased yields (and subsequent nutrient removal in the hull, shell and kernel) and no significant addition of calcium in fertigation programs. Calcium removal via the fruit is slightly less than phosphorus, yet calcium is rarely applied as part of an ongoing fertigation program whereas phosphorus is regularly applied. In addition, increased potassium applications may be affecting the cation exchange balance within the soil and leading to reduced uptake of other cations. However, most almond soils are relatively high in native calcium. Calcium is also less readily available for uptake in acidic soils especially when the pH is less than 6 and high input fertigation systems have been shown to make soils more acidic. More research is required in this area.

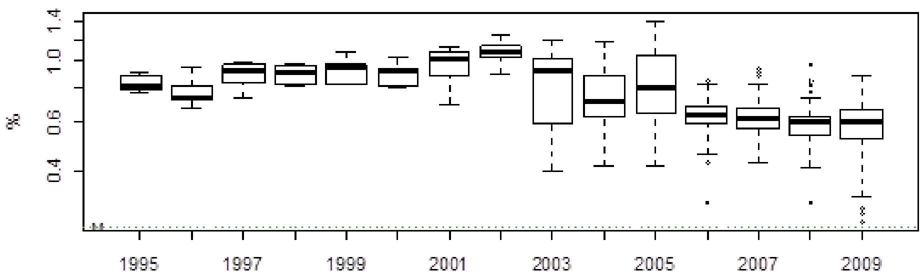


Figure 19: Trends in time of January leaf magnesium (Mg) levels for all samples

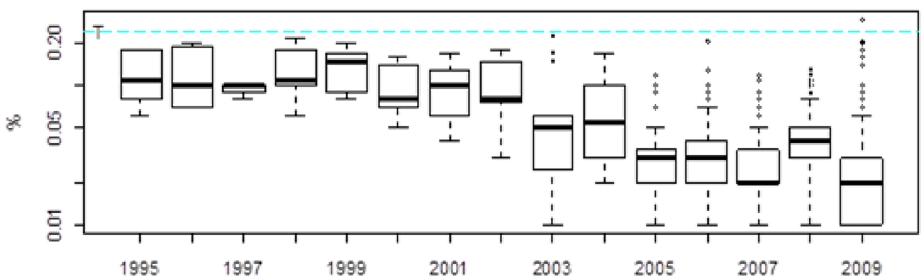


Figure 20: Trends in time of January leaf sodium (Na) levels for all samples

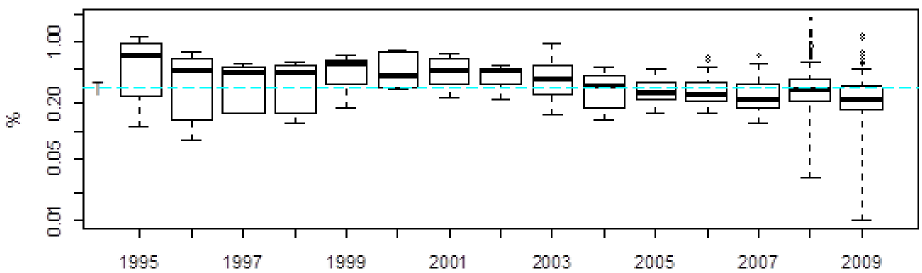


Figure 21: Trends in time of January leaf chloride (Cl) levels for all samples

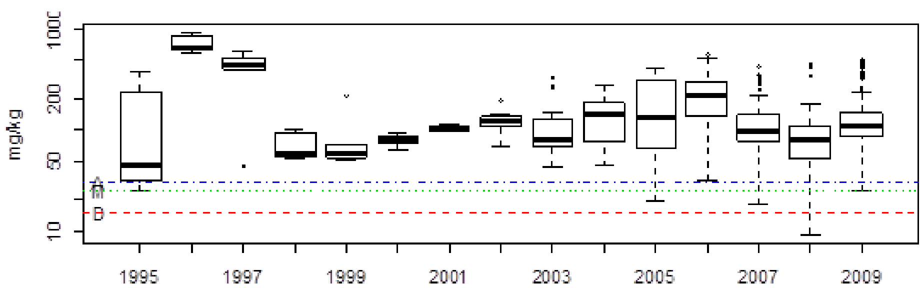


Figure 22: Trends in time of January leaf zinc (Zn) levels for all samples

Magnesium - Levels remained relatively constant until 2003, but have steadily declined since. The trend is very similar to Calcium in regards to the steady decline from 2003. Magnesium is the fifth most nutrient removed by the crop, and like calcium is not regularly included in current fertigation programs. Similar to calcium, magnesium is less taken up in soils that are acidifying due to high nitrogen fertiliser use. High potassium inputs are known to interfere with magnesium uptake by the roots. This trend should be monitored.

Sodium - Levels were more or less steady from 1995 to 2002 at 0.1% but dropped to approximately 0.04% from 2003. The number of samples taken from drip irrigated orchards increased from 2003, thus the decline from 2003 could be attributed to an increase in irrigation uniformity and efficiency, and better water uptake by the tree. It must also be taken into account what the influence of younger orchards on virgin ground and different water sources has had on the variability of sodium since 2003.

Chloride - Levels have shown a steady decline, starting at 0.5% and falling to approximately 0.2%. Again the steady decline could be due to an increase in irrigation uniformity and efficiency associated with an increase in drip irrigated orchards. The increase in variance in 2008 and 2009 may be a result of a larger data set and the modified irrigation practices through the drought and reduced water allocations. An increase in the number of samples from younger orchards on virgin ground and better water sources could also have an effect.

Zinc - Levels varied greatly from 1995 to 1997. From 1998 to 2002 there was a gradual increase in levels, which have since plateaued and become more variable. The increase in zinc levels could be in part due to the industry adopting some of the CT Trials foliar nutrient program and growers applying more NZn. Zinc doesn't exist in large quantities in the leaf or fruit, but the increased levels over time have occurred in parallel to the increased industry yields, and may indicate its small but critical role in yield improvements. There was a period when people saw some leaf burn from zinc sprays which may have led to the lower values in the late 90s. The increase from 2003 onwards could be attributed to increased foliar nutrient sprays as a general recommendation from the CT Trial.

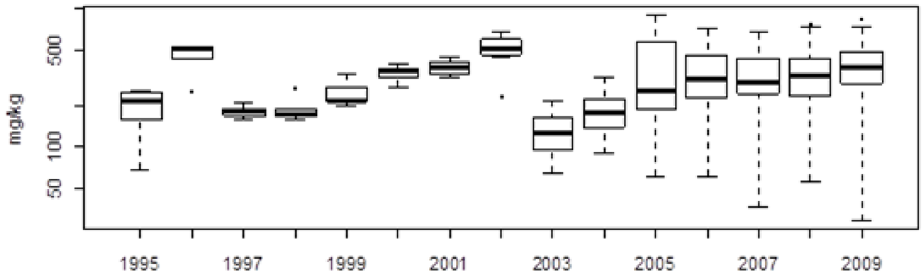


Figure 23: Trends in time of January leaf manganese (Mn) levels for all samples

Manganese - Levels showed a similar pattern to zinc but from 2005 to 2009 there was less variation in the mean. The slight increase in manganese levels could be attributed to contamination from Mancozeb fungicide programs or the increased addition of trace elements (e.g. Ferti-Mix) in fertigation programs. A drop in soil pH can also mean manganese is more readily available for uptake.

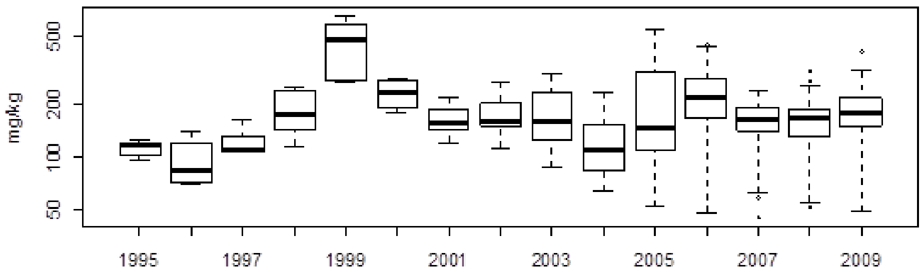


Figure 24: Trends in time of January leaf iron (Fe) levels for all samples

Iron - Levels varied until 2001, but there was little variation in the mean after 2001.

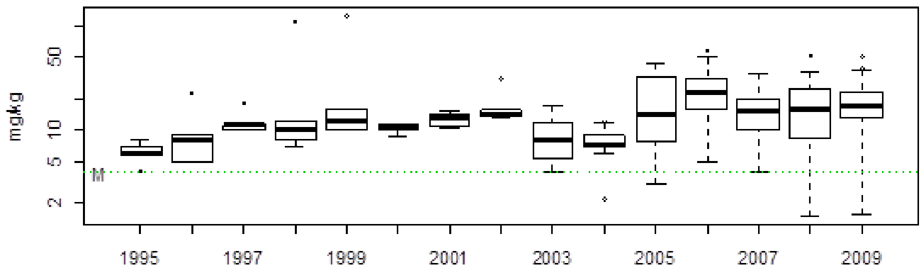


Figure 25: Trends in time of January leaf copper (Cu) levels for all samples

Copper - Levels have risen from approximately 7 mg/kg in 1995 to almost 20 mg/kg in 2009 and difficult to explain. Copper availability is known to increase as fungal protection residues build up in the soil. This might just be an orchard age effect.

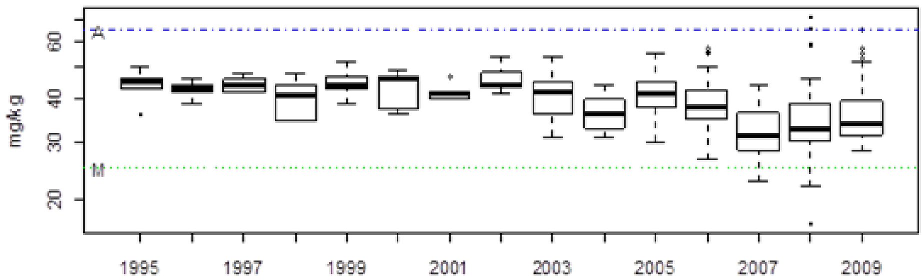


Figure 26: Trends in time of January leaf boron (B) levels for all samples

Boron - Levels have declined from approximately 45 mg/kg in 1996 to about 35 mg/kg in 2009. The decline in boron levels is concerning since it is an important element in fruit set and fruit development. A more accurate measure of boron is analysis of boron in the hulls.

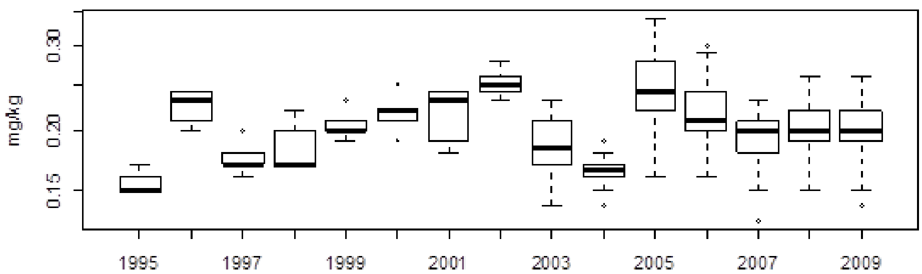


Figure 27: Trends in time of January leaf sulphur (S) levels for all samples

Sulphur - Levels were erratic from 1995 to 2005 (due to a small number of samples presented) but have stabilised at approximately 0.2 mg/kg. The steady levels may be attributed to an increase in the use of Potassium Sulphate in many orchards.

Table 3: CT Trial (Average of Treatment 1 & Treatment 2) leaf analysis results for October, November, December & January

Nutrient		October	November	December	January
N	%	4.07	3.51	3.05	2.99
P	%	0.20	0.16	0.14	0.14
K	%	3.13	2.76	3.32	2.76
Ca	%	1.49	1.82	2.44	2.42
Mg	%	0.40	0.40	0.47	0.46
Na	%	0.07	0.07	0.08	0.07
Cl	%	0.35	0.35	0.51	0.41
Zn	mg/kg	266.09	361.88	410.48	335.20
Mn	mg/kg	158.05	158.98	149.25	162.83
Fe	mg/kg	85.54	87.45	105.28	88.76
Cu	mg/kg	8.12	5.91	5.42	5.65
B	mg/kg	50.82	39.91	41.40	40.25
S	%	0.23	0.20	0.19	0.17

Proposed New Standards from the CT Trial & Grower Survey

Working standards for October, November and December sampling

The combined average leaf analysis results for Treatment 1 and Treatment 2 (the higher yielding plots in the CT Trial) are shown in Table 3. These data are from leaves collected from fruiting spurs on one year old wood. These data may be helpful for growers who would like to monitor nutrient levels through the growing season.

Working standards for January sampling

In Table 4 we proposed some new working standards for leaf analysis in Australian almond orchards. These are presented along with those currently used and results from the CT Trial to allow growers to compare them. The higher nutrient levels obtained from the CT Trial are likely to be a result of a more intensive foliar nutrient program and more generous fertigation programs than are likely to be economic in commercial orchards. These nutrients include nitrogen, potassium, zinc and boron. The standards have been modified to reflect the current standards of industry practice and the results of the CT Trial. While some of the changes only seem small, it must be remembered that the proposed new standards refer to leaves that are sampled from fruiting spurs.

Standards for the macro nutrients are proposed to be slightly higher than the current standards. Standards for the micro nutrients are similar to previous standards or have been increased only a little. For those nutrients that had no previous standards, new ones have been proposed based on the CT Trial data.

Table 4: Current and proposed leaf analysis standards for January sampling

Nutrient		Current Australian	Current Californian	CT Trial Averages (T1,T2)	Grower Survey Averages	Proposed New Australian
N	%	2.0 - 2.5	2.2 - 2.5	2.99	2.71	2.5 - 2.7
P	%	> 0.1	0.1 - 0.3	0.14	0.14	> 0.1
K	%	1.4 - 1.7	> 1.4	2.76	2.47	2.2 - 2.5
Ca	%	> 2.0	> 2.0	2.42	3.23	> 2.0
Mg	%	> 0.25	> 0.25	0.46	0.68	> 0.40
Na	%	< 0.25	< 0.25	0.07	0.04	< 0.25
Cl	%	< 0.3	< 0.3	0.41	0.31	< 0.40
Zn	mg/kg	25 - 30	> 15	335.20	144.23	> 30
Mn	mg/kg	> 20	> 20	162.83	347.16	> 20
Fe	mg/kg	-	-	88.76	183.88	> 50
Cu	mg/kg	> 4	> 4	5.65	18.72	> 4
B	mg/kg	25 - 65	30 - 65	40.25	36.54	30 - 65
S	%	-	-	0.17	0.21	> 0.15

Possible change in leaf sampling method

The method of leaf sampling may need to be altered to give a better indication of nutrient demand when yields vary. The current method of sampling leaves from a non-fruiting spur from last year's growth may not give an accurate indication of the current crop's nutrient demand. We propose that sampling fruiting spurs on last year's growth may give a better indication of the status of the trees. If a large crop is present then it seems logical that a nutrient deficiency would be visible first in fruiting spurs, rather than non-fruiting spurs. The CT Trial used leaves from fruiting spurs on one year old wood.

This logic is supported by preliminary research work from UC Davis (Brown, 2011) which suggests the leaves on fruiting spurs may show nutrient deficiencies while non fruiting spur leaves on the same tree may have adequate nutrition levels. The implication from this observation is that while leaf analysis of non-fruiting spur leaves may show adequate nutrition levels, the tree may have a nutritional deficiency depending on the crop load. Further work here and collaboration with UC Davis is needed to verify this.

Growers may like to compare values from the same blocks by sampling both ways for two or three years to gain some familiarity with the proposed revised working standards and changed sampling method in their orchards. This will be necessary to gain an appreciation of how much the standards may vary before making major changes to nutrition programs.

Figure 28: Photo from 2006 (Left) Smaller almond leaf size - Conventional nutrition program; (Right) Improved almond leaf size - CT Trial

References

Brown, P (2011) Assessment of Nutrient Status in Almond Update 2011.
Brown, P (2009) Are Critical Values for Nutrient Management in Almond and Pistachio Orchards Invalid?
Reuter, DJ & Robinson, JB (1997) Plant Analysis: an interpretation manual

For further information contact Brett Rosenzweig, Industry Development Officer

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ACKNOWLEDGEMENTS
The input and suggestions made by Dr Ben Robinson. The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER
Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.8 – Fact Sheet: Managing Rust in Almonds

ALL ABOUT ALMONDS

AUSTRALIAN ALMONDS

www.australianalmonds.com.au

Managing Rust of Almonds

Peter A. Magarey, Magarey Plant Pathology

Introduction

Almond rust is a wet weather disease. It grows best in warm humid conditions especially when there are extended periods of leaf wetness. Defence against rust is a major factor triggering orchard sprays in spring and summer. In recent years there has been good progress toward improving the clean green image within the industry. This, linked with more sustainable orchard practices, gives focus to ways in which specific information on the risk of disease events can guide the need to apply fungicides against rust. A "Three-step Rust Reckoner" provides a guide to the conditions that favour rust infection and indicates when sprays are needed.

The Disease

Rust is most obvious on leaves where rusty-brown powdery pustules develop on the undersides of small yellow leaf spots. The disease is sporadic in most regions of Australia because it is driven by warmth and moisture, and only at irregular times and seasons when the conditions are sufficiently warm and wet enough for long enough.

Crops Infected

Commonly called 'prune rust', the disease in almonds is more correctly known as 'almond rust' or more simply, 'rust'. This is because the fungus that causes the disease (*Tranzschelia discolor f. sp. dulcis*) infects almonds but not plums. Similarly, the form of the fungus that infects plums or prunes will not 'cross-infect' almonds. However, it is interesting to note that the two forms (sub-species) of the rust fungus spread in similar conditions.

Figure 1a

Figure 1b

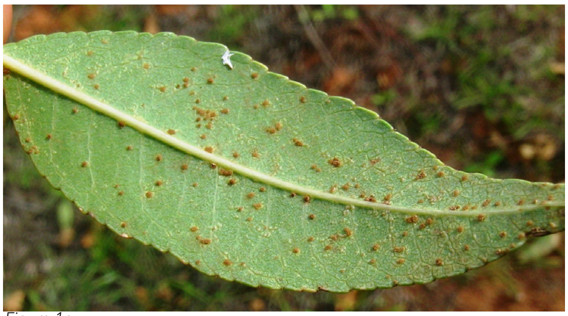


Figure 1c

Typical angular, yellow lesions (spots) of the rust fungus on the upper surface of almond leaves (1a, b) and the characteristic raised, orange-brown rusty pustules beneath each spot (1c – same leaf as 1b).
The disease spreads rapidly in warm moist conditions.

Many different species of rust occur on a wide range of plants such as apricot, wheat, legumes, weeds and flowers. Rust spores from these plants do not spread to infect almonds.

Symptoms

On leaves

Rust first appears as many small (1-2 mm) angular, pale-bright yellow lesions (spots) on the upper surfaces of infected leaves (Figures 1a, b & 2a). These spots are usually limited in size and shape by the finest veinlets and are often grouped in small irregular clusters of 3 or more spots. With age, the spots often turn a golden yellow.

After the leaf spots appear, the lower surface of the spot breaks open forming a powdery pustule through which the orange-brown rust spores of the rust fungus (uredospores) erupt. In favourable conditions, each pustule produces yellow-orange to rusty brown, rounded tufts of these spores (Figures 1c & 2b). If touched, the spore masses readily leave a rusty brown deposit on your finger. This is diagnostic for rust disease.

As the leaf spots age, they turn golden yellow and then brown as the affected tissue within the spot dies. As symptoms progress on affected leaves, the tissue between the leaf spots turns yellow more quickly than the initial infection sites (Figures 3 a, b). This is because the disease disrupts normal leaf function and causes the green chlorophyll activity to decline so that, eventually, a severely diseased leaf may appear yellow with scattered small green spots across the surface at each of the initial rust infection sites. This is characteristic of rust on severely diseased foliage late in the season.

Old pustules particularly in the autumn may turn black when a different type of spore, the winter or black rust spores (teleutospores) are produced. These appear to play no role in almond rust in Australia.

Figure 2a

Figure 2b

Figure 2: To monitor for almond rust, look for the typical yellow lesions (spots) of the rust fungus on upper leaf surface of almonds (2a). Confirm their identity by turning the leaf over to find the characteristic raised, rusty pustules on undersides (2b).

On shoots

The disease only affects shoots when disease severity on leaves is high. Rust on shoots appears as dark brown spots from which the characteristic rusty-brown pustules emerge in warm humid weather.

Diagnosis

Severely affected leaves fall from diseased sectors of trees. If infection is severe across trees, patches of defoliated trees will appear in the orchard.

Do not confuse rust spots with similar symptoms caused by other factors. Some symptoms will show yellow spots that also have a tiny dark centre. These may be the result of herbicide damage, for example, caused by the knock-down herbicide, paraquat. The fungal disease shot hole also causes similar spots but these have tan centres and develop a reddish brown margin (halo). Sometimes, tiny dark brown spores of the fungus (sporodochia) develop in the centre of these spots which later die and fall out, leaving a 'shot holed' appearance. Distinguish herbicide damage from shot hole by the spots that will sometimes cross the finest veinlets. Wherever a droplet of herbicide makes contact with the leaf it burns a little spot, even across the veinlets. In contrast, the shot hole fungus causes spots usually delimited by the finest veinlets. Herbicide damage will appear a few days after application whereas like rust disease, the spots from shot hole will appear more than 10 days after favourable wet conditions. But, only rust produces the rusty brown spore tufts in pustules on the undersides of the leaf spots.

Varietal Susceptibility

Most of the commonly grown almond varieties are susceptible to rust. A few varieties, when infected, show limited symptoms on upper leaf surfaces displaying only a few leaf spots before the rust pustules appear on the under surface of leaves. To the contrary, some varieties produce the yellow leaf spots but few pustules on the under surface.

Disease Cycle

Overwintering

In Australia, rust begins from inoculum (urediniospores) on leaves infected last season but remaining attached over-winter in trees (Figures 4, 5). The disease is rarely triggered by inoculum from fallen leaves.

First infection

Rust is a 'green disease' meaning that it only infects green tissue. As a result, on unsprayed foliage, infection can begin if favourable conditions, particularly surface moisture on leaves, occur anytime from when leaves first emerge (Figure 4 a-d).

Figure 3a

Figures 3: Progression in chlorosis (yellowing) of leaves severely affected by rust. The disease disrupts chlorophyll function (which relies on green tissue to produce food for the developing crop). Affected leaves turn yellow (3a) with scattered green speckling (3b) indicating where the rust infection had occurred. Severely diseased leaves fall prematurely – this can defoliate trees in patches or across an orchard.

Figure 3b

Figure 4a

Figure 4b

Figure 4c

Figure 4d

Figure 4: Important stages in the growth cycle of almonds. The season begins as the buds crack open (green bud) (4a). Flowering (full bloom) (4b) is a critical time because young shoot growth soon develops (4c & d). In favourable conditions, this begins the rust season on the young susceptible leaf tissue. As the foliage matures, the leaves develop a level of tolerance to rust.

Spores from leaves infected last season spread in the wind and rain to infect nearby foliage.

Incubation

Once infection has occurred, a period of incubation follows. This is the time between infection and when symptoms first appear. It will last several days (see later) after which small yellow spots will appear wherever infection occurred in the foliage.

Spread

The rust pustules beneath the spots produce more spores and if fungicide sprays have not adequately protected the foliage, the disease will spread. A second incubation period will follow after which many more spots will appear.

The disease cycle continues as long as favourable weather occurs and unsprayed foliage is available to infect. The youngest foliage is very susceptible. As leaves mature, they gain a level of age-related (ontogenic) resistance though they never become fully resistant.

Usually, only a few spots (with pustules beneath) will show after the first infection event. Perhaps initially 5-50 pustules/leaf will develop in a cluster of foliage 20-50cm in diameter around the initial source of inoculum. These spots may pass un-noticed. Subsequent infections, especially in early-mid season, can produce many hundreds of leaf spots, often from 15-500 pustules/leaf within a zone 0.5–1.5mm in diameter. In this way, if favourable conditions persist and adequate controls are not applied, rust spore numbers initially build-up slowly but then may explode, infecting several branches in one sector of a tree and/or often spreading rapidly across an unsprayed block of a susceptible variety in the orchard.

Crop Loss

In wet seasons, a series of favourable weather events can trigger a number of infection periods that will lead to severe disease in unprotected trees. This can defoliate trees by mid-late season. As a result, rust can cause significant crop loss this season and reduce tree vigour and bud viability in the next.

Favourable Conditions

Rust spreads in warm humid conditions especially when the foliage is more susceptible in early spring and summer. The spores of the rust fungus are very durable and survive long periods of dryness but they need free-water and adequate temperature to germinate, grow and cause infection.

Infection

The main factors required for infection are rainfall (or precipitation) to wet the foliage for sufficient length of time while there is adequate warmth for the fungus to develop and grow.

Spores of the rust fungus germinate at temperatures from 5 to 30°C but grow best at optimal temperatures of 15 to 24°C.

Incubation period

Temperature is the main factor that governs the speed with which the yellow spots appear after infection, ie the length of the incubation period. Preliminary evidence suggests that in cooler conditions between 10 to 15°C, the incubation period is about 20 to 22 days whereas in warmer conditions around 20 to 25°C, it appears to be nearer 13-19 days.

Spread

The main factors that control the rate and extent of the spread of rust *ie* the speed and severity of the epidemic, are the initial number of spores (overwintering inoculum), the timing of rain events and the relationship between temperature and length of leaf wetness in the prevailing conditions.

Managing Disease

Spores of the rust fungus cannot infect unless there is water on the leaf or shoot surface. The cultivation of almonds in semi-arid environments, as occurs in most almond regions of Australia, provides good basis for minimum risk from rust. Spray schedules for other foliage diseases of almond, including shot hole and blossom blight, may contribute to suppression of rust epidemics in the orchard.

Figure 5a

Figure 5b

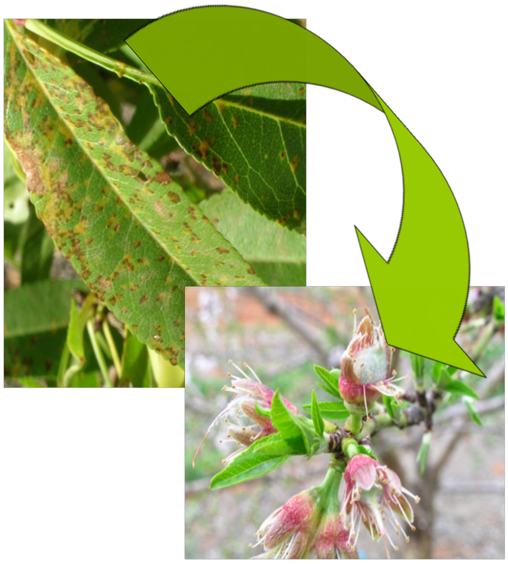


Figure 5c

Figure 5: Rust disease overwinters on leaves that were infected last season and remain on the trees (5a). In spring, the sporulating pustules on the undersides of these leaves are in close proximity to the developing foliage (5b). The disease easily infects new leaves if favourable conditions occur (5c).

For a given climatic region and for a specific variety cultivated, the main direct means of controlling rust involve reducing inoculum carry-over from one season to the next, and the use of well-designed spray programs.

Over-wintering inoculum

Good disease control in the previous season results in fewer infected leaves hanging on the tree over winter (Figure 5) and, as a result, less risk of disease if favourable weather prevails next spring. In autumn, consider cultural practices that lead to complete leaf fall (Figure 6).

Figure 6: A preferred view in late winter. This tree has completely defoliated overwinter, carrying no leaves infected the previous season and so bringing no inoculum to infect the new foliage about to develop.

The Three T's of Good Spray Practice

Type

Event based. Prior to spraying, select the type of fungicide best suited to the timing of disease events:

1. **Pre-infection sprays.** 'Protectant' or surface acting fungicides ***protect*** the foliage from infection. Because these fungicides do not move to cover new leaf and shoot growth, apply these ***as close as possible prior*** to an infection event.

   Examples of pre-infection fungicides that prevent almond rust infection include Strobilurin fungicides, chlorothalonil and mancozeb.

2. **Post-infection sprays.** 'Curative' fungicides are better known as 'trans laminar' products. Absorbed by the sprayed foliage, they move within and across leaves and kill or at least, inhibit the rust fungus developing inside infected foliage. Because these products also have activity in protecting against rust infection, it is best to apply these fungicides ***as soon as possible before*** infection, or as close possible after an infection event.

   Being absorbed in sprayed tissue, these fungicides are quickly rain-fast. Like the pre-infection fungicides though, these products do not move in adequate concentrations to control the fungus in unsprayed foliage.

   Examples of post-infection fungicides that inhibit existing rust infections include the DMI fungicides.

Timing

Seasonal. It is critical to ensure good disease control for rust in early to mid-season when the foliage is most susceptible and when the leaves are most needed as food factories to supply nutrients to the developing fruit crop.

Monitoring Infection Events. Optimise

Figure 7: The Model T MetStation™, is both an automatic weather station (AWS) and a disease predictor for almond rust. The solar cell powers a mobile phone attachment allowing easy access to the data from a remote location.

This AWS and similar units collect weather data including temperature, rainfall, relative humidity and leaf wetness at 10 minute intervals. This information allows assessment of when infection by the almond rust fungus occurs. As a result, calculations can be made of the best times to spray for rust to provide the most effective and efficient control of the disease.

spray timing by assessing the suitability of the prevailing conditions for infection. Do this by measuring temperature, rainfall, relative humidity and leaf wetness (a measure of how wet is the foliage) in your orchard. For best result, use an automatic weather station (AWS) to sample canopy conditions every 10 minutes (Figures 7 and 8). A prototype disease predictor can give a guide in reviewing the weather data and assessing the risk of infection by the rust fungus.

Alternatively, as a guide to the timing of infection events, use the prototype '**Three-step Rust Ready Reckoner**' (Table 1). The Rust Reckoner in three steps allows you to link the prevailing orchard temperature to the estimated length of foliage wetness needed for infection to occur.

Three steps to estimating the duration of leaf wetness for rust infection in your orchard:

1. First, check the prevailing temperature in your orchard.
2. Next, locate that temperature, in either the left or the right hand column;
3. Then read off the corresponding figure in the central column for a guide to the number of hours leaves need to be wet for infection to occur at that temperature.

   Note: This Rust Reckoner is to be used as a guide only. It was derived from data in a prototype infection model for almond rust (Magarey and Western, unpublished data - as reported in Magarey, Wicks and Learhinan, 2009).

Knowledge of when an infection event is/was likely, provides indication of the value of sprays applied and/or the need for a subsequent spray. Determine the time interval between the application of the previous spray and the timing of an infection event to assess:

- If a spray applied prior to the infection event gave effective spray cover at the time infection occurred; or where spray cover was not achieved prior to the event,
- If a spray is needed as soon as practical after the infection event.

Note: Given the large areas in which almonds are grown in many Australian orchards, the above methods may only provide a guide as to the effectiveness of the regular spray schedules that are deployed. The ratio of the number of spray machines to area of orchard to be sprayed, may limit the flexibility to apply sprays at optimum timing. This has particular relevance in many orchards that comprise a mixture of varieties each at different stages of foliage development and with differing susceptibilities to rust.

Technique

Effective spray application technique requires careful attention to:

- choice of spray machinery that allows good spray coverage of the trees in your orchard;
- configuring the spray machine according to the structure, shape and size of the trees. This includes turning appropriate nozzles on or off to ensure the target foliage receives an effective spray cover, or alternatively, if using a multi-head machine, adjusting the spray heads for maximum spray coverage;
- calibration of the spray machine and tractor speeds to deliver a volume of liquid adjusted to the target size of the foliage as it expands during a season;
- selection of an appropriate rate of product to deliver the correct dose of fungicide to the current target for optimum control.

Table 1. Use the 'Three-step' Rust Reckoner as a guide to the conditions required for infection by almond rust in your orchard.

Temperature (Average °C)	Leaf wetness (Hours)	Temperature (Average °C)
15-24	6	
14	8	
13	10	25
12	12	
11	15	26
10	18	
9	20	27
8	23	
7	24	28

Comment

Generally, across Australian almond orchards, there have been relatively few infection events and regular schedules of fungicide spraying has been effective in protecting the foliage from rust. However, there is scope to use the Three T's to design better spray schedules for cleaner, greener production of almonds in orchards with optimised use of fungicides and pesticides. The world trend to a more prescriptive trace-back system in marketing fruit products will allow consumers to determine the reason why and when sprayed chemicals were used.

Use of more targeted approach to spraying is both possible and likely to be useful in marketing strategies for Australian

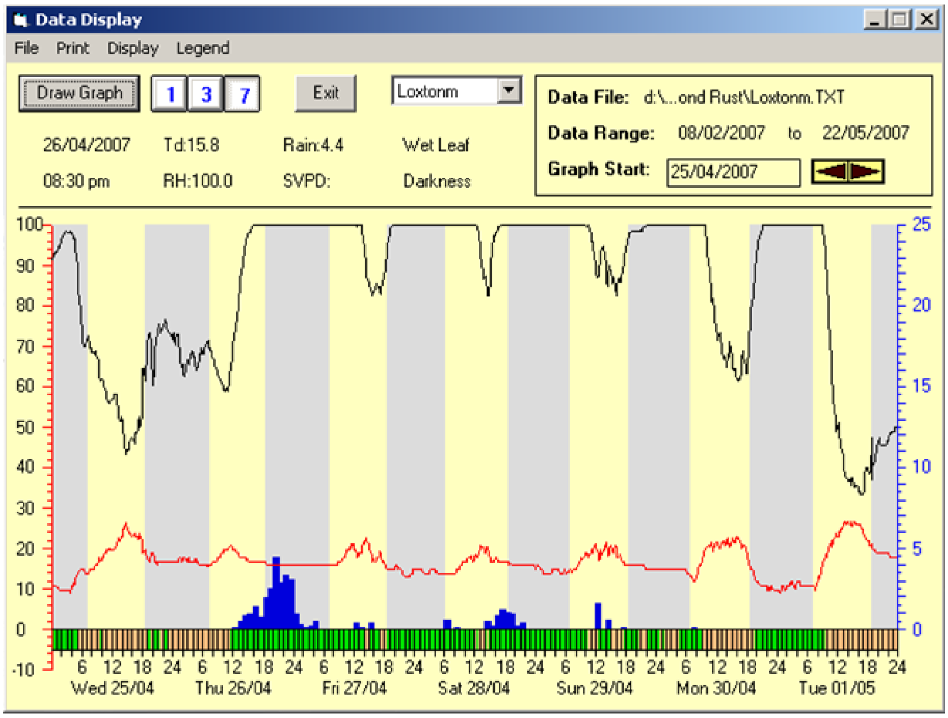


Figure 8: Graph of the data produced by the Model T MetStation™ (as above). Data are for the period 25th April to 1st May 2007. Rainfall (blue bars) began at midday (buff background) 26th April and continued overnight (gray background), bringing 33.4 mm over a 75 hour period of more or less continuous leaf wetness (green bar) whilst temperatures (red line) remained above 13^{0}C and relative humidity (RH) (black line) above 85%. These conditions triggered an infection by the almond rust fungus.

Further Reading

Presentations/publications on almond rust:

Adaskaveg, J., et al. (2011). Efficacy and timing of fungicides, bactericides, and biologicals for deciduous tree fruit, nut, strawberry, and vine crops. 2011. Univ California. http://www.ipm.ucdavis.edu/PDF/PMG/fungicideefficacytiming.pdf

Adaskaveg, J., Soto-Estrada, A., Forster, H., Thompson, D., Hasey, J., Manji, B. and Teviotdale, B. (2000). Peach rust caused by Tranzschelia discolor in California. Univ. of California Agric and Natural Resources Publication 8011, 9 pp.

Anon. (1990). Disease Management Research. Prune Rust Infection Prediction Service, Biological and Chemical Research Institute, NSW Dept Ag and Fisheries Technical Manual, September 1990. ISBN 0 7305 66463.

Kable, PF, Ellison, PJ, and Banbach, RW. (1986). Physiologic specialisation of Tranzschelia discolor in Australia. Plant Disease 70:202-204.

Magarey, PA and Wicks, TJ. (2007). 'Improving the Management of Almond Rust', Newsletter article 'In a Nutshell' August 2007 pp 8-9.

Magarey, PA and Wicks, TJ. (2008). Presentation of project objectives and outcomes was made to levy payers at their meeting at the 'We're Blossoming', Australian Almond Industry 2008 Conference, Novotel Barossa Valley Resort, 29 - 31 October 2008, Rowland Flat, South Australia.

Magarey, PA and Wicks, TJ. (2009). Managing rust on almonds. Controlling the disease with fewer sprays. Australian Almond Industry Conference, Novotel Barossa Valley Resort, October 2009, Rowland Flat, South Australia.

Magarey PA, Wicks TJ and Learhinan NA. (2009) 'Improving the Management of Almond Rust', Report to Horticulture Australia Ltd, Project No: AL06007, SARDI, Adelaide, South Australia. 37pp.

Magarey PA, Wicks TJ, Learhinan NA and Horsefield A. (2009). Evaluating an infection model of prune rust to improve the management of disease for almond and prune growers. Australasian Plant Pathology Conference, Newcastle, NSW, September 29th – October 1st, 2009.

Slack, JM et al (1988), Prune Rust – A practical guide to its control. NSW Agriculture & Fisheries Agdex 216/633, September 1988. 20pp.

Strands, LL. (2002). Rust p 132, in Ch. on Diseases, pp 108-150, in Integrated Pest Management for Almonds, 2nd Ed. Publication No. 3308 Univ of California, Div. Ag. & Nat. Res., Oakland, CA, USA. 199pp.

Teviotdale, B. (1996) Diseases of Almond. Ch 30. pp 215-216 in Micke, WC.Tech. Ed. Almond Production Manual, Publication No. 3364, Univ of California Div. Ag. & Nat. Res., Oakland, CA, USA. 289pp.

For further information contact Ben Brown, Industry Development Manager

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343

Telephone (08) 8582 2055 Facsimile (08) 8582 3503

Email admin@australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

Magarey Plant Pathology

HAL Horticulture Australia

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.

Dr Trevor Wicks, Senior Plant Pathologist, SARDI, Waite Institute, SA, was co-author of the work upon which the text of this Fact Sheet is based, see Magarey et al, (2009), and he made valuable review of the content of this Fact Sheet. Photos 2a and 2b taken by Tash Learhinan.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia December 2011

All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.9 – Fact Sheet: Managing Mice for the Australian Almond Industry

ALL ABOUT ALMONDS

AUSTRALIAN ALMONDS

www.australianalmonds.com.au

Managing mice for the Australian Almond Industry

Dr Peter R Brown, CSIRO Ecosystem Sciences

Summary

House mice can cause serious problems to all aspects of the almond industry, from orchards, through to processing facilities. A range of control methods are available to manage mice. Mouse populations need to be monitored and management must be conducted over large areas to minimise reinvasion. In orchards, a combination of poisoning and habitat manipulation is recommended. In processing facilities, a combination of poisoning, habitat manipulation, trapping, and mouse-proofing is recommended.

Introduction

Problems of mice and why it is important to manage them

The house mouse (*Mus domesticus*) is a serious pest to agriculture in Australia. Mouse populations occasionally undergo widespread eruptions (= mouse plagues) in the grain-growing regions of Australia. In 1993/94, a mouse plague caused losses estimated at up to $100 million.

House mice have caused significant damage to almond orchards and in hulling/shelling and processing facilities over the last 18 months or so. Densities of mice have been high and it is unknown when they will decline.

Mice need to be managed to reduce the damage that they are causing to almond orchards, and to reduce damage and contamination to shelling and hulling and processing facilities.

Damage mice cause to the almond industry

Mice can cause problems in food processing and storage areas through:

1. Direct consumption of food;
2. Food contamination and damage;

3. Loss of consumer confidence and damaged public relations;
4. Structural damage;
5. Disease transmission to workers and consumers (e.g. Leptospirosis; Salmonellosis); and
6. Costs associated with pest control operations.

For the almond industry, mice can cause damage to almonds through various stages from flowering to harvest, but also post-harvest in hulling, shelling and processing facilities. Damage can be through gnawing on the product, allowing infections to the pod, also through contamination through urine and faeces. In hulling, shelling and processing facilities, damage/contamination can occur prior, during and after processing.

Importance of working together across the processing chain

An effective rodent control strategy must have clearly defined objectives and be well planned. In particular, a rodent management plan for the almond industry means all aspects of the almond processing chain: from the orchard, through the shelling/hulling facilities through to the processing facilities; must work together to minimise or eliminate potential rodent infestations.

Mouse biology and ecology

Characteristics of mice

The success of the house mouse as a pest species can be attributed to its ability to live in a wide variety of habitats, to its small size, behaviour, reproductive potential and omnivorous feeding habits.

Food preferences

The house mouse is omnivorous, consuming seeds, plant material, invertebrates, fungi and other mice. In an urban setting, they would also eat food scraps from compost bins, vegetable garden produce and pet food. They also gnaw on electrical wires, wood frames, soap and cricket bats. They have been blamed for causing house fires (by gnawing on electrical wires). They are neophilic, which means they readily explore new environments and food types.

Biology and breeding

In the field, house mice have a reasonably well-defined breeding season. It commences early in spring after good rainfall has promoted growth of important food resources that can trigger breeding. It seems that the quality, not quantity, of the food is important in triggering breeding activity. Mice continue breeding through summer and into early winter. Breeding continues provided there is sufficient high quality food available.

Mouse populations have an ability to increase rapidly in size in a very short period of time. Theoretically, one breeding pair of mice can produce 500 mice within 21 weeks.

Population dynamics

Mouse populations increase through breeding activity and through movement of animals into an area (immigration).

Table 1. Summary of some characteristics of the main rodent species that are likely to be pests in almond orchards and hulling/shelling/processing facilities.

Scientific Name	*Mus domesticus*	*Rattus rattus*	*Rattus norvegicus*
Common name	**House mouse**	**Roof rat, black rat, ship rat**	**Sewer rat, brown rat**
Adult size **HB** = head+body, **T** = tail, **W** = weight	HB = 60 - 95 mm T = 75 - 95 mm W = 10 - 20 g	HB = 160 - 205 mm T = 185 - 245 mm W = 95 - 340 g	HB = 180 - 255 mm T = 150 - 215 mm W = 200 - 400 g
Description	Small size. Tail length about same as head+body. Wide range of body colours	Body slightly smaller than R. norvegicus, large ears. Tail length longer than head+body.	Body slightly larger than R. rattus, large head with small ears. Tail length shorter than head+body.
Litter size	1-10 (Average 5-6)	1-10 (Average 6-7)	1-12 (Average 6-7)
Diet	Omnivorous	Omnivorous	Omnivorous
Nesting habitat	Subterranean, buildings	Building (especially roofs)	Subterranean
Gestation period	19-21 days	20-21 days	20-21 days
Age at sexual maturity	5-8 weeks	8-10 weeks	8-10 weeks
Breeding season in fields	October-April	Not known	Not known
Feeding habitat	Fields, buildings	Trees, fields and buildings	Buildings
Neophobic (fear of new objects)	No. Mice will readily explore new items found in their territory or try new types of food.	Yes. Rat will not explore new items or new foods readily.	Yes. Same as for R. rattus.
Communication of food preferences to other animals	Rarely	?	Yes
Effectiveness of 1st generation anticoagulants	Low	Low	High
Colour vision	Colour blind	Colour blind	Colour blind
Sense of smell	Acute	Acute	Acute
Physical abilities	Can squeeze through gaps as narrow as 6 mm, can jump vertically up to 50 cm mm, can fall 2.5 m without injury. Mice can climb almost any surface, which allows them to explore virtually any environment. Excellent swimmer.	Can squeeze through gaps as narrow as 12 mm, can jump vertically 1 m, can jump horizontally >1 m, can fall several metres without injury. Excellent swimmer.	Same as for R. rattus.
Home range size	Breeding season: 0.04 ha (20x20 m) Non breeding season: 0.12 ha (36x36 m)	Males: 1.1 ha, Females: 1.7 ha	Males: 0.4 ha Females: 0.6 ha

Mouse populations decrease through deaths and movement of rodents away from an area (emigration). Mouse control therefore needs to be achieved by killing animals, preventing them from entering facilities, and/or denying them places for nesting and breeding.

Mouse populations in southern NSW (Coleambally) peak in early winter after breeding has ceased (around April each year), and fall to a low in late spring after the breeding season for mice has commenced (around November) (Fig 1).

Activity and movements of mice

Mice are generally most active at night. They may have a number of feeding bouts during the night, but will return to their burrow before sunrise. Only when densities of mice are high and/or resources are scarce will mice be active during the day. Mice are excellent climbers.

Mice are reluctant to move across open areas of ground. Mice and rats have long hairs along their bodies, which together with their whiskers, they use to assist navigation when it is dark. They tend to restrict their movements to along walls and other objects and rarely venture out into open areas. Mice are social animals and in a wheat field in the breeding season have an average home range size of roughly half the size of a tennis court (0.04 ha, or about 20 x 20 m). After the breeding season, home-range size increases dramatically (0.12 ha, or about 35 x 35 m). Average daily movements from nest site to feeding areas for mice are up to 100 m.

Disease Transmission

Rodent infestations present a health hazard wherever they occur. The nature of the hazard and severity of the risk will vary with the species of rodent and the conditions of the facility. Diseases can be transmitted through direct contact with faecal matter, urine, dead animals, and saliva (through biting), as well as by inhalation of contaminated particles (e.g. disturbance of dust).

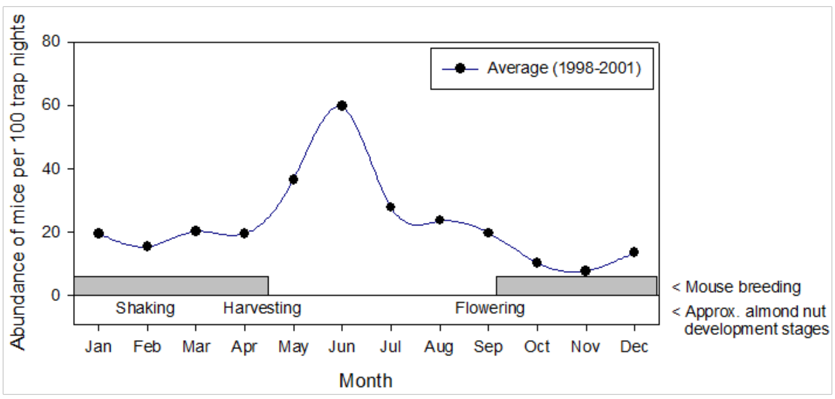


Figure 1. *Average abundance of mice (number of mice caught per 100 traps) from farms near Coleambally, Southern NSW, from a project looking at the effectiveness of farm management practices on mice. Mouse population abundance generally peaks in early winter (June) each year and is lowest in late spring (November). The breeding season is indicated by the shaded bars. The approximate timing of almond flowering, development, shaking and harvesting is shown.*

A rodent management plan for the almond industry means all aspects of the almond processing chain, from the orchard, through the shelling/hulling facilities through to the processing facilities work together to minimise or eliminate potential rodent infestations

A range of bacterial diseases can be transmitted from rodents to humans. These diseases are generally transmitted by direct contact with rodents (saliva or blood through broken skin or bites) or their urine or faeces. These include:

- Salmonellosis (*Salmonella typhimurium*), transmitted by consumption of contaminated faeces.
- Leptospirosis (*Leptospira interrogans*), transmitted through infected urine.
- *Rickettsia* spp. (murine typhus, spotted fever, scrub typhus) transmitted by fleas, ticks and larval mites.

Protozoal diseases are transmitted through eating infected or contaminated food or water:

- Toxoplasmosis (*Toxoplasma gondii*) - the main reservoir/vector of the disease is the domestic cat, but many other animals and birds can be infected. Cats eating insufficiently cooked meat can be infected with the cysts of the disease, or by eating rodents infected with T. gondii. The oocysts are then shed in their faeces. These oocysts survive for long periods of time and can be consumed through contaminated food or water.

Nematode and trematode infections (internal worm parasites) can cause disease in humans. The most important is Angiostrongyliasis:

- Angiostrongyliasis (*Angiostrongylus cantonensis*) affects the central nervous system in humans. Food contaminated by the excreta of infected snails may be a source of infection. Infection rates in wild-caught rodents may be high.

Other possible diseases are Cryptosporidiosis (*Cryptosporidium parvum*) and Giardiasis (*Giardia intestinalis*), both of which are microscopic parasites that live in the intestine of humans and animals and can be transmitted by consumption of infected faeces or from contaminated water.

Management practices

Principles of rodent management

An effective rodent control strategy must have clearly defined objectives and be well planned. The plan should consist of an objective, which for the almond industry, would be no positive salmonella samples. The strategy must include a method of monitoring and regular recording of information so that effectiveness can be determined.

Part of a rodent control strategy should be aimed at reducing the risk of disease transmission. Furthermore, workers involved in checking bait stations, setting traps or cleaning up areas where rodents have been living should be aware of the potential risks of rodent-borne diseases and should take appropriate preventative measures. These include wearing a dust mask in confined areas, wearing disposable plastic gloves when handling dead mice and when checking bait stations, and ensuring that staff wash their hands thoroughly prior to eating food and handling the almond facilities products. Employees should be screened (blood samples) routinely for a number of these diseases.

Poisoning

There are different types of baits and depending on what is used, they can be broadcast onto the ground or placed inside bait stations. However, poison bait stations may not be the "best" method available, may be ineffective if used inappropriately, or it may take a few days after an animal that consumed the poison bait to die, thus causing damage or spoiling product prior to death.

There are two categories of rodenticides available:

1. Acute rodenticides (fast acting) such as strychnine and zinc phosphide. Death usually occurs 20 minutes to 24 hours after ingestion. They generally act by affecting the nervous system or through muscular convulsions leading to asphyxia or sheer exhaustion. The chance of "bait shyness" is high because of the short period of time from ingestion of the bait and the onset of symptoms of poisoning, and animals can associate their consumption of the bait with the sickness. Bait shy animals will subsequently avoid contact with

Figure 2. Example of bait stations that are not set properly at hulling/shelling/processing facilities. Bait stations must be placed against the walls of the structures to increase the chance of rats or mice entering and consuming the bait.

the bait in the future. There are no antidotes to these acute rodenticides. Zinc phosphide (Zn_3P_2) is readily available and strychnine is available as "Dynamice" ® in South Australia.

2. Chronic rodenticides (slow acting) such as Warfarin, a first generation anticoagulant that requires multiple feeds and kills in up to 10 days; and Brodifacoum, a second generation rodenticide that requires only a single feed and kills in 3-7 days after consumption. Anticoagulant poisons block the recycling of the active form of vitamin K that is essential for blood clotting. The animal dies of internal bleeding (haemorrhage). The advantage of the anticoagulant rodenticides is that vitamin K can be administered as an antidote. Bait shyness is rare when using anticoagulants because of the long delay from ingestion of bait and onset of sickness.

Zinc phosphide is not registered for use in bait stations and cannot be used in and around buildings and storage sheds. Furthermore, zinc phosphide lacks an antidote and can only be used once every 3 months because surviving animals develop strong bait aversion, and may also require pre-feeding.

Bait stations need to be set correctly (Figure 2). It is important to ensure they are set against the external walls of warehouses and sheds. Mice use the edges of these structures to move about the facility and so the bait stations should intercept these movements as much as possible to increase the chance of animals entering the stations. If the bait stations are not touching the structures, there is a strong chance that rats and mice will walk straight past the bait station.

Figure 3. Example of how a drift fence could be set up along a chain link fence to help direct mice into bait stations. A 30-cm high length of shade cloth/silt fencing could be attached to the bottom of the chain link fence. The fence would guide mice into bait stations set along the bottom of the fence. Bait stations could be set alternatively on either side of the fence.

A drift fence (Figure 3) could be considered to enhance the likelihood that mice encounter bait stations located along the perimeter fence. Shade cloth or similar material (e.g. silt fence) could be tied to the chain link fence along the base of the fence to help guide mice to the stations. If mice are moving through the perimeter fence and they encounter the drift fence, they are more likely to traverse it to find an opening (where a bait station is located) rather than climb the drift fence. Mice can readily climb this material, but it might assist in guiding them to bait stations.

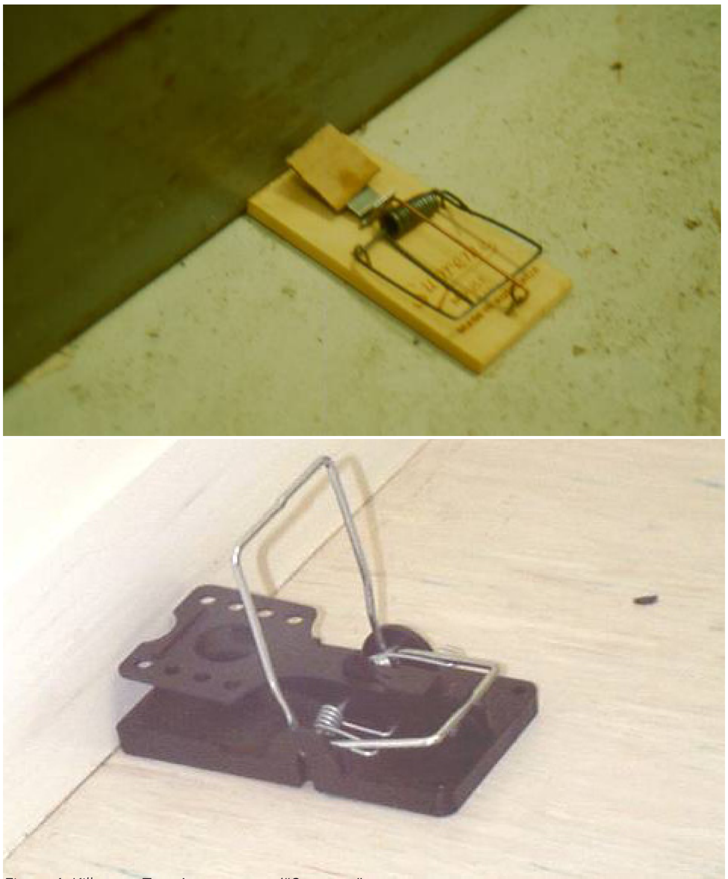


Figure 4. Kill traps. Top: A mouse trap ("Supreme" snap trap, trap is 10 cm long) set against a wall. The surface of the trigger has been enlarged using some leather. The leather has been soaked with linseed oil. Bottom: A strong plastic moulded rat trap made in the USA (trap is 14 cm long). These photos are not at the same scale.

Trapping

Trapping can be an effective technique if used correctly, but its effectiveness is reduced during a mouse plague (when densities are sometimes very high). An advantage of using traps is that mice do not develop resistance to the traps (although they can learn to avoid the traps) and they act as a measure of abundance of mice in the facility.

There are different types of traps available, including live-capture traps and kill traps (such as snap traps). Care is needed to ensure that traps are set correctly and routinely checked. A few simple things can improve the effectiveness of a mouse or rat trap:

- Bait type. Rats and mice prefer to eat bacon rind, chocolate or leather soaked in linseed oil and do not really like to eat cheese. An advantage of leather is that it can be tied securely to the trap trigger so the rodents cannot remove the bait, and it can be used repeatedly.
- Positioning of trap. Set each trap at right angles to a wall or barrier with the trigger next to the wall. Rodents do not like moving away from walls into the open (Figure 4).
- Enlargement of trigger. Use a piece of cardboard or leather to increase the size of the trigger (Figure 4a).
- Use plenty of traps. There is an increased chance of catching rodents if an excess number of traps is set.

For rats: leave traps baited but unset for a few days. Once there is evidence that rats are chewing on the leather, re-bait and set the trap. Snap traps made of strong moulded plastic are a good option (Figure 4b).

Other methods

Site Housekeeping

In any rodent control program, it is important to keep all potential hiding or nesting sites to a minimum (Figure 5). These include piles of old rubbish and areas of thick grass and weeds. Seeds from grasses and weeds can be a source of high quality food for mice, while long grass can provide shelter from predators. Clean up piles

of rubbish or move them further away from facilities, and keep vegetation short (mowing, slashing etc) to reduce cover and food sources for mice.

Monitoring

Monitoring can be in the form of number of mice captured in snap traps, amount of poison baits consumed, number and proportion of census cards eaten, and/or presence of rodent faeces in set areas. These techniques are all relatively simple to conduct. It is important to keep good records, so that when activity increases, control efforts can be implemented accordingly.

A census card (canola square) is a piece of paper with a 10 x 10 cm grid marked on it, which is soaked in canola oil and pegged into the ground (Figure 6). On cereal farms, these are set 10 metres apart on the edge of the crop in lines of 10 or in a crop in a 5 x 5 grid. In almond orchards, they could be set in lines through the orchard, on perimeters and in adjacent crop fields. In hulling/shelling and processing facilities, they could be set along the boundary fence, inside the warehouse or adjacent to the wheat fields. The census cards are left overnight. The percentage eaten on each card is recorded, and then averaged over all cards to give an average amount of card eaten. This technique provides a rough indication of relative abundance of mice.

There is little science behind the level of "take" of the census cards. There are many factors at play here, including hunger, inquisitiveness, behaviour etc. There is no hard and fast rule, but the card chewing results will help with a "gut feel" for the situation. It is also good to look around the orchard while setting and checking the cards the next day to help with understanding the level of mouse activity present. As a rough guide:

- If < 10% of the cards have significant chewing evident, then it is likely that activity levels of mice are reasonably low.
- If > 20% of the cards has significant chewing evident, then there are moderate levels of mice present.
- If > 50% of the cards has significant chewing evident, then there is a high level of activity.

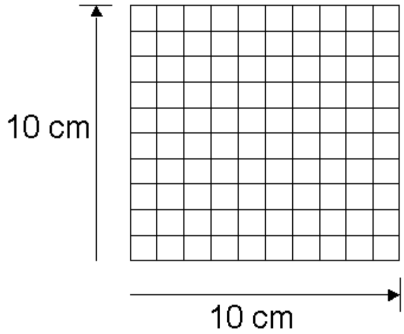


Figure 6. Design of census card (top) and a census card that has been set out in the field overnight and held in place by a piece of bent wire (bottom): approximately 40% of this card has been chewed by mice.

Figure 5. Top: Piles of rubbish provides ideal mouse habitat. This needs to be cleaned up or moved further away from the processing facilities. Bottom: Long grass and old rubbish provides cover and food. The grass needs to be mowed to remove the cover and food and the old rubbish needs to be cleared or moved off site.

Orchard control actions

Management of mice in adjacent agricultural fields

There is a range of farm management practices that can be used to reduce the abundance of mice in nearby cereal fields. Results of field trials have shown that when refuge habitats were manipulated to reduce the amount of weeds and grasses along the margins of crops (e.g. fence lines) through spraying, slashing or grazing by sheep, there were fewer mice and in some cases less damage to crops compared to untreated areas. Fence lines are an important habitat for mice because it is undisturbed (does not get ploughed) and high quality food and cover is often available (roly-poly tumble weeds, barley grass etc). When mouse abundance is high, especially at sowing, grain farmers should think about baiting their fields to reduce damage and prevent subsequent re-sowing costs. For the almond industry, the management of surrounding cropping fields should be considered as part of an overall management package

(management units of around 1,000 ha).

Perimeter baiting

Perimeter baiting using anticoagulant baits in bait stations has been implemented in many orchards. These are "hand-made" using 75 mm PVC stormwater pipe (Figure 7). In most cases, a single bait station can be positioned at the end of a row of trees and every 10 m or so along perimeter fences, which would be adequate coverage.

Management of habitats within orchards

In almond orchards, the ground surface is largely undisturbed which means mouse burrows are also not disturbed. Some weed spraying is conducted to clean the ground surface to assist with clean harvesting of the almonds (Figure 8). Weeds around the perimeter of orchards and neighbouring areas also should be sprayed. This can help remove potential cover and food sources provided by weeds. Mice seem to be construct mouse burrows near the base of the almond trees, and this may be a result of the shaking process to knock the almonds off the tree at harvest which loosens the soil. This enables mice to easily dig in the loosened soil near the tree trunk (Figure 8). Mice are unlikely to cause damage to the roots of the trees.

Key issues for management in orchards are set out in Table 2. Some other considerations are:

- Management should be conducted over > 1,000 ha to minimise reinvasion of mice from surrounding areas.
- If mouse activity is high and mice are seen running around in the orchards and in the trees causing damage directly to the nuts, then consider baiting with zinc phosphide.

Figure 7. Top: A close-up of the anticoagulant bait inside the bait station with the top cover removed. Bottom: A bait station set on the edge of an orchard. Small holes are located at the ends of the tube.

Table 2. Summary of management practices to control mice in almond orchards.

Timing	Mouse activity low	Mouse activity moderate	Mouse activity high
Spring	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions)
Summer	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources	Manage habitat using weed spraying and slashing of grasses and weeds to remove cover/shelter Remove potential food sources	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions) (beware of withholding period before harvest)
Autumn	Management may not be necessary	Remove potential food sources	Remove potential food sources Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions) (beware of withholding period before harvest)
Winter	Management may not be necessary	Remove potential food sources	Remove potential food sources Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions)

Table 3. Likely routes of access by mice into the hulling/shelling and processing facilities sheds.

Access point	Action required to remedy situation
Through open doors	Keep doors closed whenever possible
Through holes in walls or gaps in doors (Fig 9)	Repair holes in the wall using sheet metal, and fix the doors so that there is a snug fit (Fig 9).
Through cracks in the floor	Cracks in the floor can be sealed with cement.
Through drain pipes	Place snug fitting covers over drainage holes, these should be made of strong steel and have a hole size of less than 6 mm.
From overhead wires and trees	Ensure that there are minimal overhanging wires and trees.

Figure 8. Top: the floor of the orchard is relatively clean because of spraying that is conducted to control weeds; this can benefit mouse control because there is little food and cover provided by weeds. Bottom: Many mouse burrows were constructed near the base of trees, presumably because the soil was loose as a result of the shaking to drop the almonds to the ground during harvesting.

Figure 9. Small holes (>6 mm) allow entry by mice into sheds and facilities. This is especially important on the edges of roller doors, where it is difficult to reduce the gaps. Top: a small gap along the side of a roller door will allow access by mice into the facility. Bottom: well-fitting metal door strips will stop mice entering the facility.

Control actions for hulling/shelling and processing facilities

Baiting

Bait stations should be set surrounding the facilities (spaced every 10 m) (e.g. boundary fences and internal fences) and on external walls and internal walls of sheds and buildings. Bait stations should be set using anticoagulant rodenticide baits and checked every 1-2 weeks. Ensure they are set correctly.

Trapping

Live traps or kill traps should be used inside the facilities. Sticky traps should not be used because of animal welfare concerns.

Management of vegetation and general site hygiene

Areas of vegetation surrounding the facilities should be regularly mown or slashed to keep ground cover down. Piles of rubbish should be cleaned up and spills of almonds were cleaned up.

Mouse-proofing facilities

Proofing can be used to minimise the chance or even prevent rodents from entering certain facilities. Rodents are able to gnaw, climb, dig and jump. It is therefore important to consider rodent behaviour in any proofing. Rodents can gain access to a building through:

- holes or cracks in the foundations (pipes and cables can be sealed with concrete); mice can squeeze through holes >6 mm; rodents can enlarge any small hole by gnawing,
- sewers and drains,
- brick or concrete walls (rodents only need a claw-hold), downpipes, overhead wires, cables and overhanging trees, and
- open doors, windows, air vents, air conditioning units, chutes etc.

The options available for preventing access to buildings and facilities are provided in Table 3. Once rodents are inside the facilities, they can take up residence and make nests for breeding.

Key issues for management in processing facilities are set out in Table 4.

Table 4. Summary of management practices to control mice in hulling/shelling and processing facilities.

Time of year	Mouse activity low	Mouse activity moderate	Mouse activity high
Spring	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources Set and check anticoagulant bait stations at least every month Ensure floors are swept and kept clean	Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter Remove potential food sources Set and check anticoagulant bait stations at least every 2 weeks Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) Ensure floors are swept and kept clean	Apply rodenticide over surrounding fields to reduce resident mouse population abundance (obtain necessary approvals and permissions) Set and check anticoagulant bait stations at least every 1 week Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) Ensure floors are swept and kept clean
Summer	Remove potential food sources	Remove potential food sources	Apply rodenticide over surrounding fields (obtain necessary approvals and permissions)
Autumn	Remove potential food sources	Remove potential food sources	Apply rodenticide over surrounding fields (obtain necessary approvals and permissions) Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors)
Winter	Ensure grasses and weeds are managed Remove potential food sources Set and check anticoagulant bait stations at least every month Ensure floors are swept and kept clean	Manage habitat using weed spraying and slashing of grasses and weeds to remove cover/shelter Remove potential food sources Set and check anti-coagulant bait stations at least every 2 week Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) Ensure floors are swept and kept clean	Apply rodenticide over surrounding fields to reduce resident mouse population abundance (obtain necessary approvals and permissions) Set and check anticoagulant bait stations at least every 1 week Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) Ensure floors are swept and kept clean

References

Brown, P.R., Davies, M.J., Croft, J.D., and Singleton, G.R. (2004). Can farm management practices reduce the impact of house mouse populations on crops in an irrigated farming system? Wildlife Research 31, 597-604.

Brown, P.R., Singleton, G.R., Pech, R.P., Hinds, L.A., and Krebs, C.J. (2010). Rodent outbreaks in Australia: mouse plagues in cereal crops. In 'Rodent Outbreaks: Ecology and Impacts.' (Eds Singleton, G.R., Belmain, S.R., Brown, P.R. and Hardy, B.) pp. 225-238. (International Rice Research Institute: Los Baños, Philippines) [download at: http://books.google.com/books/irri?id=yaI0NFQb36UC&printsec=frontcover&dq=rodent+outbreaks&cd=1#v=onepage&q&f=false]

Buckle, A.P. (1994). Rodent control methods: chemical. In Rodent Pests and Their Control. (Eds. A.P. Buckle and R.H. Smith.) pp. 127-160. (CAB International: Wallingford, UK.)

Buckle, A.P. (1999). Rodenticides - their role in rodent pest management in tropical agriculture. In Ecologically-based Management of Rodent Pests. (Eds. G.R. Singleton, L.A. Hinds, H. Leirs, and Z. Zhang.) pp. 163-177. (Australian Centre for International Agricultural Research: Canberra.)

Caughley, J., Bomford, M., Parker, B., Sinclair, R., Griffiths, J., and Kelly, D. (1998). Managing Vertebrate Pests: Rodents. 130 pp. (Bureau of Resource Sciences and Grains Research and Development Corporation: Canberra.)

Caughley, J., Monamy, V., and Heiden, K. (1994). Impact of the 1993 mouse plague. GRDC Occasional Paper Series No.7. (GRDC: Canberra, Australia.)

Chambers, L.K., Singleton, G.R., and Krebs, C.J. (2000). Movements and social organization of wild house mice (Mus domesticus) in the wheatlands of Northwestern Victoria, Australia. Journal of Mammalogy 81, 59-69.

Kenney, A.J., Krebs, C.J., Davis, S.A., Pech, R.P., Mutze, G.J., and Singleton, G.R. (2003). Predicting house mouse outbreaks in the wheat-growing areas of south-eastern Australia. In Rats, Mice and People: Rodent Biology and Management. (Eds G.R. Singleton, L.A. Hinds, C.J. Krebs and D.M. Spratt) ACIAR Monograph 96. pp. 325-328. (ACIAR: Canberra)

Mason, G., and Littin, K.E. (2003). The humaneness of rodent pest control. Animal Welfare 12, 1-37.

Pech, R.P., Hood, G., Singleton, G.R., Salmon, E., Forrester, R., and Brown, P.R. (1999). Models for predicting plagues of house mice (Mus domesticus) in Australia. In Ecologically-based Management of Rodent Pests. (Eds. G.R. Singleton, L.A. Hinds, H. Leirs, and Z. Zhang.) pp. 81-112. (ACIAR: Canberra.)

Prakash, I. (1988). Bait shyness and poison aversion. In Rodent Pest Management. (Ed. I. Prakash.) pp. 321-329. (CRC Press: Boca Raton, Florida.)

Singleton, G.R., Brown, P.R., Pech, R.P., Jacob, J., Mutze, G.J., and Krebs, C.J. (2005). One hundred years of eruptions of house mice in Australia - a natural biological curio. Biological Journal of the Linnaen Society 84, 617-627.

For further information contact Ben Brown, Industry Development Manager

Published by Almond Board of Australia, PO Box 2246, Berri, South Australia 5343
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

HAL Horticulture Australia

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.

This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia December 2010
All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 1.10 – Fact Sheet: What Threatens the Safety of Almonds?

Fact Sheet 10 –
What Threatens the Safety of Almonds?

Dr Prue McMichael
Scholefield Robinson Horticultural Services

Welcome to the tenth edition of "All About Almonds": What Threatens the Safety of Almonds? Fact sheets are distributed to almond growers via email, in addition to being made available for download from the ABA website: www.australianalmonds.com.au (follow links to the login section of the growing page).

1. Introduction

Although almonds are not a readily perishable commodity, they are like other fresh foods, subject to contamination of food safety concern. Almond contaminants are categorised as being **chemical, biological,** or **physical** in nature.

The 'cost' of contaminated nuts is multi-faceted. Not only is there a potential human cost in terms of health (and occasionally life), but also significant costs associated with sorting and testing product, re-sorting and re-calling, loss of markets and consumer confidence.

Any surface in contact with almonds is a potential source of contamination. The premature fall of almonds (windfalls), the natural splitting of hulls (and shells, in some varieties), and the harvest practice of shaking mature almonds to the ground, make bacterial and fungal presence in almonds, unavoidable.

Risk management is required and the responsibility for safe and sanitary almonds is shared across the production and value chains throughout the industry. Risk reduction strategies in the orchard relate to conditions, practices and hazards over which growers have control. Specific documentation and record-keeping maximise the value of your risk-reduction steps, and your capacity to identify early and trace threat sources.

This factsheet outlines for almond producers, food safety threats and how they may be minimised in the orchard. The responsibilities of hullers, crackers and processors in almond food safety are detailed in other publications and quality assurance programmes.

Chemical contamination
Chemical contaminants include pesticide residues, allergens and mycotoxins. Pesticide residues are minimised by the correct use of registered (or permitted) chemicals. Aflatoxins are a specific form of mycotoxin and worldwide, nut aflatoxins are of concern. Aflatoxins are natural but toxic by-products of fungi, odourless and colourless, and cannot be visually detected in a food product. They may enter the almond food chain in the orchard, in stockpiles or in storage, and persist in finished, raw product.

Biological contamination

Biological contaminants include parasites and pathogens that are usually fungal, viral, or bacterial in nature. The most important biological food safety contaminants of almonds are bacterial - *Salmonella* spp. and *Escherichia coli* (*E. coli*). Both are indicative of food exposure to faecal material. These organisms have serious human health consequences, and therefore all food production and handling management must ensure such exposure is minimised.

Physical contamination

Foreign matter of concern in almonds is that which is solid, and capable of causing human injury or illness, e.g. stones, glass, plastic, metal fragments. These may be from the orchard floor or equipment, and are generally removed during hulling and cracking.

2. Aflatoxins – chemical contaminants of concern

Aflatoxins are derived from fungi, primarily *Aspergillus flavus* and *Aspergillus parasiticus*. They are carcinogenic and mutagenic, even in low concentrations. Aflatoxin B_1 can be found in almonds, and it is the most potent natural carcinogen known.

Humans are exposed to aflatoxins by eating *Aspergillus*-contaminated food. Historically, corn, peanuts, cereals, figs, tree nuts and milk (from animals that have eaten contaminated grain), have been the main sources of aflatoxin ingestion. Recurring consumption of such food has serious human health effects, especially on the liver and immune system. As such, internationally-traded commodities, including almonds, must comply with aflatoxin monitoring and regulations regarding acceptable levels of detection. World food authorities have extremely low tolerance levels for aflatoxins in food. Australia's limit is 10-15 ppb (parts per billion), depending on the product. Some other markets are even lower.

Some commodity processors impose significant economic penalties on aflatoxin-affected deliveries. The Australian peanut industry for example, deducts 40% of the clean value, from aflatoxin-affected loads.

Prevention of aflatoxin production has a greater chance of success than corrective action, and therefore risk reduction strategies are the basis of on-farm contaminant management programmes.

2.1 Aflatoxins in almonds

2.1.1 Aspergillus growth causes aflatoxins

Both *A. flavus* and *A. parasiticus* are present in Australian agricultural environments. There are no almond varieties resistant to infection by these fungi. To manage *Aspergillus* growth and aflatoxin production in almonds, the influence of orchard conditions and agricultural practices need to be understood.

Fungal growth and aflatoxin production occur in almonds pre-harvest, but may proliferate in stockpiles, and continue in the handling stage. Almonds are vulnerable as soon as the fruit is exposed following damage (e.g. insects) or hull split. *Aspergillus* spores from the soil, dust, or air enter the exposed hull, shell or kernel while nuts are on the tree, ground and/or in stockpiles.

The growth of the fungi inside hulls and shells are affected by temperature, humidity and moisture levels. In mild-warm temperatures (15-37+C), spores of *Aspergillus* spp. can germinate and produce the heat stable aflatoxin within 24-48 hours of nut exposure to a moist environment (≥7% kernel moisture). Once inside the shell, the nutrients of the kernel provide a rich growth environment. Affected nuts are not always 'mouldy' but one should be suspicious of any kernels that display yellow-green growth. Not all moulds however are *Aspergillus* spp.

Figure 1 *Aspergillus* growth on almonds

Figure 2 Mould growth from kernels. The dense, pale yellow mats are those of *Aspergillus spp*

2.2 Risk reduction and prevention

2.2.1 Orchard practices and aflatoxins

Almond producers must minimise food safety threats in the orchard. Producers can best manage risk by understanding the potential contribution of orchard design, winter sanitation, orchard floor conditions nut damage (mechanical, vermin, pest and disease), harvest operations and stockpile conditions, on almond contamination. For example, tree density, canopy size, and irrigation techniques, affect light penetration, humidity and soil populations of fungi and nut drying times. Orchard size and the relative demands on equipment may affect the timing of crop protection applications and harvest activities.

Aflatoxin risk management in your orchard requires focus in several specific areas and documentation of your inputs and activities.

2.2.2 Pest and vermin management

- Damaged nuts with the white meat of the kernel exposed are susceptible to fungal contamination.
- Bird, vermin and insect damage provide entry points for fungi
- Birds, vermin and insects are sources and vectors of fungal spores and bacteria
- In Australian orchards, the larvae of Carob moth (*Ectomyelois ceratoniae*) have been shown to carry *Aspergillus* spp
- A strong and significant correlation of Carob moth and aflatoxin in Australian almonds is possible, as exists for the navel orangeworm (NOW) and aflatoxin in Californian almonds

Insects and aflatoxins in Californian almonds

In California almonds and pistachios, aflatoxin contamination has been strongly correlated with insect presence, especially navel orangeworm (NOW) - *Amyelois transitella*. Kernels of mummies with *A. parasiticus,* in the presence or absence of NOW larvae, have been compared. Those with NOW larvae had aflatoxin levels six times higher than those without larvae (Higbee and Siegel, 2009). Navel orangeworm infestations clearly increase aflatoxin detections in almonds.

Once hulls split, NOW larvae feed on shells or penetrate the developing kernels in soft-shelled varieties (e.g. Nonpareil). Curtis *et al.* (1984) found the longer nuts remained in trees after maturity, the more likely was NOW infestation. Overwintering mummies carry most of the NOW eggs for the next season. Larval infestations and mummy numbers are strongly correlated.

Orchard-wide removal of mummies has reduced insect damage and aflatoxin detections the following season. Fewer than 2 mummies/tree has been until recently the goal of NOW (and aflatoxin) management in Californian orchards. However more recent winter sanitation research has suggested 0.2 mummies/tree (i.e. 1 mummy in five trees) and no more than 4 mummies/tree on ground by budswell is needed to minimise NOW damage the following season.

Dormant sprays are not effective on NOW larvae harboured in mummies. Integrated management practices are needed. Moth trapping, pheromone and egg trap monitoring, degree day calculations, mating disruption and pre-harvest nut assessments allow strategic spray applications.

Attempts to 'displace' aflatoxigenic *A. flavus* strains at the soil surface, with non-toxic strains, is being trialled in some Californian orchards. This form of 'biological control', based on soil-borne population manipulation and competition for infection sites, has shown promising results in other aflatoxin-affected food crops (e.g. corn and peanuts), but it is only in the early research phase for almonds and pistachios.

Figure 3 Carob Moth larvae in almonds

Figure 4 Moulds associated with insect/vermin damaged almond kernels despite surface sterilisation

2.2.3 Orchard floor management

- *Aspergillus* spp. in the top 1-2 cm soil under the tree canopy, threaten almonds
- Slow drying and re-wet soils (e.g. under large, shaded canopies) potentially harbour more fungi and bacteria
- Dust from this area reaches tree nuts, so minimise dust movement
- Minimise the time nuts are in contact with the soil
- In nuts exposed to direct sunlight, NOW larvae and pupa survival is reduced (in California)
- Canopy density influences direct sunlight exposure, nut drying times and internal temperatures
- Scattered nuts dry faster than those in shaded windrows
- Soil and organic matter incorporated into windrows slows the drying of nuts
- Windfalls harbour more fungi than mature nuts on trees

2.2.4 Harvest timing

- Minimise cross-contamination
- Early windfall pick-up may be beneficial
- Harvest on time whenever possible
- 'Optimal harvest' guidelines suggest 95-100% hull split (30-40 days after hull split initiation) at 1.8-2.5 m in the canopy
- Delayed harvests (and re-wetting of mature nuts on the ground or in trees) increase fungal infection

2.2.5 Stockpile management

- The starting point for moisture levels in hulls and kernels before stockpiling is very important
- High humidity and temperatures in stockpiles increase incidence of moulds and aflatoxins
- Fungal growth and aflatoxin production increase in poor stockpiles and primarily at top and bottom of stacks
- Minimise cross-contamination. Segregate re-shakes and mummies from others
- Do not stockpile nuts with wet hulls (>12% moisture) or kernels (>6%)
- Shells, hulls and kernels snap when bent at suitable moisture levels BUT moisture monitors are more accurate and reliable
- Stockpiled nuts dry slowly because of air movement limitations, condensation and/or re-wetting
- In Australia, run stockpiles north-south and minimise the creation of furrows and valleys
- Drying time in stockpiles is influenced by height, shape, orientation and covers
- The diurnal temperature range (day to night) influences condensation and therefore moisture, particularly in covered stockpiles. Under covered stockpiles moisture can condense at the top and affect top nuts, or moisture can run off down to the base of the stockpiles and affect the bottom nuts.
- Slope the stockpile base/pad to reduce pooling of condensate and rain entry
- Cover stockpiles only when rain threatens and during evenings - remove covers in daylight
- Monitor stockpiles at top, middle and bottom of piles with moisture, humidity and temperature readers

2.2.6 Winter sanitation

- Mummies harbour fungi and insects
- Remove all mummies before budswell of the next season
- Minimise cross-contamination. Segregate re-shakes and mummies from others
- Destroy (e.g. with flail mower) mummies on ground

Figure 5 Two 'generations' of almond fruit, mummies from last season (black, mouldy almonds) and new season fruit (green fruit)

Figure 6 Two 'generations' of almond fruit, mummies from two seasons ago (black, mouldy almonds) and from the previous season (brown fruit). Three 'generations' of almond fruit will exist once the new season begins.

2.3 Treatment (decontamination) potential

There are no efficient means of degrading or removing aflatoxins from contaminated food. There is some suggestion that removal of the skin of almonds (e.g. blanching) can reduce the level of aflatoxin present, but this has not been demonstrated. The heat stability of aflatoxins limits the effectiveness of cooking or roasting.

Decontamination and clean-up efforts, even if effective, are very expensive and the net value of nuts requiring such treatments is greatly reduced.

3. Biological contaminant – *Salmonella*

Salmonella is the leading cause of food-borne illness in many countries. The USA reports on average, 1.79 million cases/yr. Various strains of *Salmonella* are common in the environment and food chain, and people usually come into contact with these bacteria via wildlife, pets, and consumption of unpasteurised or raw animal food products (e.g. dairy, poultry, meat, eggs). Several significant outbreaks of 'salmonellosis' (a form of gastroenteritis) due to consumption of nuts, including almonds and pistachios, have been reported in the USA and Europe.

3.1 *Salmonella* in almonds

The primary habitats of *Salmonella* spp. are the intestines of birds, animals, some insects, reptiles and humans. The persistent on-farm sources of *Salmonella* spp. are soil, sediment, dust and 'open' water; organic inputs (e.g. manure, biosolids, effluent); exposed produce, feed and waste piles; farm workers, equipment and containers.

Salmonella spp. rapidly proliferate in wet almond hulls and free moisture allows bacteria located in the dust on the outside of hulls, to move onto shells and into kernels. Once inside shells, the bacteria are protected from drying conditions and direct sunlight, and they rapidly multiply.

Salmonella spp. grow over a wide temperature range (5°-45°C) at moisture levels above 10%, but even at lower moisture levels these bacteria remain a problem because their high temperature tolerance is increased at low moisture levels. Nut contamination levels are highest in warm, moist nuts, but the capacity of *Salmonella* spp. to survive in water, soil and on organic and plant matter, makes them an on-going concern in almond production, handling, processing and storage.

Research on one *Salmonella* strain (*Salmonella* Enteritidis phage type [PT] 30) has demonstrated its survival for 550+ days in finished almonds, under normal storage conditions.

3.2 Risk reduction and prevention

Salmonella risk reduction in orchards, requires particular focus on water sources; soil and nutritional amendments; hygiene of orchard and product handling personnel; bird, animal and vermin management; harvest operations and cross-contamination.

Salmonella and almond contamination in California

Orchards with high planting densities (i.e. 370 trees/ha), shading, and greater areas of wet ground (e.g. from mini-sprinklers) have high humidity within and around each tree. Rainfall extends the conducive conditions, especially in summer when windfalls may be in contact with the ground over a long period, or when shaken nuts are re-wet on the ground.

The 2001 *Salmonella* outbreak in California was traced to an orchard that had soil infested with the same *Salmonella* strain. The orchard was, and remains productive, but its orchard floor is fully shaded. UC Davis academic, Bruce Lampinen has suggested the lack of direct light, use of mini-sprinklers, conducive soil temperatures, and natural rainfall resulted in the clay loam topsoil retaining moisture and providing a suitable environment for *Salmonella* proliferation. *Salmonella* was still detectable in the soil in 2007, and the orchard therefore remains quarantined.

3.2.1 Orchard history

- An orchard's history requires early and careful consideration because it alone may overwhelm subsequent risk management efforts
- Animal, human and vermin manure carry *Salmonella* spp. which may persist even when dried
- Orchards with a history of grazing or dairy/livestock (including sheep) operations, are at greater risk
- Trees and orchards on or near landfill, septic tanks or sites that have incorporated manure (as soil amendments) are at greater risk
- Orchards sharing water channels or dams with livestock/grazing operations are at greater risk, especially if there is potential for overflow or leakage

3.2.2 Water sources and quality

- Almonds are in contact with water in orchards via irrigation, foliar spraying and rain
- Water may introduce and spread microbial contaminants, like *Salmonella* spp.
- Protect dams, holding ponds and open channels from wildlife (including birds) wherever possible
- For foliar spraying use mains or protected (ground, bore) water only
- Test for and record 'total faecal coliform' bacteria and generic *E. coli* in surface water
- Know the bacterial thresholds at which water quality becomes unsuitable for spraying or irrigation
- Keep all water test results especially if open, re-cycled water is used

3.2.3 Soil and nutritional amendments

- *Salmonella* spp. survive long periods in soil, sediments, and dust
- Manure, whether fresh or aged, carries *Salmonella*
- Do not use equipment for collection or movement of almonds that has contacted or carried animals, animal products, soil or organic matter exposed to animals
- Avoid manure (also biosolids, effluent) use, storage or distribution on or near almond trees
- Use only fully-composted amendments meeting Australian standards – if necessary

3.2.4 Worker hygiene

- Personal hygiene of workers directly affects transmission of contaminants and food safety
- Properly-serviced facilities are necessary in orchards or within easy access, for every worker
- Use of the facilities must be a requirement of all orchard workers
- Do not place facilities near irrigation sources
- The contents of portable toilets must be disposed of off-site – outside the orchard
- Hands, clothing, shoes, and equipment require proper cleaning
- Training in food safety practices is recommended for all staff

3.2.5 Orchard floor management

- *Salmonella* spp. in surface soil threaten the safety of almonds that make contact
- Minimise wildlife movement through orchards
- Minimise dust. Dust movement and aerosols spread contaminants
- Dust carries fungi and bacteria, including *Salmonella* spp.
- Avoid standing water in orchards through good irrigation management, orchard floor grooming (remove low spots), and canopy management
- Avoid nut contact with wet /damp soil and nuts becoming wet on the ground
- Minimise slow-drying of nuts and the time windrows are shaded
- Avoid creating preferred habitats for wildlife (e.g. waste piles, vegetation cover)

3.2.6 Wildlife, bird and vermin management

- Birds, animals (and insects) in orchards and processing facilities threaten food safety
- Animal and human faecal deposits contaminate soil, dust, plant material, water sources and equipment
- Every nut that comes into contact with a surface shared by animals is at high risk
- Warm and cold-blooded animals carry *Salmonella* spp.
- Clear weeds and ground around orchards, as rodents and other vermin avoid open spaces
- The size, shape and colour of some excrement makes its physical separation from almond kernels difficult and it may not be achieved until late in the handling and sorting stages
- Do not allow equipment scrap heaps and waste piles in the orchard, as they become hiding and nesting refuges for vermin and birds

3.2.7 Harvest operations

- Minimise dust; dust movement spreads contaminants
- Manage windrows to ensure nuts are drying as rapidly as possible
- Do not stockpile damp nuts
- Separation of windfalls, wet nuts, re-shakes from other nuts will reduce cross-contamination
- Avoid fumigation of warm, moist nuts as this can result in dark kernels

3.3 Treatment (decontamination) potential

Salmonella contamination, unlike aflatoxin, may be reduced by heating and washing, depending on the bacterial strain present. Steam pasteurisation, hot water blanching and oil roasting may effectively reduce *Salmonella* populations in almonds. Pasteurisation *reduces* rather than kills all the bacteria and therefore the starting population in the kernels, determines if a 10,000-fold reduction in the population is sufficient to meet food safety standards.

Pasteurisation

In 2007, the Almond Board of California in recognition of the food safety re-calls of raw Californian almonds determined that industry-wide, aggressive measures were required to increase the safety and quality of their almonds were justified. They mandated pasteurisation of domestic almonds to achieve a 10,000-100,000-fold reduction in *Salmonella*, on the basis of decontamination research by Danyluk et al.

A validated procedure to achieve the minimum 10,000-fold bacterial reduction is required, by all almond processors selling raw almonds in USA, Canada and Mexico before product shipment. Those being sold elsewhere are marked 'unpasteurised'. The actions have been mandated (with USDA support) to ensure full adoption, auditable compliance and the use of approved technology. Mandatory pasteurisation does not absolve growers of their orchard responsibilities. Almond producers in California are still expected to follow Good Agricultural Practices (GAPs), and hullers and crackers are expected to follow Good Manufacturing Practices (GMPs).

4. Orchard guidelines for aflatoxin and *Salmonella* management

As almond producers, you and your employees are the people most capable of influencing and managing aflatoxin levels and *Salmonella* contamination, in your almonds. Crackers and processors can *maintain* the quality of almonds delivered to them, but can rarely improve it.

There are several documents that include recommended food safety practices for producers and processors of almonds. Good Agricultural Practices (GAPs) were prepared in California, but have direct relevance also to Australian almond orchards. The guidelines of the United Nations Food and Agriculture Organisation (FAO) and the CODEX code of practice for the prevention and reduction of aflatoxin contamination of tree nuts are also useful.

A summary of recommendations relevant to Australian almond orchards is tabled below (Table 1).

Table 1. Risk reduction steps for aflatoxin and *Salmonella* contamination

Stage	Risk reduction category	Risk reduction steps
In the orchard		
Orchard - plan	Knowledge and traceability	Avoid orchards with land use history involving animals Map adjacent land use, water courses, drainage patterns Map orchard layout, harvest sequence Document all activities and weather events Consider equipment capacity and availability Train workers in food safety practices
Orchard – Pre-harvest	Damage minimisation	Minimise habitats and hiding places Control insect pests Avoid bird, insect, disease, vermin, mechanical damage
	Minimise introduction of contaminants	Enforce highest worker hygiene standards in orchard and handling areas Clean anything that contacts almonds -equipment, hands, shoes, clothing Test (or access results) water quality and record results Foliar spray only with ground or mains water Do not apply manure, biosolids, or untreated effluent Minimise animal, bird, vermin presence in orchards Minimise bird life in water courses and dams Do not irrigate with water sourced or held near animal operations Minimise pet presence in orchards and on almond equipment
Orchard - Harvest	Maturity of crop	Harvest in good conditions, at full maturity Avoid rain, re-wetting, delayed harvests Dry rapidly; manage windrows Minimise time on ground Re-shake to remove all mummies and stick-tights before budswell Destroy winter re-shakes on ground Destroy re-shakes with high insect infestation Isolate re-shakes, mummies, wet nuts from others
Orchard – After shaking	Stockpile management	Test nut moisture before stockpiling Orient piles north-south Stockpile low moisture (< 7%) nuts only Monitor nut moisture (top, middle, bottom) in stockpiles Manage covers and stockpile form (height) to achieve low moisture equilibrium Slope stockpile pad to avoid pooling of condensate or rain at base

Table 1. (cont) Risk reduction steps for aflatoxin and *Salmonella* contamination

Beyond the orchard*		
Hulling and cracking*	Cross contamination	Do not share equipment with animal operations Train workers in food safety and handling requirements Isolate late season nuts – (ie mummies, windfalls, re-shakes) from others Isolate organic nuts from others Do not mix (or process) loads of moist and dry nuts Remove 'inedibles' and physical contaminants early in handling stage Clean all equipment and contact surfaces thoroughly
Processing*	Cross contamination and re-contamination	Focus on QA and GMPs requirements Clean surfaces and equipment between lots Clean with low moisture, fast-evaporating sanitisers Ensure personnel trained in hygiene Linear directional flow in plant – air, product Re-mediate, treat 'at risk' lots (*Salmonella*) Do not combine re-runs
Storage*	Product protection - moisture	Use dry, clean, protected (from rain, dust, vermin), ventilated storage Maintain low moisture (< 7% water activity)
	Product protection- temperature	Store at low temps and monitor for 'hot spots'
Transport	Contamination - equipment hygiene	Use only dry, sanitised/lined containers, vehicles, machinery Do not use equipment or transport used in animal industry
	Product protection -temperature	Monitor Avoid long periods/distances without temperature control

Source: adapted from FAO; CODEX code of practice (CAC/RCP 59 –rev 1-2006); GAPs
*Summary only. Specific QA and food safety requirements must be met for all food handling activities beyond orchard.

5. References

Almond Board of California. 2009. *Salmonella* Western Farm Press.
Almond Board of California. 2009. *Food quality and safety* www.almondboard.com/programs
Almond Board of California. 2009. Good Agricultural Practices – Quick-start guide. 16 pp.
Bennett and Klich Clinical Microbiology Reviews 16 (3): 497-516.
Curtis, C.E., Curtis, R.K. and K.L. Andrews. 1984. Environ. Entomol. 13:146-149.
Danyluk, M.D., Harris, L. J. and D.W. Schaffner. 2006. J. Food Prot.69:1594-1599.
Higbee, B.S. and J.P. Siegel. 2009. California Agriculture 63: 1 24-28
Lampinen B, 2009. 37th Annual Almond Industry Conference, Modesto, California.
Lampinen B and J. Connell. 2004. UC Division ANR, publication 8126. 3 pp.

For further information contact Ben Brown, Industry Liaison Manager

Published by Almond Board of Australia, *PO Box 2246, Berri, South Australia 5343*
Telephone (08) 8582 2055 Facsimile (08) 8582 3503
Email admin@australianalmonds.com.au

ACKNOWLEDGEMENTS

The input and suggestions made by Australian almond processors, marketers and growers.
This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.

©Almond Board of Australia

All rights reserved. No part of this publication can be reproduced or copied without the prior written consent of the Almond Board of Australia unless permitted under the Copyright Act 1968 (Cwlth).

DISCLAIMER

Almond Board of Australia and its employees do not guarantee the use, or results of the use, of the information contained herein as to its correctness, accuracy, reliability, currency or otherwise. The information supplied in the Fact Sheet was the best available at the time of publication. However, the understanding and management of almonds is constantly evolving and recommendations regularly change. As such, the reader should seek professional advice before acting upon any information in this Fact Sheet and should always comply with the relevant processing factory requirements, food safety legislation and the information listed on chemical labels.

Appendix 2 – Almond Canopy Spray Coverage and Dosage Assessment

BRIEFING NOTE

Canopy Spray Coverage Assessment

Prepared By: Brett Rosenzweig

Background

Late last year Geoff Furness was contacted to investigate his availability and ideas on how the almond industry could make improvements and increase the efficiency of canopy spraying operations. The range of airblast equipment in the almond industry is wide ranging and varies from aged single fan units to newer engine driven dual fan airblasts. The 2010/11 season showed that while chemical choice can influence the incidence of rust in orchards, the biggest factor is canopy coverage i.e. the typical rust 'waterline'.

With this in mind, the ABA approached Geoff to draw on his expertise gained in the citrus and wine grape industries to evaluate current machinery and develop strategies for growers to improve their canopy spray coverage. A side note to this was to investigate new technology that might be suitable for implementation within the industry i.e. SARDI Fan multi-head style of machinery.

A summary of the proposed evaluations are provided below.

Treat #	Machine	Tree Height (m)	Canopy Height (m)	Canopy Density	Nozzle Array	Total Flow (L/min)	Spraying Speed (km/hr)	Pump Pressure (bar)	Water Rate (L/Ha)
1	Engine driven, twin fan airblast	9.2	7.7	Sparse/ Medium	Standard	86.0	5.5	12.4	1,470
2	Engine driven, twin fan airblast	9.2	7.7	Sparse/ Medium	Fine*	86.0	5.5	10.3	1,500
3	Engine driven, twin fan airblast	5.8	5.0	Medium	Fine*	78.6	5.5	12.4	1,290
4	PTO driven, twin fan airblast	6.0	4.5	Medium	Standard	70.0	5.5	6.0	1,200
5	PTO driven, twin fan airblast	6.0	4.5	Medium	Fine*	Not Completed Yet			
6	PTO driven, single fan airblast	6.0	4.5	Medium	Standard	70.0	5.5	15.0	1,200
7	Multi-head Tower with SARDI Fan	Not Completed Yet							

*Geoff's recommended changes were to increase the number of nozzles of a smaller jet size to achieve the same overall output.

Draft Results

Interpretation of the results is based on samples taken in the following positions:

- CT = Centre Top
- CB = Centre Bottom
- N, S, E & W = orientation from which leaf/fruit sample was taken
- 1, 2, 3, etc = canopy position from which leaf/fruit sample was taken. 1 = lowest, 6 = highest.

Interpretation of the results is based on the following guidelines of droplets per cm2:

- 1000-1200 = approaching point of runoff
- 800 = good coverage
- <400 = very poor coverage

A quick comparison of Figure 1 and 2 shows the large trees still struggle for optimum coverage at the top of the tree (N3, E5, E6, W5 & W6 are around 200-400 droplets) while the bottom two thirds of the tree is receiving adequate coverage. Figure 2 with very fine nozzles has all droplets above 800 indicating good coverage. An important fact to be noted with the medium trees is that there was sufficient gap between trees along the butt line to allow overspray into the adjoining rows. This would've helped increase the coverage.

Figure 3 indicates the pattern of spray coverage is significantly worse, in particular in the upper heights of the canopy. Additional evaluation and trials is still to be complete including the evaluation of a Croplands Quantum Mist citrus tower to assess the coverage of a multi-head SARDI fan unit. Whilst a citrus tower is not suitable for most almond orchards, the focus will be on whether the SARDI fan will give better penetration and coverage in the tree using a mixture of air volume and turbulence.

Further coverage tests will be carried out in spring 2012 to further improve the knowledge gained so far. At the end of the project, Geoff will alter an existing SARDI publication about canopy spray coverage in wine grapes to suit almonds. A series of field days highlighting spray coverage will also be held to provide growers a better understanding on how to improve their coverage efficiency when spraying.

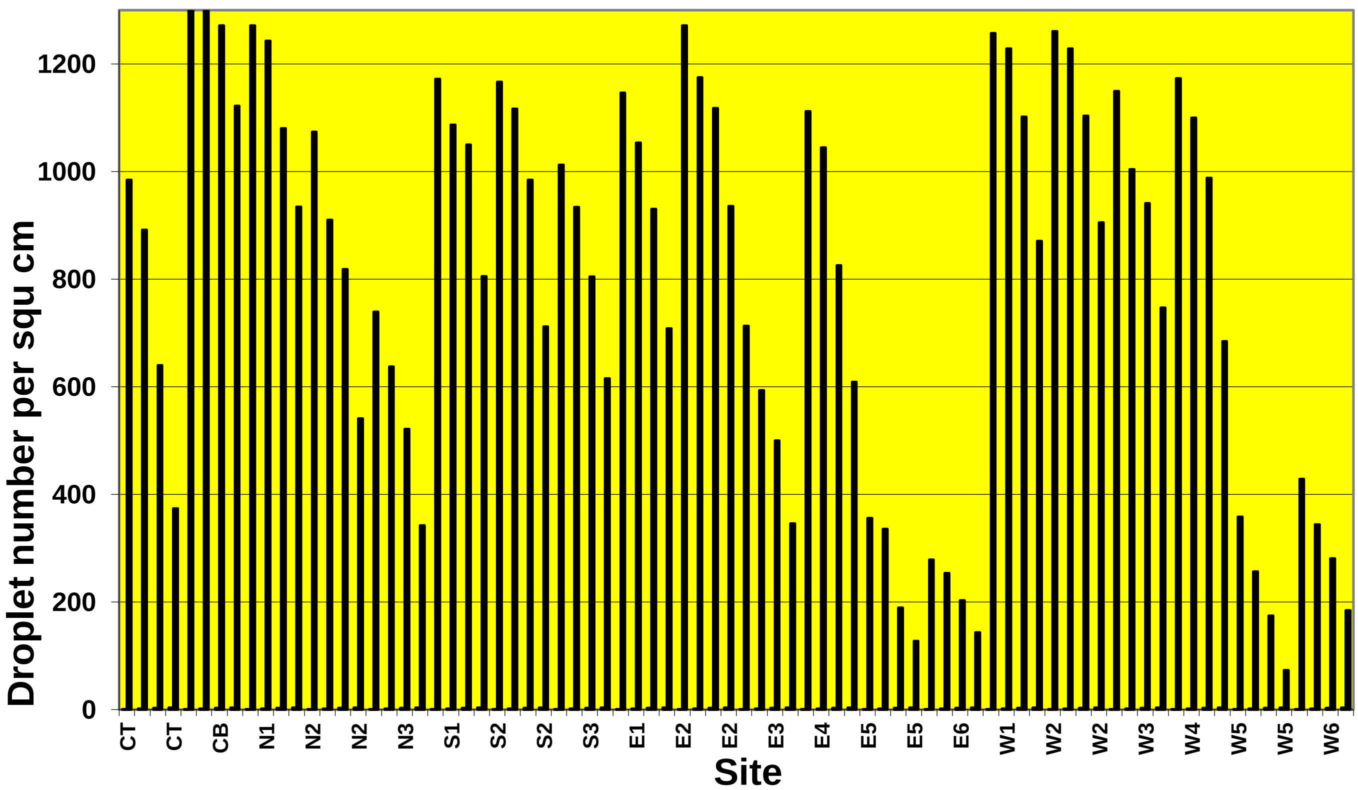


Figure 1: Treatment 1 - engine driven twin fan airblast, standard nozzles, and large trees.

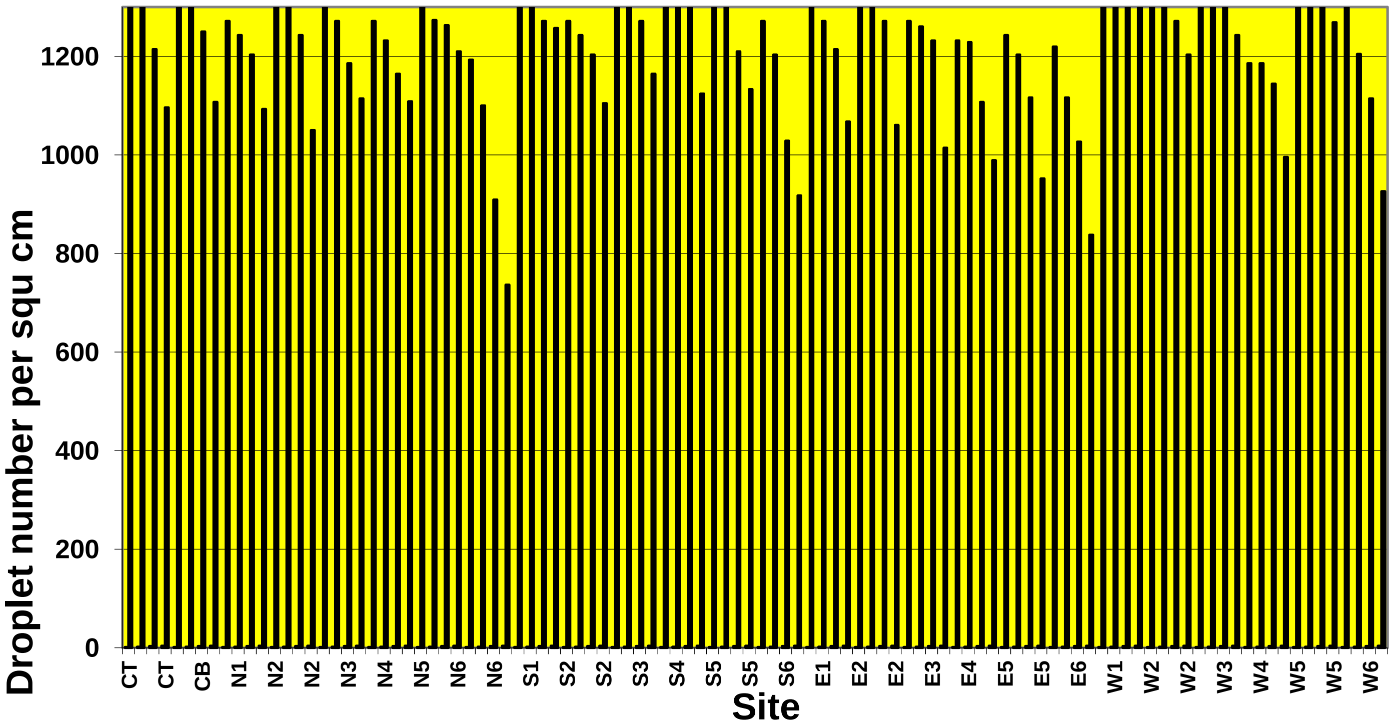


Figure 2: Treatment 3 - engine driven twin fan airblast, fine nozzles, medium trees.

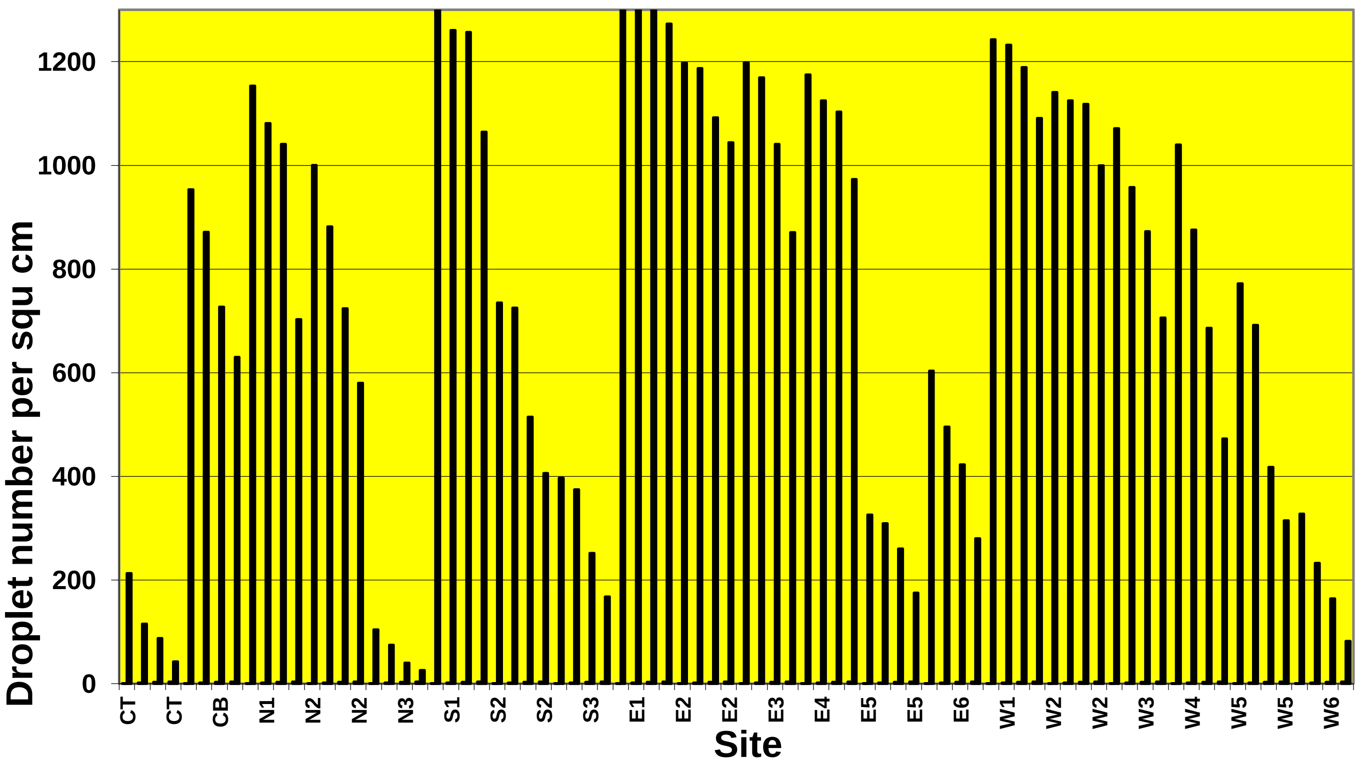


Figure 3: Treatment 4 - PTO driven twin fan airblast, standard nozzles, and medium trees.

Engine Driven Twin Fan airblast sprayer on Almonds

Spraying date: 4 November 2011

Large Trees - Non Pariel
Tree Heigth 9.2 m
Canopy Height: 7.7 m
Canopy width 6.8 m
Canopy Density - Sparse - Medium
Hedgerow
Row spacing 6.7 m, rows run NS

Small Trees - Non Pariel
Tree Heigth 5.8 m
Canopy Height: 5.0 m
Canopy width 6.0 m
Canopy Density - Medium
Single trees almost touching
Row spacing 6.7 m, rows run NS

Temp 24 deg C, Wind 0.3 m/s from NE 0.3 m/s, min 0 max 1.1, Zero in orchard

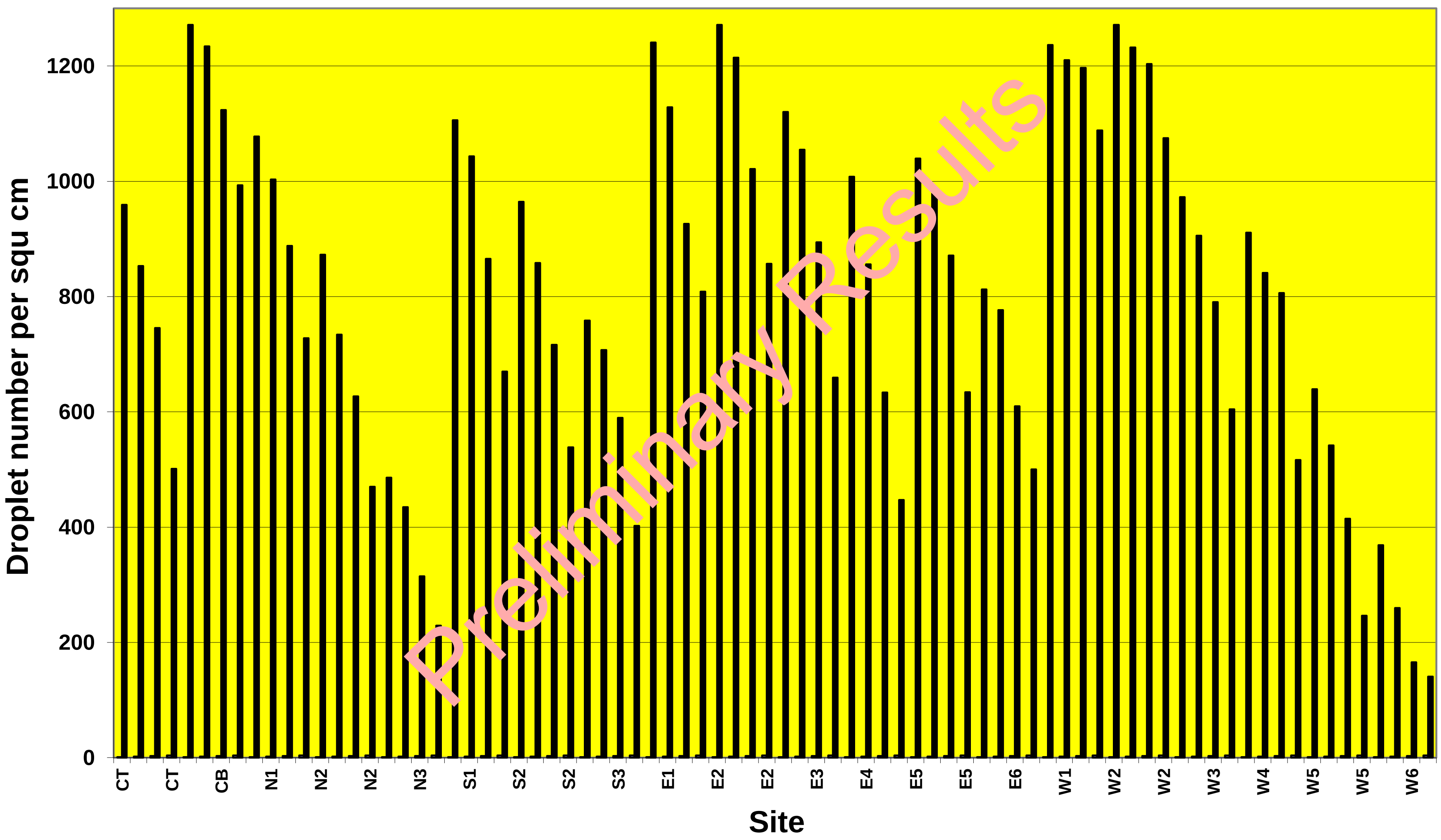
TREATMENTS
Standard Nozzle array - large trees
Total F = 86 L/min
Spraying Speed, 5.5 km/h
Pump pressure 12.4 bar (180 psi)
L/100m = 98.5, L/100m/m canopy height = 12.8 (1470 L/ha)
Note - L/100m from flow rate differs from rate calculated from L/ha from tractor
L/Ha from tractor used because compensates for changes in pressure and flow rate

Fine Nozzle array - large trees
Total F = 86 L/min
Spraying Speed, 5.5 km/h
Pump pressure 10.3 bar (150 psi)
L/100m = 100.5, L/100m/m canopy height = 13.1 (1500 L/ha)
Note - L/100m from flow rate differs from rate calculated from L/ha from tractor
L/Ha from tractor used because compensates for changes in pressure and flow rate

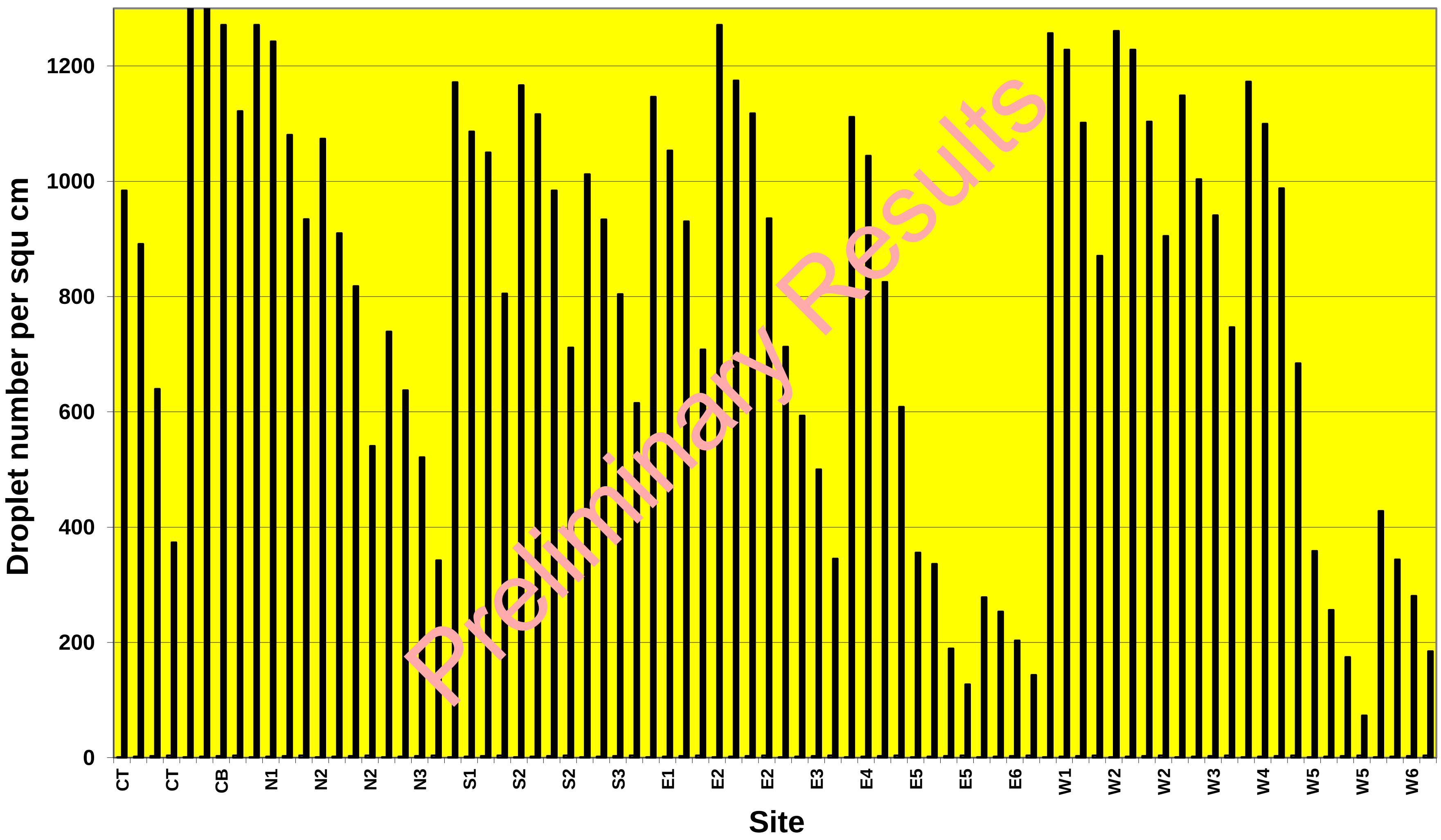
Fine Nozzle array - small trees
Total F = 78.6 L/min
Spraying Speed, 5.5 km/h
Pump pressure 12.4 bar (180 psi)
L/100m = 86.4, L/100m/m canopy height = 17.3 (1290 L/ha)
Note - L/100m from flow rate differs from rate calculated from L/ha from tractor
L/Ha from tractor used because compensates for changes in pressure and flow rate

Preliminary Results

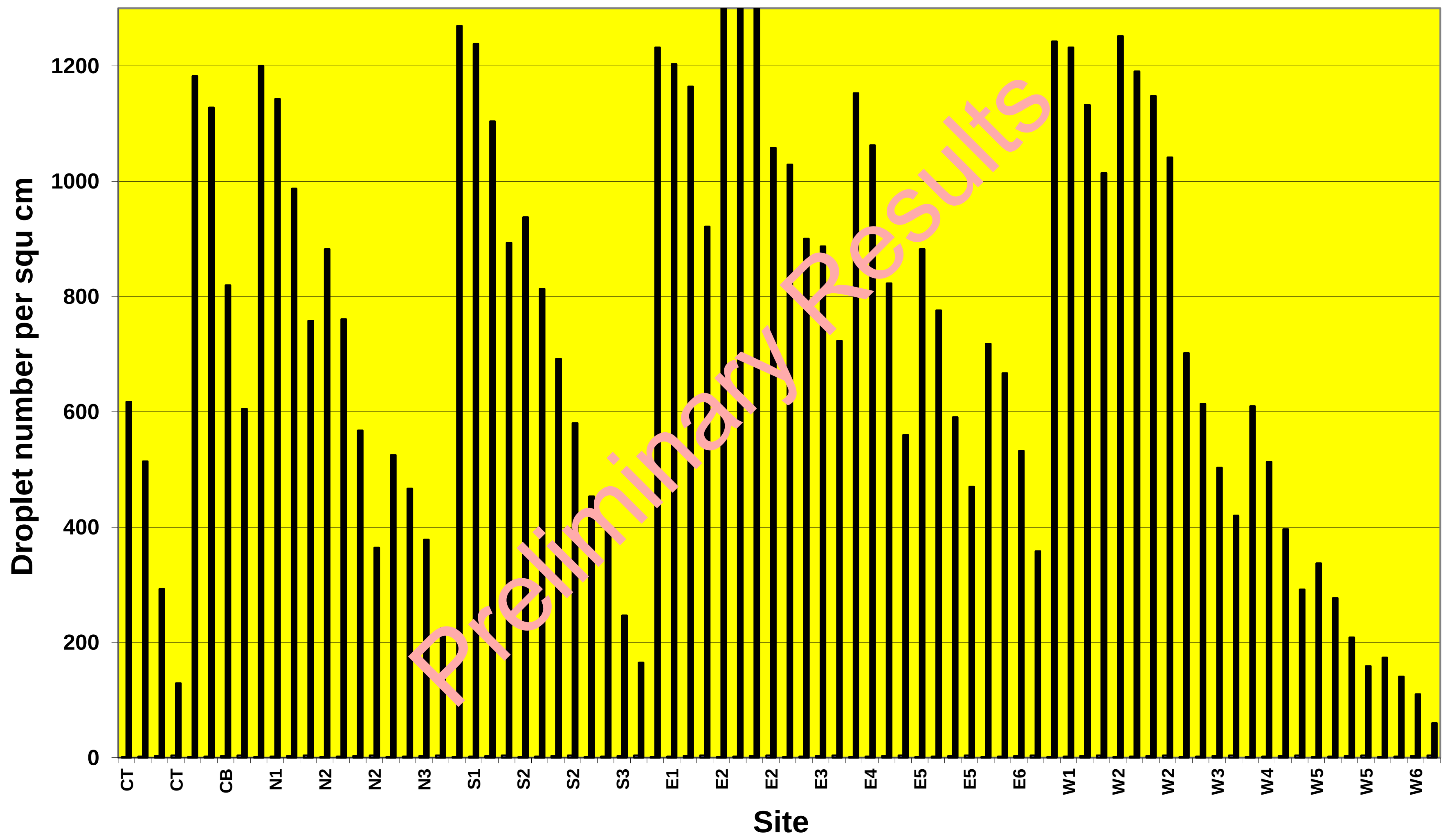
Engine Driven Twin Fan, std fine nozzles, large trees, ULS



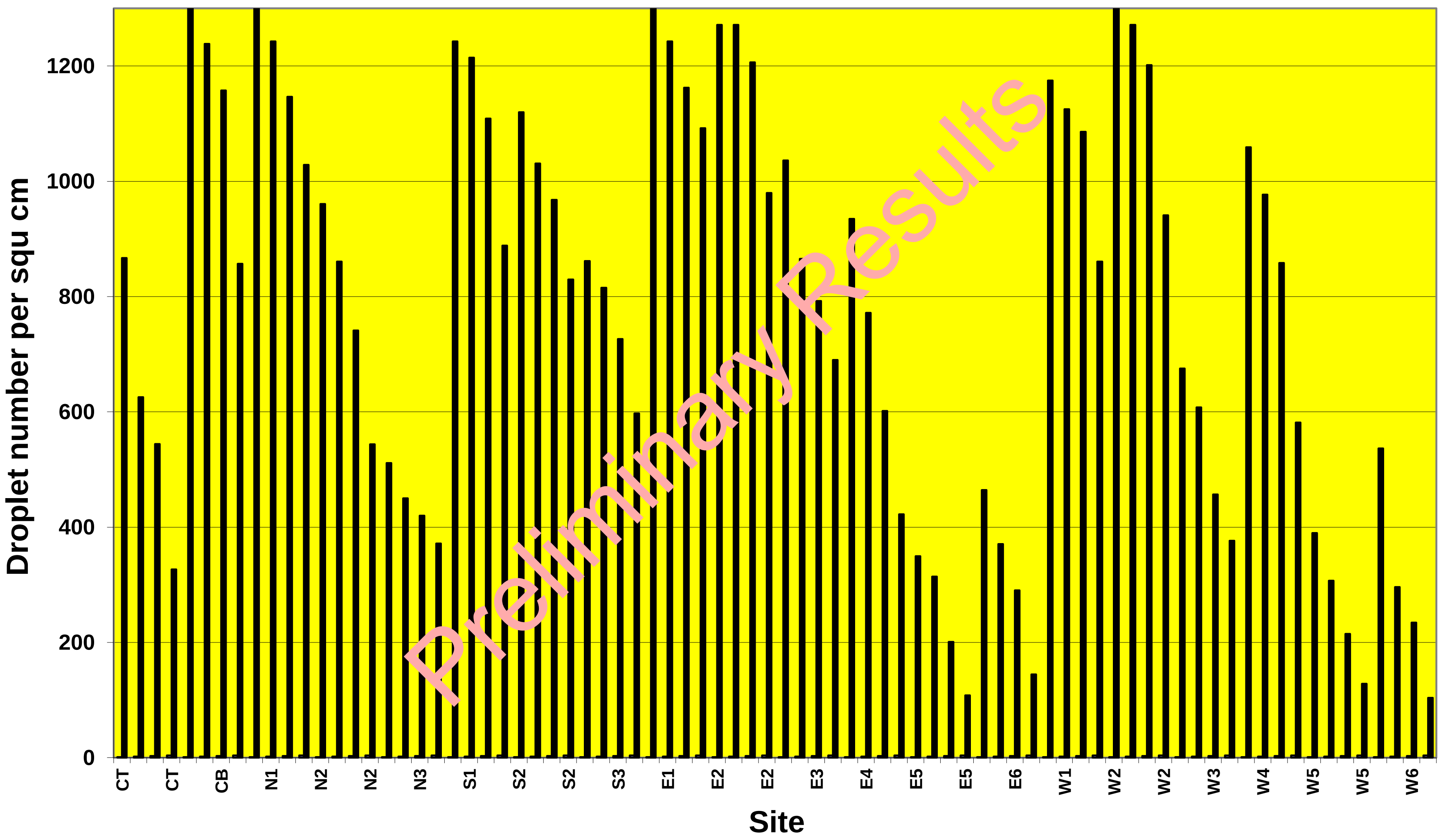
Engine Driven Twin Fan, std fine nozzles, large trees, LLS



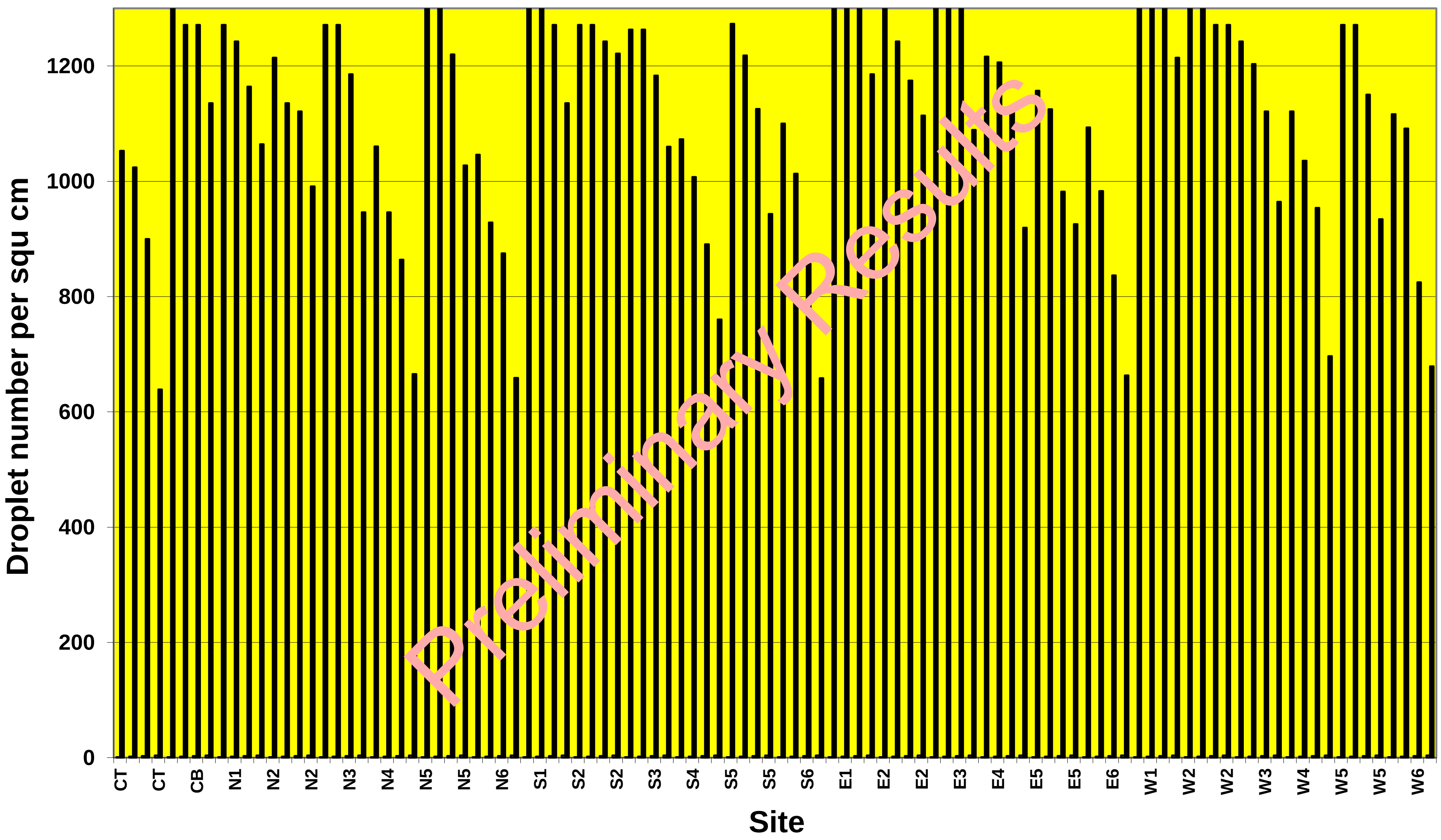
Engine Driven Twin Fan, very fine nozzles, large trees, ULS

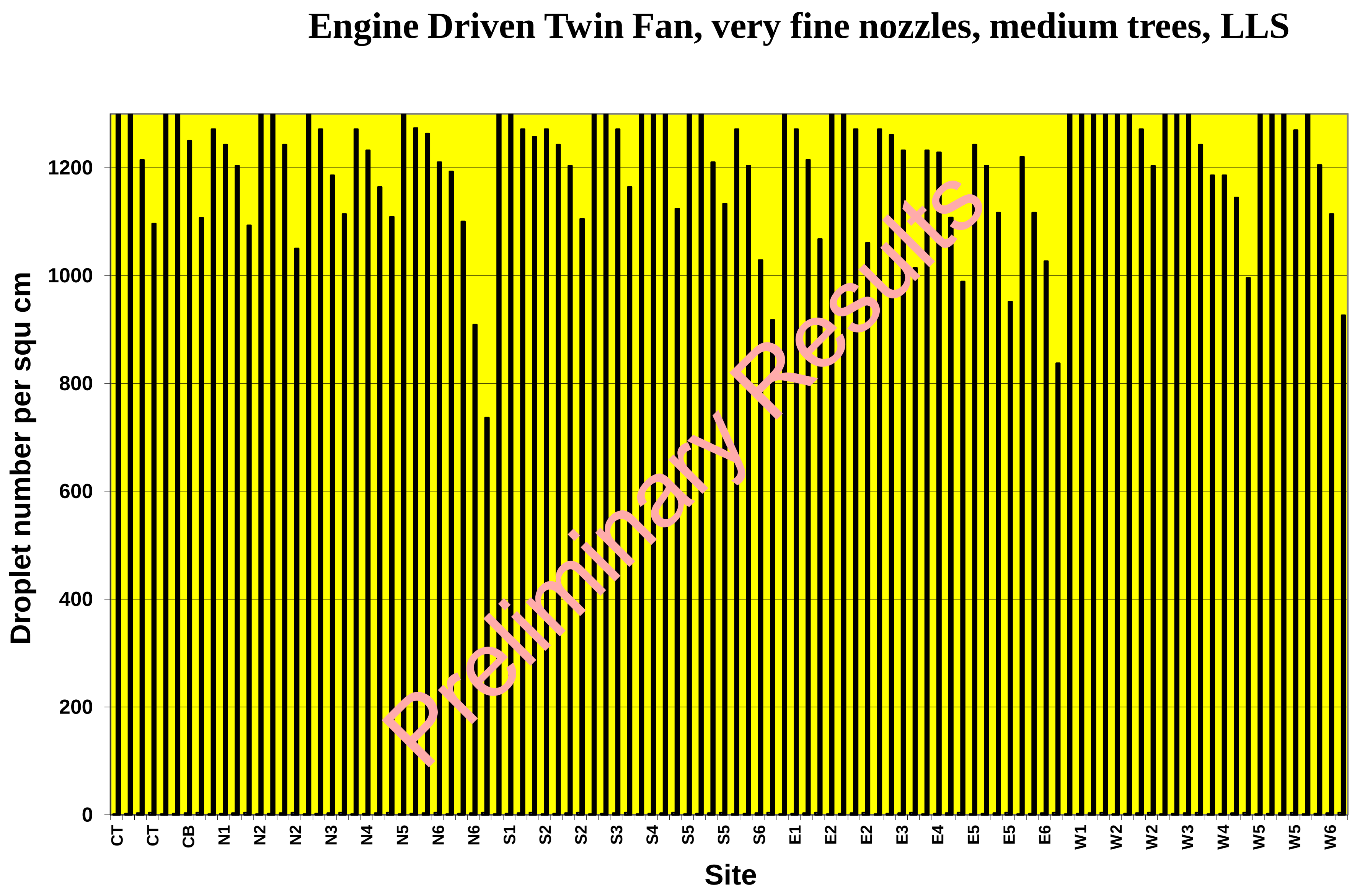


Engine Driven Twin Fan, very fine nozzles, large trees, LLS

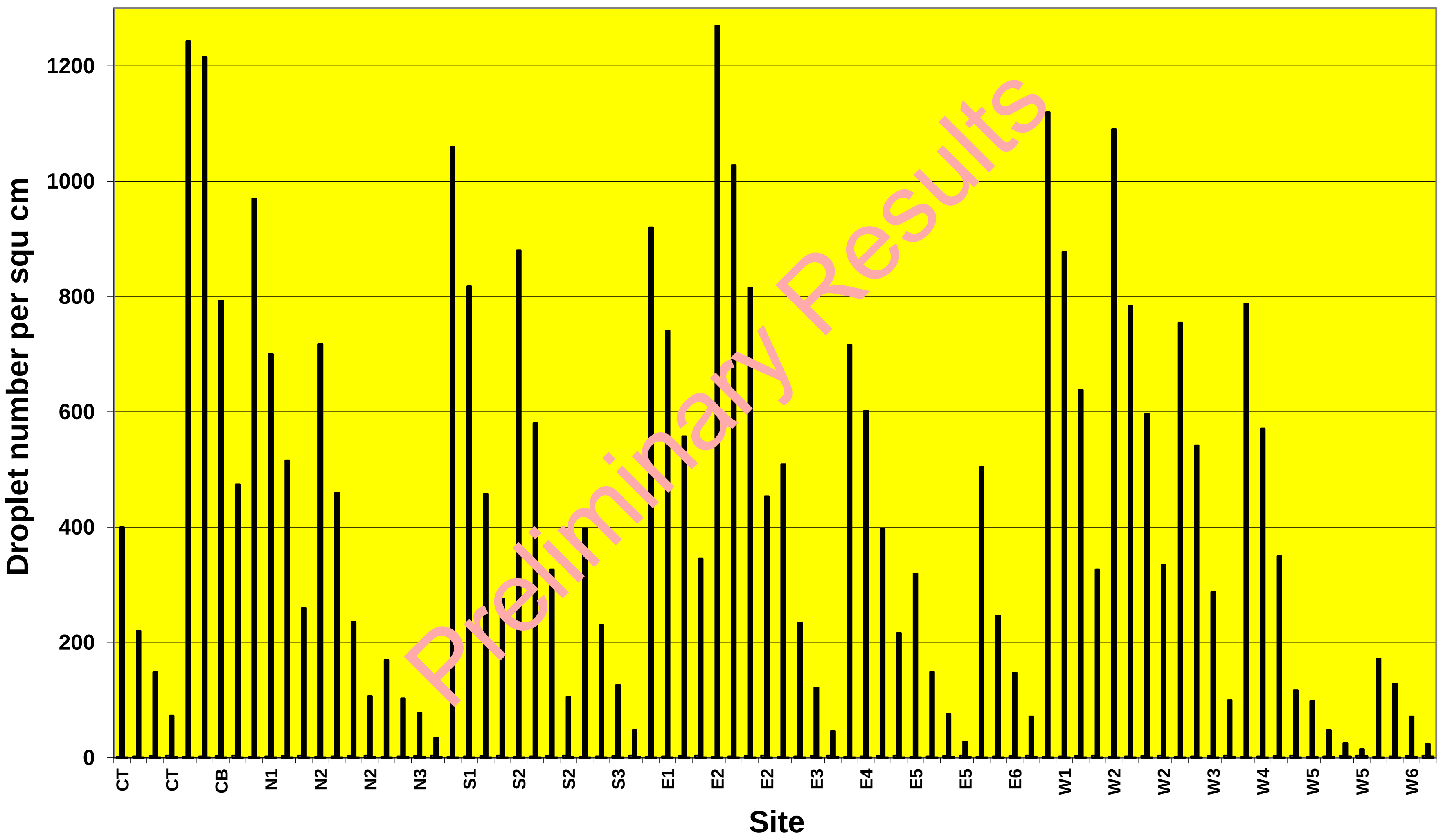


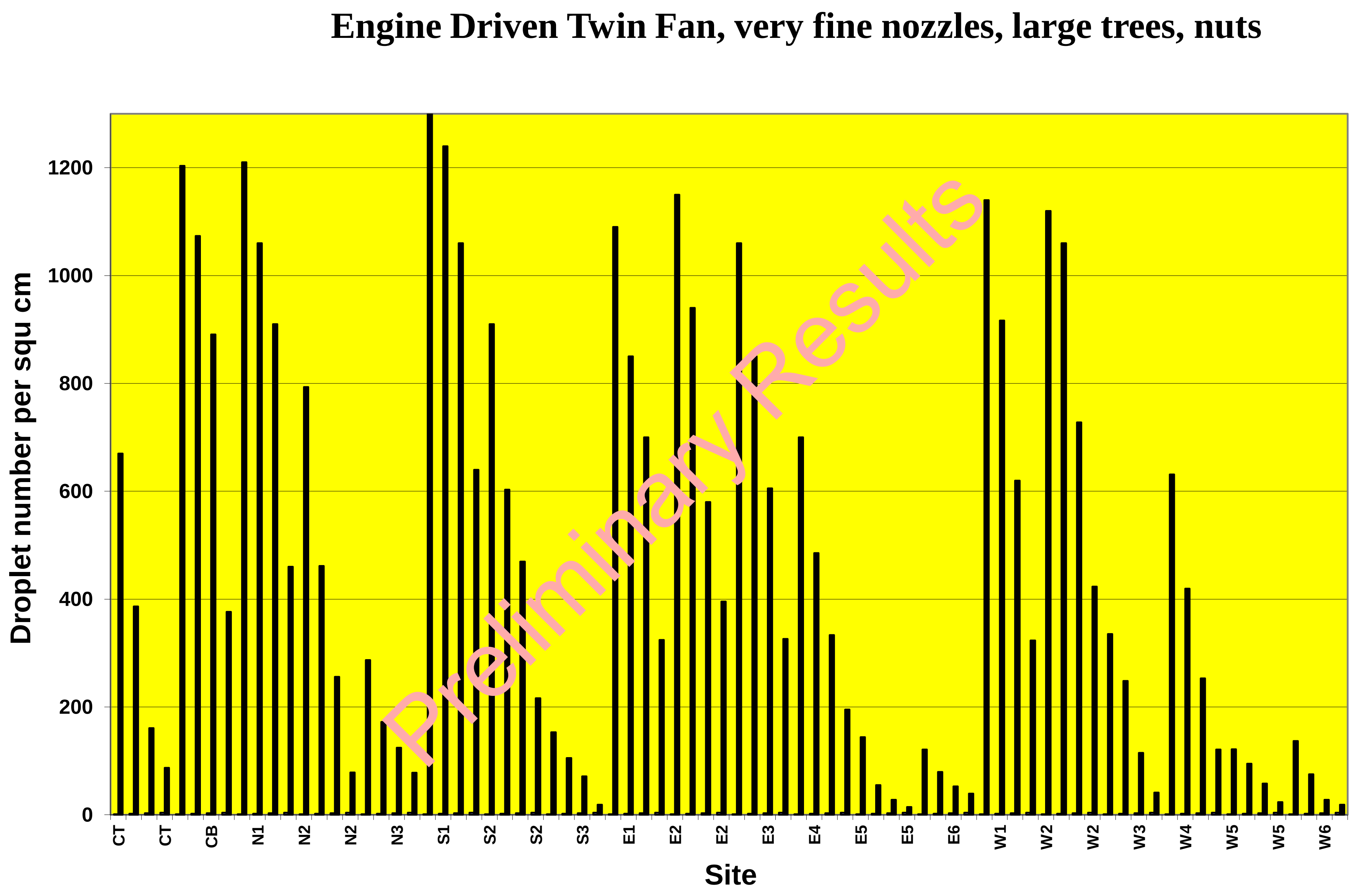
Engine Driven Twin Fan, very fine nozzles, medium trees, ULS




Engine Driven Twin Fan, very fine nozzles, medium trees, LLS
Droplet number per squ cm
0
200
400
600
800
1000
1200
CT
CT
CB
N1
N2
N2
N3
N4
N5
N6
N6
S1
S2
S2
S3
S4
S5
S5
S6
E1
E2
E2
E3
E4
E5
E5
E6
W1
W2
W2
W3
W4
W5
W5
W6
Site
Preliminary Results

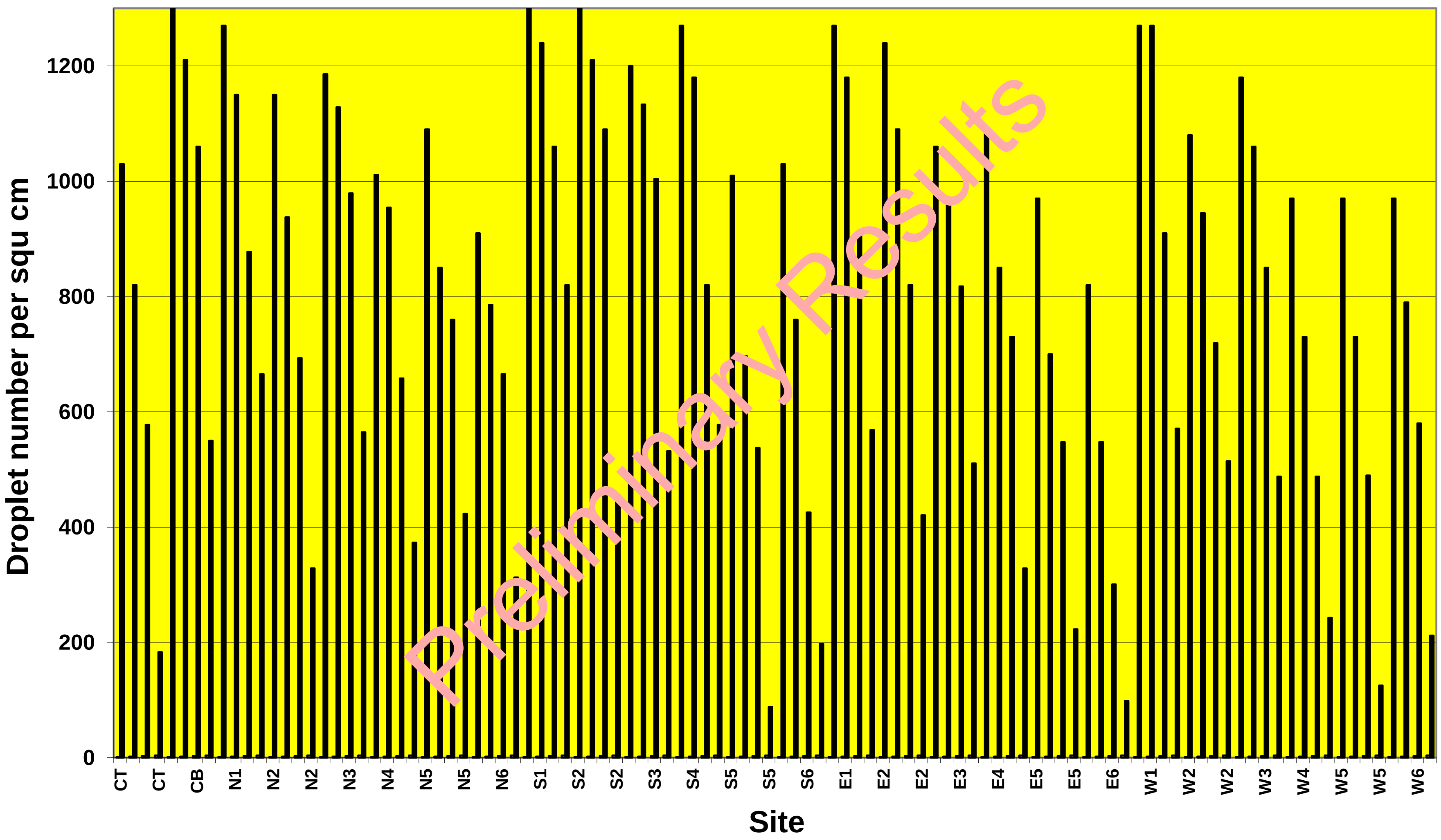
Engine Driven Twin Fan, Std fine nozzles, large trees, nuts





Engine Driven Twin Fan, very fine nozzles, large trees, nuts
Droplet number per squ cm
0
200
400
600
800
1000
1200
CT
CT
CB
N1
N2
N2
N3
S1
S2
S2
S3
E1
E2
E2
E3
E4
E5
E5
E6
W1
W2
W2
W3
W4
W5
W5
W6
Site
Preliminary Results

Engine Driven Twin Fan, very fine nozzles, medium sized trees, nuts



Airblast sprayers on Almonds

Spraying date: 22 November 2011

Medium Trees - Non Pariel
Tree Heigth 6.0 m
Canopy Height: 4.5 m
Canopy width 6.5 m
Canopy Density - Medium
Hedgerow
Row spacing 7.25 m, rows run NS

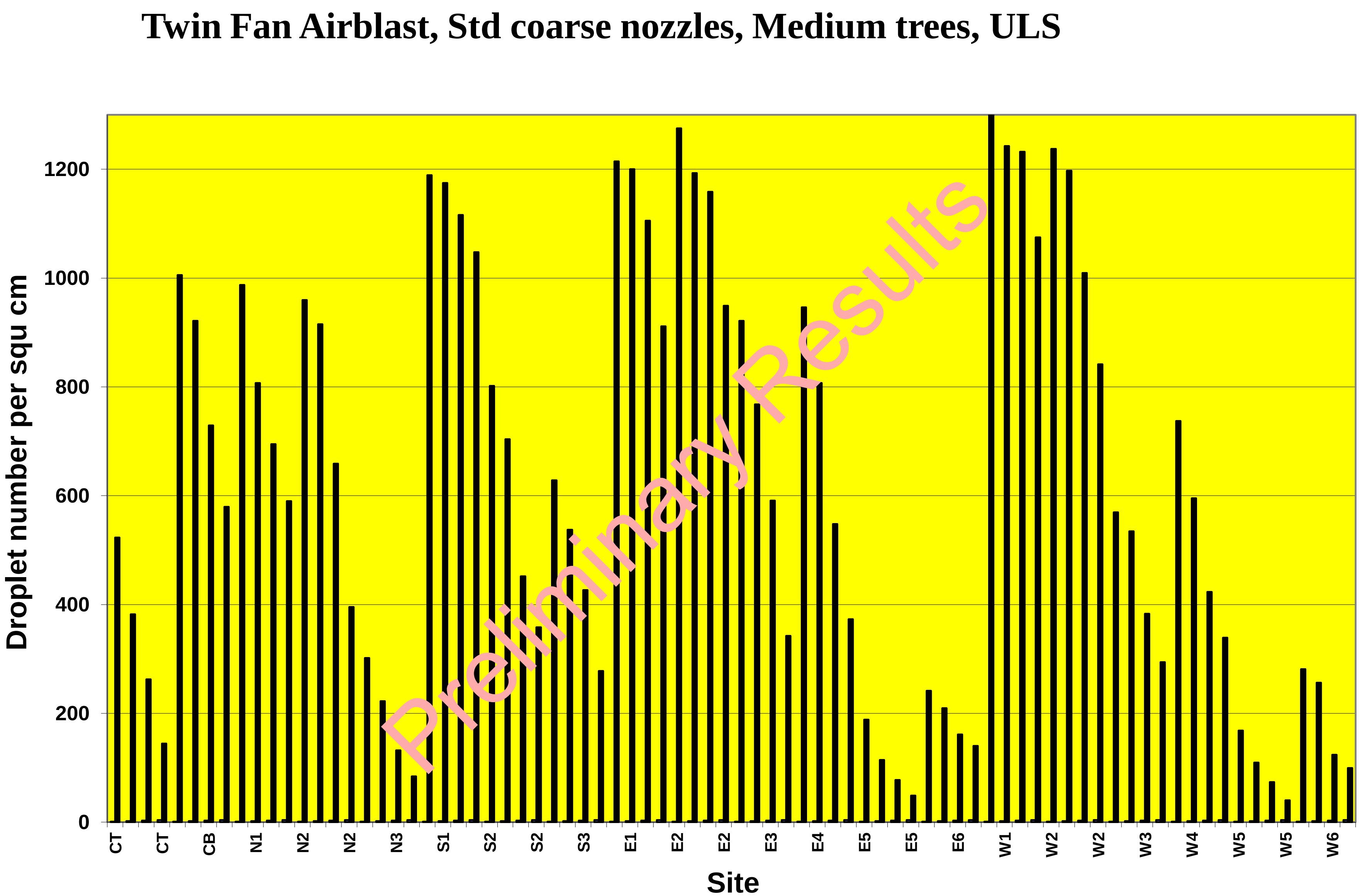
Temp 23 deg C, Wind 1.2 m/s from NE 0.3 m/s, min 0 max 1.2, Zero in orchard

TREATMENTS

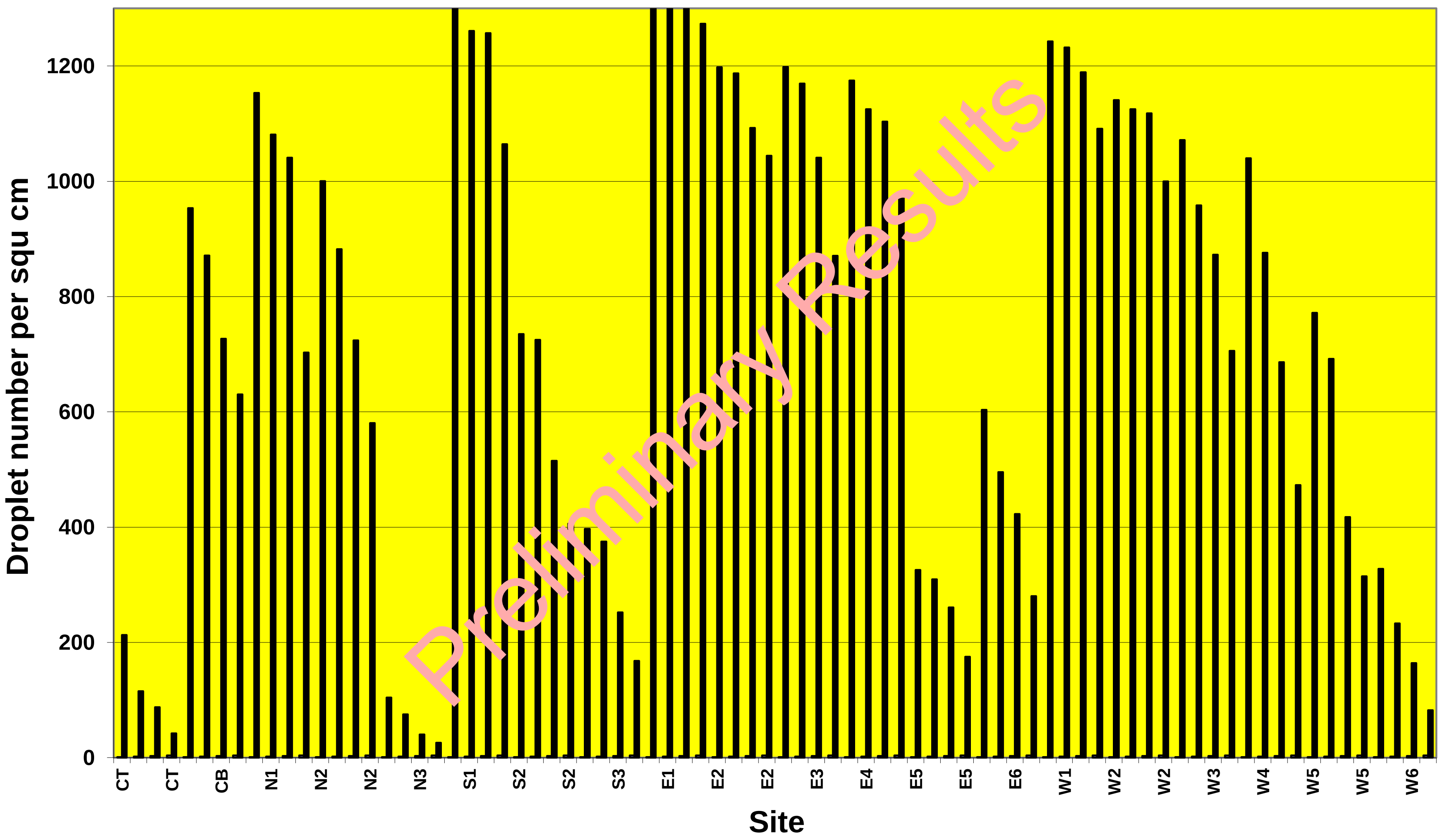
Twin fan airblast sprayer
Standard Nozzles
Total F = 70 L/min
Spraying Speed, 5.5 km/h
Pump pressure 6.0 bar (86 psi)
L/100m = 87, L/100m/m canopy height = 19.3 (1200 L/ha)

Single large fan, airblast sprayer
Standard Nozzles
Total F = 70 L/min
Spraying Speed, 5.5 km/h
Pump pressure
L/100m = 87, L/100m/m canopy height = 19.3 (1200 L/ha)

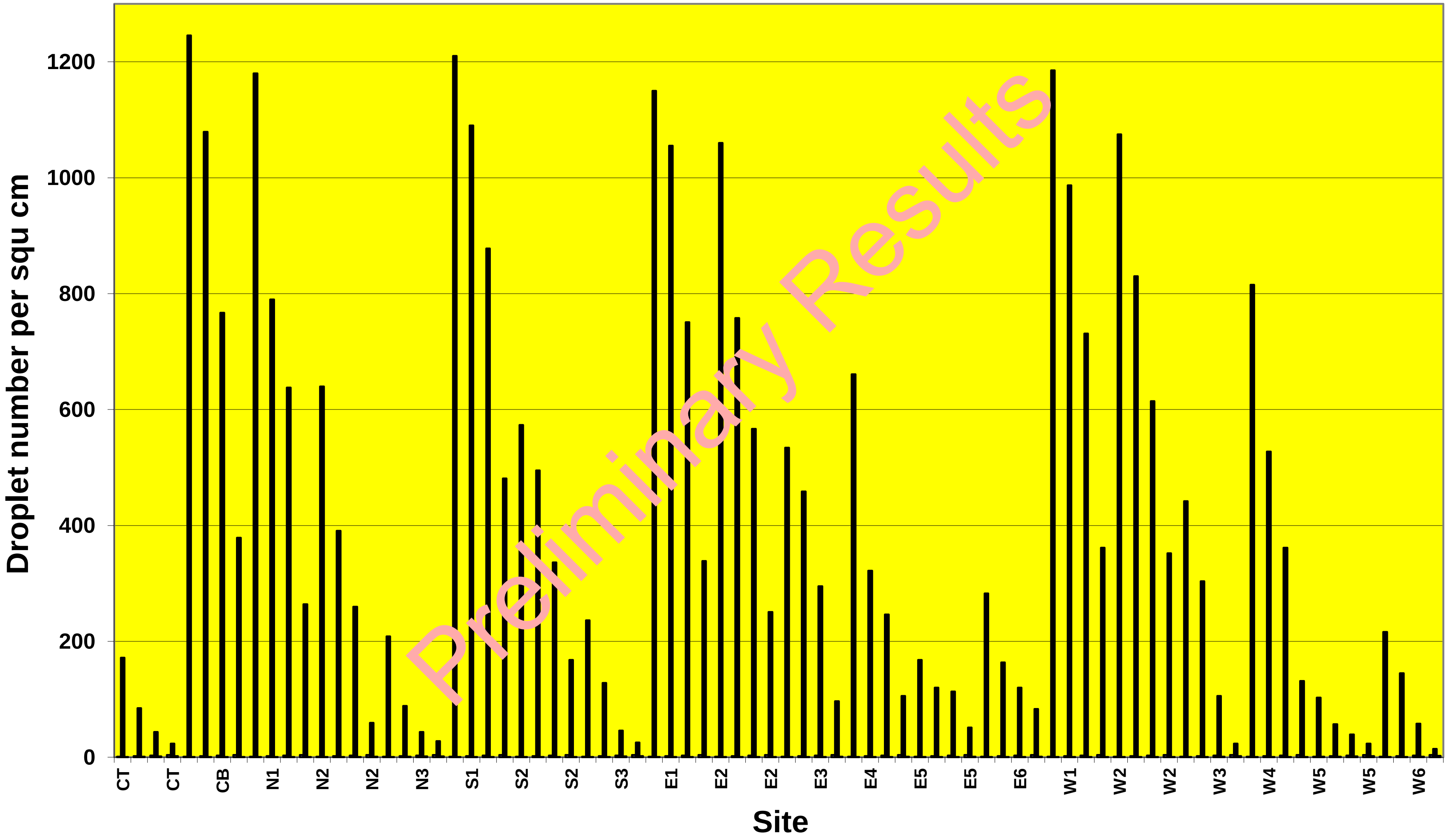
Preliminary Results

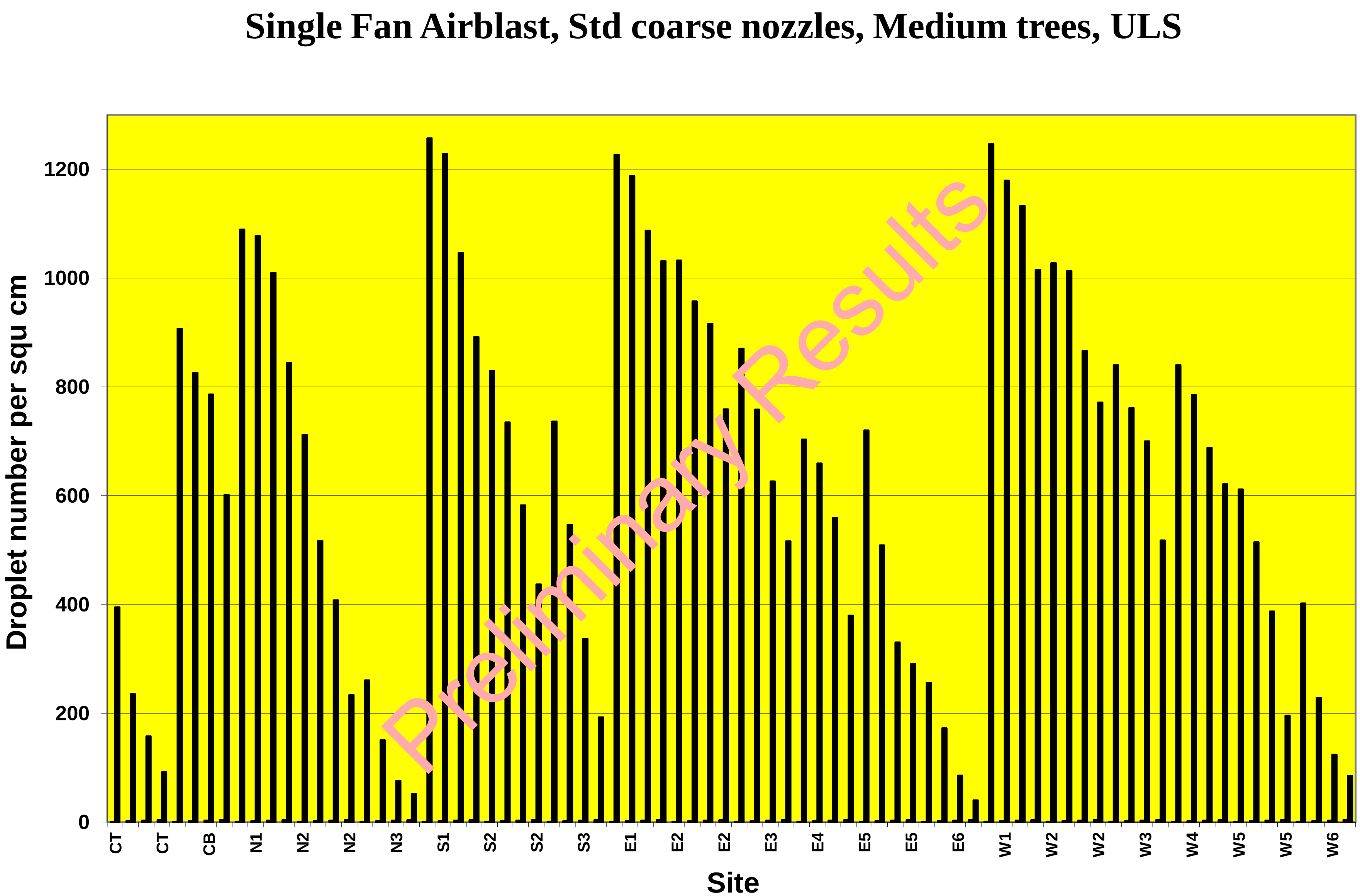

Twin Fan Airblast, Std coarse nozzles, Medium trees, ULS
Droplet number per squ cm
0
200
400
600
800
1000
1200
CT
CT
CB
N1
N2
N2
N3
S1
S2
S2
S3
E1
E2
E2
E3
E4
E5
E5
E6
W1
W2
W2
W3
W4
W5
W5
W6
Site
Preliminary Results

Twin Fan Airblast, Std coarse nozzles, Medium trees, LLS

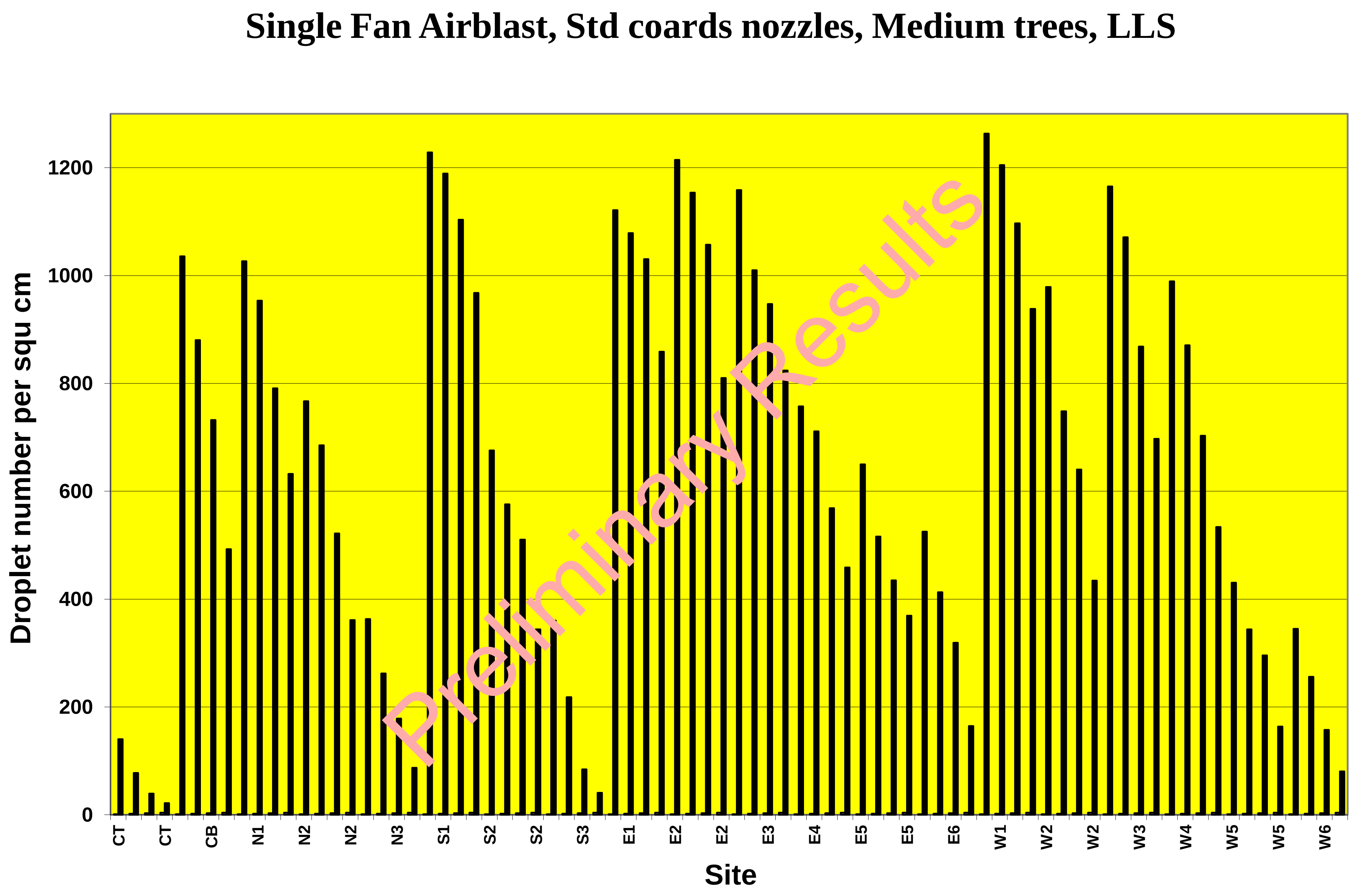


Twin Fan Airblast, Std coarse nozzles, Medium trees, nuts



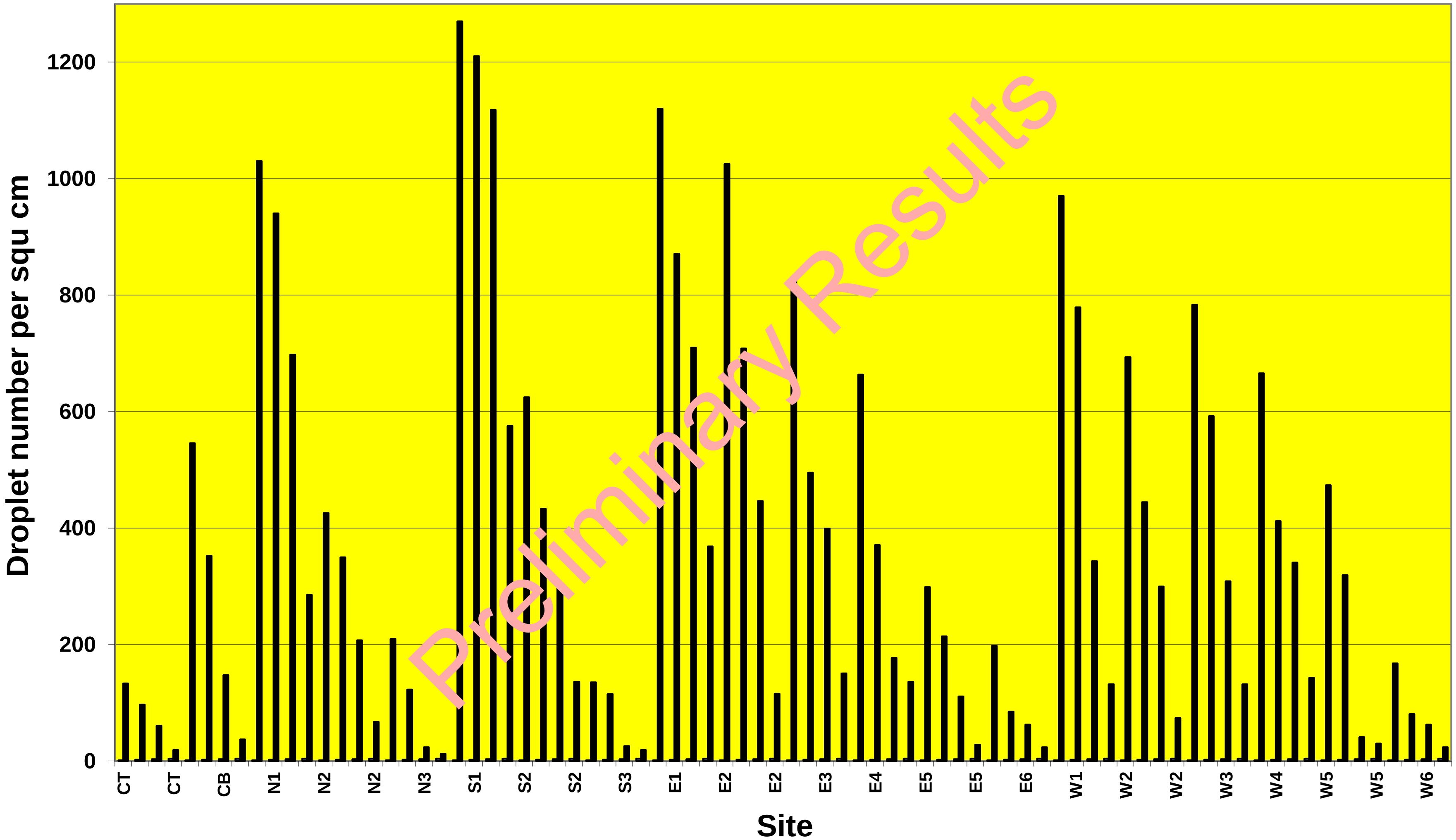


Single Fan Airblast, Std coarse nozzles, Medium trees, ULS
Droplet number per squ cm
0
200
400
600
800
1000
1200
CT
CT
CB
N1
N2
N2
N3
S1
S2
S2
S3
E1
E2
E2
E3
E4
E5
E5
E6
W1
W2
W2
W3
W4
W5
W5
W6
Site
Preliminary Results



Single Fan Airblast, Std coards nozzles, Medium trees, LLS
Droplet number per squ cm
0
200
400
600
800
1000
1200
CT
CT
CB
N1
N2
N2
N3
S1
S2
S2
S3
E1
E2
E2
E3
E4
E5
E5
E6
W1
W2
W2
W3
W4
W5
W5
W6
Site
Preliminary Results

Single Fan Airblast, Std coarse nozzles, Medium trees, nuts



Appendix 3 – Managing House Mice for the Australian Almond Industry

CSIRO

www.csiro.au

Managing house mice for the Australian Almond Industry

Peter Brown, CSIRO Ecosystem Sciences

October 2011

Consultancy Report prepared for the Almond Board of Australia

Enquiries should be addressed to:
Dr Peter R. Brown
CSIRO Ecosystem Sciences
GPO Box 1700
Canberra ACT 2601

Acknowledgements

This publication has been funded by HAL using the Australian almond industry levy and a voluntary contribution from the Almond Board of Australia and matched funds from the Federal Government (HAL Project AL09021).

This report has been developed and distributed for stakeholders of the Australian almond industry

Preferred citation

Brown, P. R. (2011). *Managing House Mice for the Australian Almond Industry*. Consultancy Report prepared for the Australian Almond Industry. CSIRO Ecosystem Sciences, Canberra. 52 pp.

Copyright and Disclaimer

© 2011 CSIRO To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

Important Disclaimer

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Contents

List of Figures

List of Tables

1. EXECUTIVE SUMMARY

1. CSIRO was engaged by The Almond Board of Australia (ABA) to provide advice about their rodent control practices for the Almond industry in and around the Sunraysia region (Mildura, Victoria), and the Riverland region (Renmark, South Australia). A visit was conducted from Monday 5 September to Thursday 8 September 2011. The ABA were primarily concerned about the damage that the current mouse plague is causing to almond orchards, and damage and contamination to shelling and hulling and processing facilities.

2. The objective of the consultancy was to review the existing management practices and to consider a range of alternative management practices to reduce direct damage to almonds (from flowering, to bud development, through to harvest) and to consider a range of management practices for the shelling/hulling and processing facilities to reduce damage and potential contamination of the almond product.

3. A series of seminars and site visits were conducted for almond growers, hullers, shellers and packers describing general principles of mouse control and general information about house mice. Through discussions with growers, hullers, shellers and packers, a series of mouse control options are described to improve mouse control operations, to reduce damage and to reduce contamination from Salmonella.

4. House mice (*Mus domesticus*) have caused significant damage to almond orchards and in hulling/shelling and processing facilities over the last 18 months or so. There has been a widespread increase in house mice over much of southern and eastern Australia following good rainfall conditions in 2010, prompting grass and weed growth and stimulating mouse breeding. Mice have also increased in broadacre farming systems and many grain farmers have suffered significant damage. Densities of mice have been high and it is unknown when they will decline. There is currently no direct ongoing monitoring of mouse populations to reliably estimate or predict mouse population abundance and breeding conditions. Some trapping of mice will be conducted shortly, coordinated by GRDC, and the results and predictions for autumn 2012 will be disseminated shortly afterwards.

5. Currently, almond growers and associated industry facilities have been controlling mice using rodentcide baits (zinc phosphide treated wheat grains spread over the ground) or anticoagulant baits (brodifacoum pellets or wax blocks set in bait stations around perimeters of orchards and facilities). Some live traps and sticky traps are being used inside the processing facilities. The facilities utilise the services of commercial pest control operators to control pests, including setting and checking rodent bait stations every 1-2 weeks.

6. Information is provided on the biology and ecology of the three main introduced rodents, house mouse (*Mus domesticus*), black rat (*Rattus rattus*), and the Norway rat (*Rattus norvegicus*). The house mouse is the main pest species in the orchards

and facilities, but information is also provided for the two rat species. Management and control techniques, particularly for house mice, need to be implemented, based on their population dynamics, movements and breeding habits. The mouse population inhabiting the adjacent agricultural fields would largely influence the mouse population in the orchards and processing facilities.

7. A range of control methods (chemical and physical) is provided. An effective rodent control strategy must have clearly defined objectives and be well planned. *In particular, a rodent management plan for the almond industry means all aspects of the almond processing chain, from the orchard, through the shelling/hulling facilities through to the processing facilities work together to minimise or eliminate potential rodent infestations.*

Recommendations

8. *Monitoring* – Regular monitoring of mouse populations in orchards and in and around facilities will help to understand the changing levels of mouse activity and assist with implementing appropriate management. A combined package of monitoring, management and evaluation will mean that management is targeted and preventative rather than reactive. Monitoring procedures using census cards (canola squares) and active burrows is described (Section 5.5).

9. *Management principles* – Management should be conducted over >1,000 ha to minimise reinvasion of mice from surrounding areas. This applies equally to orchards and processing facilities.

10. *Rodenticide baiting* – Baiting is an integral part of mouse management for orchards and in processing facilities. <u>In orchards</u>, bait stations containing anticoagulant rodenticides can be used around the perimeter. Broadacre application of zinc phosphide bait can be used when mouse numbers are considered high and are likely to cause damage to nuts developing in the trees or during harvest. However, the success of zinc phosphide might be reduced because of the availability of high quality alternative food sources (eg the almond nuts). Because of bait shyness problems, zinc phosphide should not be used within 3 months of a previous application.

    <u>In hulling/shelling and processing facilities</u>, bait stations containing anticoagulant rodenticides can be used around the perimeter of the facilities and on the external walls of sheds etc. It is not possible to use rodenticide poisons within food handling areas. Bait stations must be set correctly against the walls of the sheds and facilities to increase the chance of a mouse encountering and being caught in them.

11. *Mouse trapping* – Trapping can be a very useful control technique inside the hulling/shelling and processing facilities. Sticky traps are being used in some circumstances, and their use should cease because of animal welfare concerns. Live traps or snap traps should be used. Traps must be set correctly against the

walls of the sheds and facilities to increase the chance of a mouse encountering and being caught in them.

12. *Drift fence around perimeter fence* – A drift fence (made from lengths of shade cloth/silt fence) could be used to direct mice into the bait stations around the perimeter of the facilities.

13. *Manage adjacent habitats* – This applies to both orchards and processing facilities. Weeds and long grass should be mown and slashed to reduce cover and food for mice. Also piles of rubbish need to be cleaned up and removed so mice cannot use them as shelter. In addition spills of almonds should be cleaned up so they do not provide a food source for mice.

14. *Management of mice in adjacent agricultural land* – Baiting of adjacent agricultural fields using a registered in-crop rodenticide (eg zinc phosphide) should be considered if high densities of mice exist. This may prevent movements of mice into orchards and facilities after harvest of surrounding wheat crops if the mouse population density is high. A range of farm management practices can also be used to reduce the population abundance of mice in the nearby wheat fields.

15. *Mouse-proof fence* – Consider constructing a mouse-proof fence around the processing facilities. There are some disadvantages with these fences, but if they are constructed well, they can be effective, particularly when mouse abundance is high.

16. *Mouse-proofing of facilities* – Proofing can be used to minimise the chance or even prevent rodents from entering certain facilities. Concrete or metal skirting should be installed along the bottom of all warehouse walls to prevent access by mice.

17. *Outside lighting* – External lighting can be used to deter rodents from open areas. Some lighting already exists, but could be used strategically around doorways and access points to warehouses and sheds.

18. *Management actions during a mouse plague* – When mouse densities are high:

    a. Apply rodenticide over surrounding fields to reduce resident mouse population abundance (obtain necessary approvals and permissions);

    b. Set and check anticoagulant bait stations at least every week;

    c. Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors);

    d. Lift and store pallets off the ground, particularly for valuable almond products; and

    e. Keep external access doors shut at night to limit entry by mice to the storage areas.

2. PROJECT AIMS AND OBJECTIVES

CSIRO was engaged by The Almond Board of Australia (ABA) to provide advice about their rodent control practices for the Almond industry in and around the Sunraysia region (Mildura, Victoria), and the Riverland region (Renmark, South Australia). The ABA were primarily concerned about the damage that the current mouse plague is causing to almond orchards, and damage and contamination to shelling and hulling and processing facilities. Currently, almond growers and facilities have been controlling mice themselves using rodenticide baits (zinc phosphide treated wheat grains spread over the ground) or anticoagulant baits (brodifacoum pellets or wax blocks set in bait stations around perimeters of orchards and facilities). Some live traps and sticky traps are being used inside the processing facilities. The facilities utilise the services of commercial pest control operators to control pests, including setting and checking rodent bait stations every 2 weeks or so. The objective of the consultancy was therefore to review the existing management practices and to consider a range of alternative management practices to reduce direct damage to almonds (from flowering, to bud development, through to harvest) and to consider a range of management practices for the shelling/hulling and processing facilities to reduce damage and potential contamination of the almond product.

2.1 Terms of Reference

The ABA requested that CSIRO conduct seminars and site visits, which would serve as the basis for a rodent control strategy. The ABA sought expert advice on what they should or could be doing above and beyond what is presently taking place. The specific activities were:

1. A seminar/workshop/field day for grower, huller and shellers, and packers describing some general principles about mice, mouse plagues, and how this may relate to almond orchards. This might include mouse biology, models, behaviour, food types, foraging behaviour, food safety issues, salmonella, etc. Use experience with grain growers to know more about what farmers need to know.

2. There may be some individual huller and shellers, and packers who might like to use CSIRO specialist services regarding site specific visits, control options, auditing, etc.

2.2 Activities undertaken

Dr Peter Brown (CSIRO Ecosystem Sciences) conducted a range of seminars and site visits with the support of Ben Brown of the Almond Board of Australia from Monday 5 September to Thursday 8 September 2011.

Dr Peter Brown has 18 years direct experience in developing management practices for the control of house mice in Australia, and has extensive experience in developing practical rodent control strategies for farmers in Southeast Asia (Vietnam, Indonesia, Laos and Burma). Dr Brown has published 75 refereed scientific articles, 67 of which related to rodent management (includes 2 books). He has also been involved in 7 consultancies for industry relating to rodent management.

The details are provided below.

Day/date	**Activity**
Monday 5th Sept	Travel from Canberra to Mildura
Tuesday 6th Sept	AM = Sunraysia regional grower, processor & packer seminar PM = Sunraysia regional grower visit(s) PM = Sunraysia regional processor & packer visit PM = Travel from Mildura to Renmark
Wednesday 7th Sept	AM = Riverland regional grower, processor & packer seminar PM = Riverland regional grower visit(s) PM = Riverland regional processor & packer visits
Thursday 8th Sept	PM = Travel from Renmark to Mildura, return to Canberra

3. IMPACT OF HOUSE MICE IN AUSTRALIA

In rural and urban areas of Australia, there are three introduced rodent species that are pests for various industries (agriculture, intensive livestock production such as piggeries, food processing areas) and also present health concerns in terms of transfer of diseases. In particular, rodents can cause problems in food processing and storage areas through (Figure 1):

1. Direct consumption of food;
2. Food contamination and damage;
3. Loss of consumer confidence and damaged public relations;
4. Structural damage;
5. Disease transmission to workers and consumers (eg Leptospirosis; Salmonellosis); and
6. Costs associated with pest control operations.

Figure 1. Left: Rodent gnawing on a domestic garden hose. Right: Rodent damage to an electric power lead (source: http://www.greenpest.com.au/rodents.htm#Mice).

3.1 The house mouse

The house mouse (*Mus domesticus*) is a serious pest to agriculture in Australia. Mouse populations occasionally undergo widespread eruptions (= mouse plagues) in the grain-growing regions of Australia. In 1993/94, a mouse plague caused losses estimated at up to $100 million (Caughley et al. 1994). The impact to food processing areas and other industries during mouse plagues has not been fully assessed, but the impacts during non-plague years can be significant. Mice also reach high numbers in urban areas as a result of favourable conditions. More detailed information about house mice is presented below.

3.2 The black rat

The black rat (*Rattus rattus*) is a common pest species and currently covers most of the temperate areas in eastern Australia where the habitat has been disturbed by humans. It is common in both disturbed bushland and in urban areas. In disturbed bushland, *R. rattus* appears to occupy empty niches, rather than competing directly with native rodents. In urban areas they often occupy buildings, nesting in wall cavities or roofs, hence their other common name, the roof rat. Nests may be made in burrows in the soil and in native vegetation, such as tree-hollows and at the tops of palms. Black rats are also partly arboreal in forests and have been found to prefer dense understorey and deep leaf litter.

3.3 The Norway rat

The Norway rat (*Rattus norvegicus*) is confined to the coastal regions of eastern Australia as well as Hobart and Perth. It occupies disturbed areas, including farms, sewers, drains, refuse tips and bushland edges. These rats frequently infest farm buildings and other rural structures. Burrow systems are constructed on well-drained sites with the entrances hidden beneath cover such as trees or rocks.

In urban areas, rats cause a great deal of damage through their fouling of produce and their ability to gnaw through cables and building materials. The latter increases the risk of fire, electrical and communication outages, and incurs a great deal of cost in repairing the damage.

Both the black rat and the Norway rat also carry human zoonoses that include plague, murine typhus, Lassa fever, leptospirosis and angiostrongyliasis. The control of rat populations is therefore of great concern to councils, wildlife park managers and householders alike.

4. RODENT BIOLOGY AND ECOLOGY

In this section, we describe aspects of mouse biology and ecology (and include some information on rats for comparison) that are relevant for understanding methods for controlling rodents in almond orchards and hulling, shelling, and processing facilities. This knowledge will allow strategies to be specifically developed to meet the needs of the almond industry.

4.1 Mice and rats

The three species of rodents that have been introduced to Australia and described above are of interest as potential pests in almond hulling, shelling and processing facilities. A summary of features that characterise and distinguish these species is presented in Table 1.

Table 1. Summary of some characteristics of the main rodent pests species that are likely to be pests in almond orchards and hulling/shelling/processing facilities.

Characteristic	***Mus domesticus***	***Rattus rattus***	***Rattus norvegicus***
Common name	House mouse	Roof rat, black rat, ship rat	Sewer rat, brown rat
Adult size *HB = head+body, T = tail, W = weight*	HB = 60 - 95 mm T = 75 - 95 mm W = 10 - 20 g	HB = 160 - 205 mm T = 185 - 245 mm W = 95 - 340 g	HB = 180 - 255 mm T = 150 - 215 mm W = 200 - 400 g
Description	Small size. Tail length about same as head+body. Wide range of body colours	Body slightly smaller than *R. norvegicus*, large ears. Tail length longer than head+body.	Body slightly larger than *R. rattus*, large head with small ears. Tail length shorter than head+body.
Litter size	1-10 (Average 5-6)	1-10 (Average 6-7)	1-12 (Average 6-7)
Diet	Omnivorous	Omnivorous	Omnivorous
Nesting habitat	Subterranean, buildings	Building (especially roofs)	Subterranean
Gestation period	19-21 days	20-21 days	20-21 days
Age at sexual maturity	5-8 weeks	8-10 weeks	8-10 weeks
Breeding season in fields	October-April	Not known	Not known
Feeding habitat	Fields, buildings	Trees, fields and buildings	Buildings
Neophobic (fear of new objects)	No. Mice will readily explore new items found in their territory or try new types of food.	Yes. Rat will not explore new items or new foods readily.	Yes. Same as for *R. rattus*.
Communication of food preferences to other animals	Rarely	?	Yes

Table 1 continued

Characteristic	*Mus domesticus*	*Rattus rattus*	*Rattus norvegicus*
Effectiveness of 1st generation anticoagulants	Low	Low	High
Colour vision	Colour blind	Colour blind	Colour blind
Sense of smell	Acute	Acute	Acute
Physical abilities	Can squeeze through gaps as narrow as 6 mm, can jump vertically up to 50 cm mm, can fall 2.5 m without injury. Mice can climb almost any surface, which allows them to explore virtually any environment. Excellent swimmer.	Can squeeze through gaps as narrow as 12 m, can jump vertically 1 m, can jump horizontally >1 m, can fall several metres without injury. Excellent swimmer.	Same as for *R. rattus*.
Home range size	Breeding season: 0.04 ha (20x20 m) Non breeding season: 0.12 ha (36x36 m)	Males: 1.1 ha, Females: 1.7 ha	Males: 0.4 ha Females: 0.6 ha

The success of the house mouse (*Mus domesticus*) as a pest species can be attributed to its ability to live in a wide variety of habitats, to its small size, behaviour, reproductive potential and omnivorous feeding habits. Periodic eruptions of house mice (referred to as mouse plagues) cause serious economic damage.

The black rat (*Rattus rattus*) prefers the upper parts of dwellings and is more selective in its diet than the Norway rat, preferring fruits, seeds and grain. The black rat is more agile than the Norway rat, and can easily climb walls and along wires. It is possible that the black rat (*Rattus rattus*) might be present in some of the hulling, shelling and processing facilities, however, the Norway rat (*Rattus norvegicus*) is unlikely to be present. The main pest in orchards and these facilities is the house mouse.

4.2 Food preferences of rodents

The house mouse is omnivorous, consuming seeds, plant material, invertebrates, fungi and other mice. In an urban setting, they would also eat food scraps from compost bins, vegetable garden produce and cat and dog food. They also gnaw on electrical wires, wood frames, soap and cricket bats. They have been blamed for causing house fires (because of their gnawing behaviour on electrical wires). They are neophilic, which means they readily explore new environments and food types.

Black rats are omnivorous, consuming grain, carrion, eggs and human scraps. Rather than eat one type of food at a time, *R. rattus* has been shown to consume a variety of foods, even in the presence of large quantities of one type. In the wild, they readily switch between food types depending on their availability. They are considered neophobic.

Norway rats will eat a wide variety of foods, including human refuse, plant tissue, crustaceans, worms, insects, small mammals, bird eggs and nestlings. However, they will not readily take new food types (neophobic).

4.3 Biology and breeding of mice

In the field, house mice have a reasonably well-defined breeding season. It commences early in spring after good rainfall has promoted growth of important food resources that can trigger breeding. It seems that the quality, not quantity, of the food is important in triggering breeding activity. Mice continue breeding through summer and into early winter. Breeding continues provided there is sufficient high quality food available.

Mice have an ability to increase rapidly in population size in a very short period of time. Theoretically, one breeding pair of mice can produce 500 mice within 21 weeks. Female mice become reproductively mature at 5-8 weeks of age. They come into breeding condition immediately after giving birth and so become pregnant again within 2 days of delivering their litter. Since the gestation period is only 3 weeks, a female is capable of producing as many as ten litters or about 50-70 young during a field breeding season (September – April). In the wild, females generally produce 2-5 litters per year. The reproductive capacity of rats is similar although they take slightly longer to reach sexual maturity.

4.4 Population dynamics

The abundance of rodent populations is dictated by:

Factors that increase rodent populations:

- breeding activity; and
- movements of rodents into the area (immigration).

Factors that decrease rodent populations:

- deaths; and
- movements of rodents away from the area (emigration).

In the context of the almond industry (orchards and processing facilities), rodent control would need to be achieved by:

- killing animals;
- preventing them from entering the facility; and or
- denying them places for nesting and breeding.

Control strategies should therefore target mouse populations as outlined in Section 6 and 7.

The population dynamics of house mice living in irrigated farms around Coleambally, NSW, have been assessed as part of a project to determine the effects of farm management practices on mouse populations. This work was funded by the Natural Heritage Trust through the National Feral Animal Control Program, administered by the Bureau of Rural Sciences. These data show that mouse populations peak in early winter after breeding has ceased (around April each year), and fall to a minimum in late spring after the breeding season for mice has commenced (around September) (Figure 2).

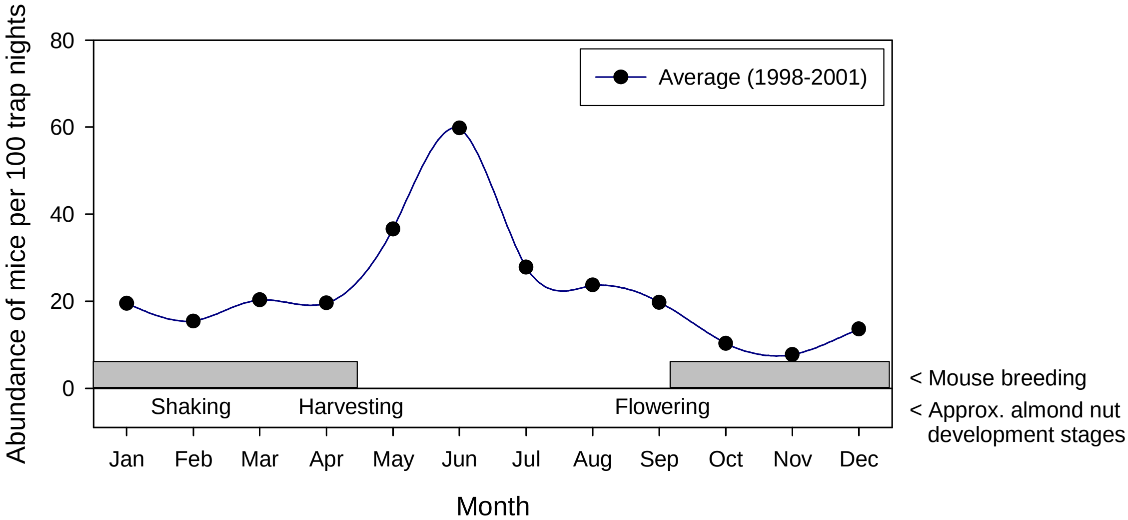


Figure 2. Average abundance of mice (number of mice caught per 100 traps) from farms near Coleambally, Southern NSW, from a project looking at the effectiveness of farm management practices on mice. Mouse population abundance generally peaks in early winter (June) each year and is lowest in late spring (November). The breeding season is indicated by the shaded bars. The approximate timing of almond flowering, development, shaking and harvesting is shown.

4.5 Activity and movements of mice

Mice are generally most active at night. In the field, they emerge from their burrow at sunset to explore and seek food. Once they have fed, they will return to their burrow. They may have a number of feeding bouts during the night, but will return to their burrow before sunrise. Only when densities of mice are high and/or resources are scarce will mice be active during the day. Mice are excellent climbers.

Mice are reluctant to move across open areas of ground. Mice and rats have long hairs along their bodies, which together with their whiskers they use to assist navigation when it is dark. They tend to restrict their movements to along walls and other objects and rarely venture out into open areas. Rats and mice scent-mark their territories with urine and use this marking to establish runways and paths. These pathways are used to move between nesting and feeding sites.

Rats and mice are social animals. During the breeding season, they live in small family groups and maintain territories. These are defended against other animals and groups. The average home range size of mice in wheat fields during the breeding season is roughly half the size of a tennis court (0.04 ha, or about 20 x 20 m). After the breeding season, home-range size increases dramatically (0.12 ha, or about 35 x 35 m). The increase can be as much as tenfold in area, and most mice become nomadic. The reason for this marked change in social organisation is not known but is thought to be linked to either increased mouse densities, reduction in food supply or because non-breeding mice do not need to defend nesting sites. Average daily movements from nest site to feeding areas for mice and for black rats is up to 100 m, but for Norway rats is 50 m.

4.6 Transmission of diseases

Rodent infestations present a health hazard wherever they occur. The nature of the hazard and severity of the risk will vary with the species of rodent and the conditions of the facility. The diseases can be transmitted through direct contact with faecal matter, urine, dead animals, and saliva (through biting), as well as inhalation of contaminated particles (eg disturbance of dust).

A range of bacterial diseases can be transmitted from rodents to humans. These diseases are generally transmitted by direct contact with rodents (saliva or blood through broken skin or bites) or their urine or faeces. These include:

- Salmonellosis (*Salmonella typhimurium*), transmitted by consumption of contaminated faeces.
- Leptospirosis (*Leptospira interrogans*), transmitted through infected urine.
- *Rickettsia* spp. (murine typhus, spotted fever, scrub typhus) transmitted by fleas, ticks and larval mites.

Protozoal diseases are transmitted through eating infected or contaminated food or water:

- Toxoplasmosis (*Toxoplasma gondii*) - the main reservoir/vector of the disease is the domestic cat, but many other animals and birds can be infected. Cats eating insufficiently cooked meat can be infected with the cysts of the disease, or by eating rodents infected with *T. gondii*. The oocysts are then shed in their faeces. These oocysts survive for long periods of time and can be consumed through contaminated food or water.

Nematode and trematode infections (internal worm parasites) can cause disease in humans. The most important is Angiostrongyliasis:

- Angiostrongyliasis (*Angiostrongylus cantonensis*) affects the central nervous system in humans. Food contaminated by the excreta of infected snails may be a source of infection. Infection rates in wild-caught rodents may be high.

Other possible diseases are Cryptosporidiosis (*Cryptosporidium parvum*) and Giardiasis (*Giardia intestinalis*), both of which are microscopic parasites that live in the intestine of humans and animals and can be transmitted by consumption of infected faeces or from contaminated water.

Part of a rodent control strategy should be aimed at reducing the risk of disease transmission. Furthermore, workers involved in checking bait stations, setting traps or cleaning up areas where rodents have been living should be aware of the potential risks of rodent-borne diseases and should take appropriate preventative measures. These include wearing a dust mask in confined areas, wearing disposable plastic gloves when handling dead mice and when checking bait stations, and ensuring that staff wash their hands thoroughly prior to eating food and handling the almond facilities products. Employees should be screened (blood samples) routinely for a number of these diseases.

5. CONTROL OF RODENTS

5.1 Planning a rodent control program

General principles for rodent management are presented here, then details specific for the almond industry (orchards and shelling/hulling/processing facilities) are presented below.

An effective rodent control strategy must have clearly defined objectives and be well planned. The plan should consist of an objective, which for the almond industry, would be no positive salmonella samples. The strategy must include a method of monitoring and regular recording of information so that effectiveness can be determined. Outlined below is a range of rodent control practices that can be conducted.

> A rodent management plan for the almond industry means all aspects of the almond processing chain, from the orchard, through the shelling/hulling facilities through to the processing facilities work together to minimise or eliminate potential rodent infestations.

5.2 Chemical and physical control

There are a number of chemical and physical control techniques available. These are discussed separately. It is important to develop a strategy, which includes a monitoring and recording system in order to determine the effectiveness of a control program.

5.2.1 Chemical control – Baiting

One of the most common methods for controlling mice is to use poison baits. There are different types of baits and depending on what is used, they can be broadcast onto the ground or placed inside bait stations. However, poison bait stations either may not necessarily be the best method available, may be ineffective if used inappropriately, or it may take a few days before an animal that has consumed the poison bait to die thus causing damage or spoiling product prior to death.

There are two categories of rodenticides available:

1. *Acute rodenticides* (fast acting) such as strychnine and zinc phosphide. These are considered fast acting poisons because death usually occurs 20 minutes to 24 hours after ingestion. They generally act by affecting the nervous system or through muscular convulsions leading to asphyxia or sheer exhaustion. The

chance of "bait shyness" is high because of the short period of time from ingestion of the bait and the onset of symptoms of poisoning, and animals can associate their consumption of the bait with the sickness. Bait shy animals will subsequently avoid contact with the bait in the future. There are no antidotes to these acute rodenticides. Zinc phosphide (Zn_3P_2) is readily available and strychnine is available as "Dynamice" ® in South Australia.

2. *Chronic rodenticides* (slow acting) such as Warfarin, a first generation anticoagulant that requires multiple feeds and kills in up to 10 days; and Brodifacoum, a second generation rodenticide that requires only a single feed and kills in 3-7 days after consumption. Anticoagulant poisons block the recycling of the active form of vitamin K that is essential for blood clotting. The animal dies of internal bleeding (haemorrhage). The advantage of the anticoagulant rodenticides is that vitamin K can be administered as an antidote. Bait shyness is rare when using anticoagulants because of the long delay from ingestion of bait and onset of sickness.

The difference between first and second-generation anticoagulants is that the first generation anticoagulants require multiple feeds over many days until a sufficient quantity of poison has been ingested. Rodents generally die within 10 days of ingestion of the bait. Second generation anticoagulants require only a single feed, but death occurs between 3 and 7 days. Different baiting strategies are therefore required for the different types of anticoagulants. If using a first generation anticoagulant, then the bait should be available continuously, whereas, if using a second-generation anticoagulant, a pulse baiting strategy should be used.

Pulse baiting involves leaving bait in stations for at least 3 nights and assessing the amount of bait taken. The bait stations should then be removed (because animals that have fed on the bait have already ingested sufficient poison to die, so there is no point in leaving the bait available for these animals). After a further 7 days, the bait stations should be replenished and left for another 3 nights, replenishing each night if required. When there is little bait taken, baiting should cease, because most rodents should have received a lethal dose or have been killed. This method reduces the chance of rodents eating excess amounts of bait once they have received a lethal dose, therefore reducing the risk of non-target poisoning. However, this technique requires more effort in checking bait stations; this may incur a greater labour cost, but is much cheaper in terms of the quantity of rodenticide used. This technique may not be suitable when >100 bait stations are set, and because most animals will be migrating from surrounding areas (non-residents).

Pre-baiting (using similar base product formulation as the poison bait but without the active ingredient) may be required to obtain effective control of rats because they generally avoid new objects and foodstuffs (neophobia). Pre-baiting allows rats and mice to get used to feeding at a known site and on a particular bait. This ensures that a lethal dose of poison is consumed before illness develops and feeding stops. A sub-lethal dose can lead to "poison shyness" or "bait shyness". The use of the second generation anticoagulants reduces the need for pre-feeding because a single feed of the bait is considered sufficient for a lethal dose.

Rodents are unlikely to consume a lethal dose of a poison if the onset of poisoning is too rapid.

Most of the anticoagulant rodenticide baits in bait stations in orchards and in processing facilities contain Brodifacoum (one of the strongest second generation, single-feed rodenticides available). There is no evidence in the literature that rats and mice are developing genetic resistant to Brodifacoum – there is however, a suggestion of higher tolerance or for behavioural resistance. This means that a baiting strategy that overcomes the higher tolerance or behavioural resistance is required.

Resistance occurs when rodents that survive a baiting operation pass their resistant genes on to the next generation of rodents, so that over a period of time, all animals become resistant. All the susceptible animals have died. Three types of resistance have been described: (a) operational, (b) toxicological and (c) genetical. Furthermore, the behaviour of rodents, such as neophobia (fear of new objects), and conditioned or unconditioned aversion to the bait base or rodenticide, can help rodents to avoid eating a fatal dose of a rodenticide. This may explain why application of rodenticides may fail and cannot be accounted for by physiological resistance. Avoidance behaviour, which could be heritable, can and does reduce the efficacy of rodenticides and may also enhance the effects of physiological resistance.

If resistance is suspected, then a stronger rodenticide should be considered, but since Brodifacoum is one of the most potent second-generation rodenticides, there is little advantage in this approach. The two approaches to overcome tolerance or behavioural resistance are:

- Consider switching to a bait containing another type of second-generation rodenticide, such as Difenacoum, Bromadiolone or Flocoumafen, but these are not considered as potent as Brodifacoum.
- Consider switching to a different bait substrate, such as pellets. Pellets may be more palatable to mice than the wax blocks.

It is generally considered that if tolerance or behavioural resistance occurs, then these animals should be eliminated using a non-anticoagulant rodenticide, fumigant or physical control methods (described below). Commercially available strychnine treated grain (Dynamice®) is available in South Australia. It can be used in small quantities in and around rural storage buildings and grain and fodder storage areas. The permit for registration will need to be checked to see if it can be used in bait stations in food processing areas. Zinc phosphide is not registered for use in bait stations and cannot be used in and around buildings and storage sheds. Furthermore, zinc phosphide lacks an antidote and can only be used once every 3 months because surviving animals develop strong bait aversion, and may also require pre-feeding.

If there is a concern that the currently used anticoagulant rodenticide baits used in the bait stations is not working properly, it is possible to collect mice from the processing facilities and to test them to determine their resistance to the anticoagulant baits. This can be done using blood clotting tests, or by conducting tests where animals are fed the rodenticide and observations are made about the length of time to death or concentrations required to kill the animal.

There is generally no need to rotate different bait types in the bait stations at almond processing facilities. Rotating baits would increase the chance of resistance to a wider range of rodenticides and should therefore be avoided. Consideration should be given to reducing the number of bait stations set around the facility, particularly during spring and summer, given mouse activity and bait consumption is lower during these times. When activity and bait consumption increases through autumn and winter, the number of bait stations could be increased again.

The design of the bait stations used at the various hulling/shelling/processing facilities appeared to be appropriate, but they need to be set correctly (Figure 3). The most important consideration is to ensure they are set against the external walls of the warehouses and sheds. Rats and mice use the edges of these structures to move about the facility and so the bait stations should intercept these movements as much as possible to increase the chance of animals entering the stations. If the bait stations are not touching the structures, there is a strong chance that rats and mice will walk straight past the bait station and thus it would be ineffective.

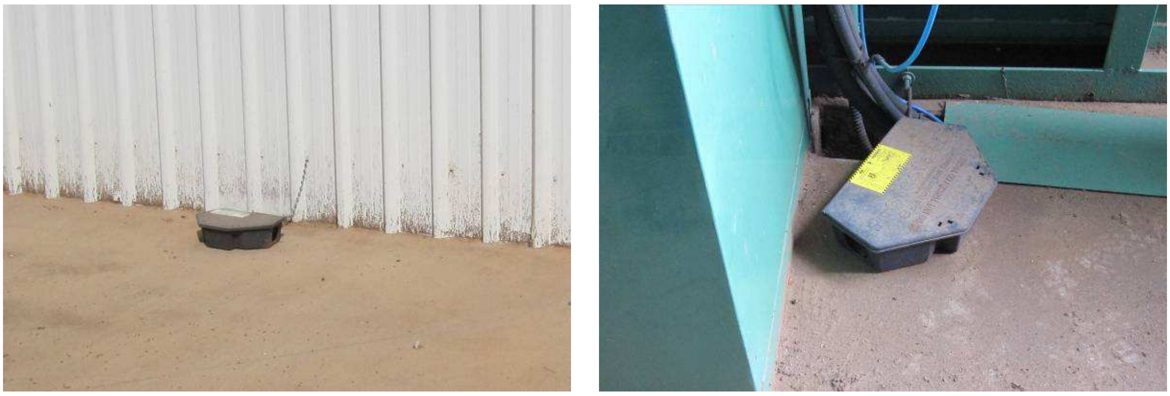


Figure 3. Example of bait stations that are not set properly at hulling/shelling/processing facilities. Bait stations must be placed against the walls of the structures to increase the chance of rats or mice entering the bait stations and consuming the bait.

A drift fence (Figure 4) should be considered to enhance the likelihood that mice would encounter bait stations located along the perimeter fence. Shade cloth or similar material (eg silt fence) could be tied to the chain link fence along the base of the fence to help guide mice to the stations. If mice are moving through the perimeter fence and they encounter the drift fence, they are more likely to traverse it to find an opening (where a bait station is located) rather than climb the drift fence. The drift fence would need to be approximately 30 cm high. Mice can readily climb this material, but it might assist in guiding them to bait stations.

Figure 4. Example of how a drift fence could be set up along a chain link fence to help direct mice into bait stations. A 30-cm high length of shade cloth/silt fencing could be attached to the bottom of the chain link fence. The fence would guide mice into bait stations set along the bottom of the fence. Bait stations could be set alternatively on either side of the fence.

Consideration should be given to baiting adjacent wheat fields surrounding orchards and shelling/hulling/processing facilities, if mouse abundance is high, to restrict movements of mice from the nearby fields into the facilities. Zinc phosphide mouse bait is the only product registered for broadacre, in-crop control of mice. Only certified people can purchase this bait and apply it.

5.2.2 Physical control – Trapping

Trapping can be an effective technique if used correctly, but its effectiveness is reduced during a mouse plague (when densities are sometimes very high). The advantage of using traps is that mice do not develop resistance to the traps (although they can learn to avoid the traps) and they act as a measure of abundance of mice in the facility.

There are different types of traps available, from live-capture traps and kill traps (such as snap traps). Care is needed to ensure that traps are set correctly and routinely checked. A few simple things can improve the effectiveness of a mouse or rat trap:

- *Bait type*. Rats and mice prefer to eat bacon rind, chocolate or leather soaked in linseed oil and do not really like to eat cheese. The advantage of leather is that it can be tied securely to the trap trigger so the rodents cannot remove the bait, and it can be used repeatedly.

- *Positioning of trap*. Set each trap at right angles to a wall or barrier with the trigger next to the wall. Rodents do not like moving away from walls into the open (Figure 5).
- *Enlargement of trigger*. Use a piece of cardboard or leather to increase the size of the trigger (Figure 5a).
- *Use plenty of traps*. You have a better chance of catching rodents if you set an excess number of traps.
- *For rats*: leave traps baited but unset, then once there is evidence that rats are chewing on the leather, re-bait and set the trap. Another type of snap trap that would be suitable for rats is made of strong moulded plastic (Figure 5b). These are made in the USA.

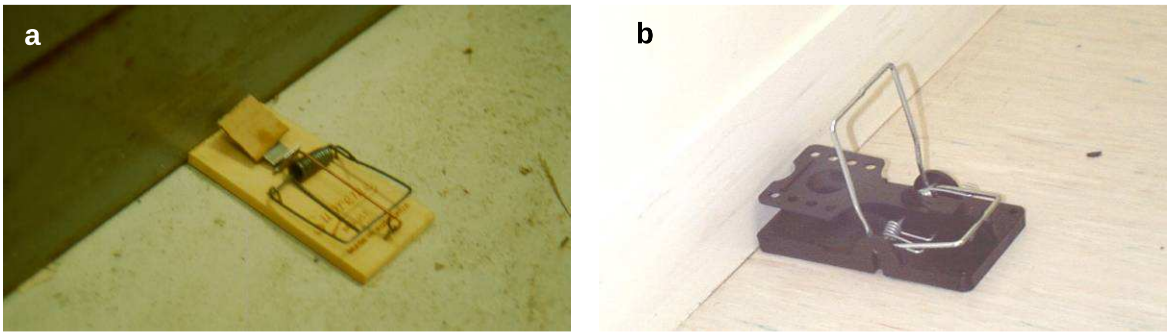


Figure 5. Kill traps (a) A mouse trap ("Supreme" snap trap, trap is 10 cm long) set against a wall. The surface of the trigger has been enlarged using some leather. The leather has been soaked with linseed oil. (b) A strong plastic moulded rat trap made in the USA (trap is 14 cm long). These photos are not at the same scale.

If live traps are used, mice need to be disposed of properly. This should be done to reduce stress on the animal and stress on the personnel checking the traps. The options available include:

- *Drowning*: Put the mouse trap containing the captured mouse into a bucket of water and ensure it is fully immersed for at least 1 minute. Dispose dead mice by incinerating of burying. Wash hands after handing the dead mouse and the trap.

- *Fumigation*: The trap containing the mouse could be fumigated either as part of the fumigation of almond product (in existing fumigation chamber in processing facilities), or by immersing into a large vessel containing CO (carbon monoxide) for 1-2 minutes. Extreme caution is needed because CO is odourless and colourless. Wash hands after handing the dead mouse and the trap.

5.2.3 Physical control – Sticky traps

Sticky traps (Figure 6) are being used in some facilities to capture mice where the almonds are being processed. It is not possible to bait in this situation. A major problem with sticky traps is that they are not a very humane form of rodent control. Mice will get caught on the sticky pad/paper, and will remain there for up to 24 hours.

Captured animals become stressed and they try to release themselves, sometimes by gnawing off their own feet. The facility staff who check these traps still need to kill the captured animals, which also might cause stress to the facility staff. It is recommended that all sticky traps be replaced with live traps or kill traps. Sticky traps will also get covered by dust and so become ineffective over time.

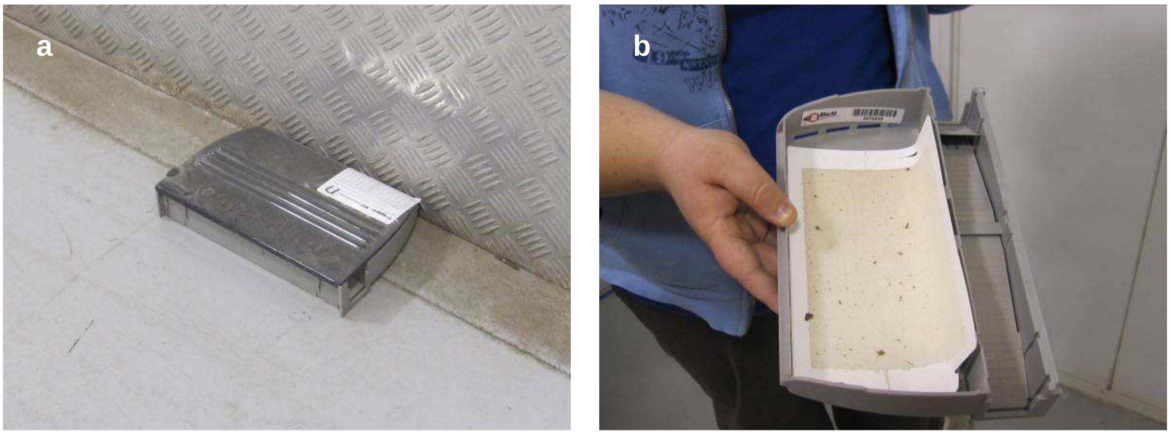


Figure 6. (a) A sticky trap set in a processing facility. In this case the trap was positioned against a wall, but the opening to the trap was set around the wrong way – the openings should be positioned against the wall. (b) Inside of the sticky trap showing the sticky paper.

5.3 Preventative measures

The information provided in this section is designed to minimise the chance that mice will gain access to the warehouses and sheds in the almond hulling/shelling and processing facilities.

5.3.1 Site housekeeping

In any rodent control program, it is important to keep all potential hiding or nesting sites to a minimum (Figure 7). These include piles of old rubbish, and areas of thick grass and weeds. Seeds from grasses and weeds can be a source of high quality food for the mice, while long grass can provide shelter from predators. Therefore, clean up piles of rubbish or move them further away from the facilities, and keep vegetation at a low height (mowing, slashing etc) to reduce cover and food sources for mice.

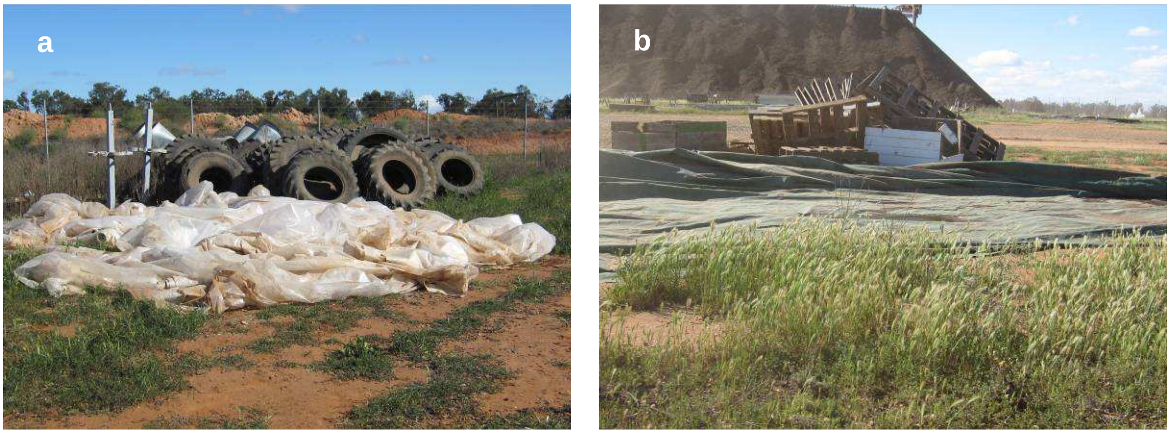


Figure 7. (a) Piles of rubbish provides ideal mouse habitat. This needs to be cleaned up or moved further away from the processing facilities. (b) Long grass and old rubbish provides cover and food. The grass needs to be mowed to remove the cover and food and the old rubbish needs to be cleared or moved off site.

There was little evidence of mouse burrows within the perimeter fence of the facilities. If mouse burrows are found in open dirt areas or near concrete foundations of the sheds or machinery, they should be destroyed and managed so that there is little chance that mice can reinvade these areas. Concrete could be poured into the burrows to seal them, but this may serve only as a temporary measure as mice would construct new burrows nearby.

5.3.2 Storage of pallets containing almonds (processes and unprocessed)

It is important to keep pallets of almonds stacked in such a way that there is little chance of provision of suitable nesting sites (Figure 8). This means stacking the pallets in a neat and orderly way, and constructing rows of pallets with gaps around them so that spills are visible and can be easily cleaned up. This practice was being conducted in the most of the facilities, but there were a few cases where pallets were stacked too close to the external walls of the facility.

The gap between walls and stacks of almond product should be at least 1 metre. There is less chance that mice will take up residence or nest in pallets if the pallets are stored away from the wall, because mice are reluctant to venture away from walls. Furthermore, if there is a gap between rows of pallets, then the risk that mice will move between stacks is reduced. Another reason for having a gap between the stacks and the wall is so that someone inspecting mouse problems can have access to bait stations and can clean up spillages easily.

A concrete curb could be fixed to the floor of the warehouse and sheds to prevent pallets being placed too close to the walls.

Figure 8. Pallets of almonds stacked near a wall. The distance from the wall to the pallets should be at least 1 metre. This allows easy access to clean up spillages and also makes it harder for a mouse to cross from the wall to the pallets. However, shed supports and other items break up this 1 metre gap.

5.3.3 Regular sweeping to remove spills

Removing sources of food for rodents is a key activity to reduce the rodent problem. We found little evidence of potential food sources for mice in the hulling/shelling or processing facilities or storage areas. Overall, the facilities were very clean.

5.3.4 Treatment of freshly palleted and wrapped product

Some possible solutions for finished product stored in pallets is to raise them off the floor and to ensure the product is moved around routinely. Facility staff were carrying out inspections on wrapped product to look for evidence of mouse inhabitation (holes in plastic or faeces). It is recommended to continue these inspections.

- *Raise product off the floor*: It will be impossible to construct mouse-proof racking systems (particularly in warehouses where there are lots of forklift movements), but by raising the product off the ground, it makes it more difficult for mice to climb and access it.

- *Ensure product is not sitting too long in one place*: If the product is sitting too long in one place, the chance of mice getting in and nesting there is substantially increased.

5.3.5 Mouse-proof fence

A mouse-proof fence should be considered around the hulling/shelling and processing facilities. If they are designed and built carefully, they can be effective. They do require some maintenance, as mice can gain entry to the facility through any gap, where overlaps are not completely smooth or where the fence is damaged. The problem with these types of fence is that they are not very practical if there are lots of heavy vehicle or forklift movements around the facility. It is also very difficult designing suitable doors or gates to allow access by forklifts or trucks. Other limitations of such a fence are the initial cost of construction, the high person-power requirements to maintain barriers, and the ability of mice to climb most surfaces and to penetrate small gaps. The specifications for constructing such a mouse-proof fence are provided in Appendix 1. If a mouse-proof fence is constructed outside, special attention would need to given to constructing a suitable drainage system so that the enclosed area does not fill with water after rain. Similarly, it is important to ensure that mice and rats cannot invade the area inside the fence through drainage systems. An additional issue is access to the facility by the workers, as the fence may pose a trip hazard (OHS issue).

This type of fence has been used elsewhere, such as around grain silos, and has proven effective in reducing the problem of mice (Figure 9). Care needs to be taken to construct and maintain the fence correctly.

Figure 9. Mouse-proof fence at a grain silo in Victoria. A bait station (PVC tube) is pictured on the right, inside the fence in case mice gain entry.

Such a fence could be designed so that sections of fence could be dismantled to allow access by trucks, forklifts and workers when mouse abundance is low. Then, when mouse abundance is high and likely to gain entry to the warehouse or processing areas, the barriers could be installed to prevent access by mice. Care is needed to ensure there are no overlapping joins that mice could climb or holes through which mice could gain entry.

5.3.6 Mouse-proofing of facilities

Proofing can be used to minimise the chance or even prevent rodents from entering certain facilities. Rodents are able to gnaw, climb, dig and jump. It is therefore important to consider rodent behaviour in any proofing. Rodents can gain access to a building through:

- holes or cracks in the foundations (pipes and cables can be sealed with concrete); mice can squeeze through holes >6 mm; rodents can enlarge any small hole by gnawing,
- sewers and drains,
- brick or concrete walls (rodents only need a claw-hold), downpipes, overhead wires, cables and overhanging trees,
- open doors, windows, air vents, air conditioning units, chutes etc.

The options available for preventing access to buildings and facilities are provided in Table 2. Once rodents are inside the facilities, they can take up residence and make nests for breeding.

Table 2. Likely routes of access by mice into the hulling/shelling and processing facilities sheds.

Access point	Action required to remedy situation
Through open doors	Keep doors closed whenever possible
Through holes in walls or gaps in doors (Figure 10)	Repair holes in the wall using sheet metal (Figure 11), and fix the doors so that there is a snug fit (Figure 10).
Through cracks in the floor	Cracks in the floor can be sealed with cement.
Through drain pipes	Place snug fitting covers over drainage holes, these should be made of strong steel and have a hole size of less than 6 mm.
From overhead wires and trees	Ensure that there are minimal overhanging wires and trees.

Figure 10. Small holes (>6 mm) allow entry by mice into sheds and facilities. This is especially important on the edges of roller doors, where it is difficult reducing the gaps. *Left*: a small gap along the side of a roller door will allow access by mice into the facility. *Right*: well-fitting metal door strips will stop mice entering the facility.

A small concrete skirting could be applied to the external walls of all the warehouses and sheds (Figure 11). This would block movements of mice underneath the walls where gaps or cracks currently exist. Concrete also could be poured on the internal side and the external side. Alternatively, if the wall of the structure is smooth (ie, not corrugated), then a strip of smooth metal sheeting could be used as a skirting that is bent at 90º and bolted to the ground. The metal skirting would need to come up about 10-20 cm from the floor.

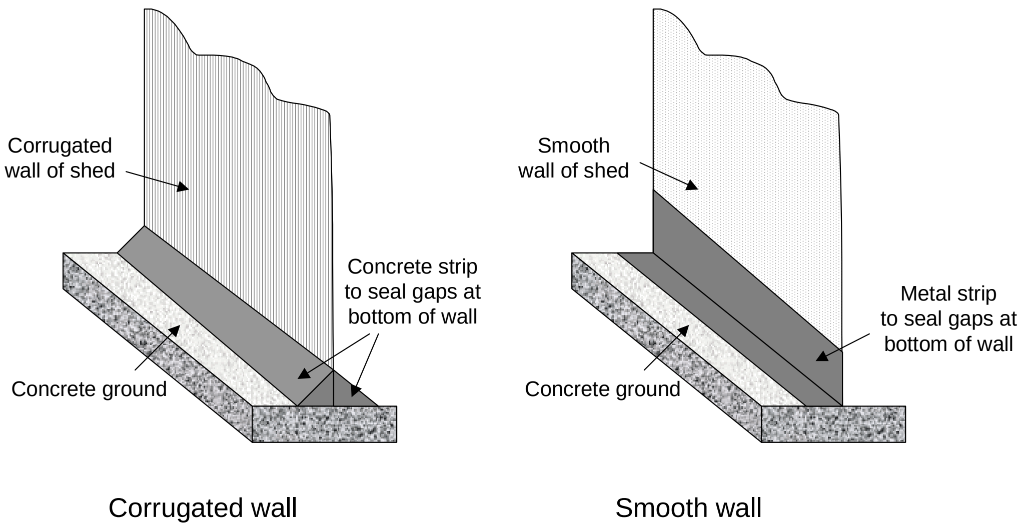


Figure 11. Examples of concrete strip and metal strips to seal the base of corrugated or smooth walls of sheds or warehouses to prevent access by mice.

5.3.7 Outside lighting

External lighting around the outside of warehouses and sheds could be considered as an additional measure to minimise the likelihood of mice crossing a lit area (Figure 12). Lighting could be used strategically around doorways and access points to warehouses and sheds.

Figure 12. External lighting used to reduce the chance that mice would enter the warehouse or sheds (example from another industrial setting).

5.3.8 Garden beds and surrounding vegetation

Garden beds can provide some cover and nesting sites for mice near the hulling/shelling and processing facilities (Figure 13). These gardens and vegetation are used as wind breaks and provide general aesthetics, so they should not be removed. However, the vegetation/bare ground should be separated from the facilities by bare ground (>10 m if possible) to minimise the chance mice will cross the open area.

Figure 13. Surrounding vegetation and garden beds can provide mouse habitat (cover and food). If possible, minimise these areas, but also ensure there is bare ground between the vegetation/garden and facilities to reduce the chance that mice will cross the open areas.

5.3.9 Management of mice in adjacent agricultural fields

There is a range of farm management practices that can be used to reduce the population abundance of mice in the nearby wheat fields. CSIRO have conducted research to test the effectiveness of a range of farm management practices on mouse abundance and subsequent damage to crops in northwestern Victoria (dryland mixed wheat and sheep agriculture) and in southern New South Wales (irrigated summer cropping area). In both cases, when refuge habitats were manipulated to reduce the amount of weeds and grasses along the margins of crops (eg fencelines) through spraying, slashing or grazing by sheep, there were fewer mice and in some cases less damage to crops compared to untreated areas. The undisturbed habitat along fencelines is an important habitat for mice because it is undisturbed (does not get ploughed) and high quality food and cover is often available (roly-poly tumble weeds, barley grass etc). When mouse abundance is high, especially at sowing, grain farmers should think about baiting their fields to reduce damage and prevent subsequent re-sowing costs. For the almond industry, the management of surrounding cropping fields should be considered as part of an overall management package (management units of around 1,000 ha).

5.3.10 Encourage natural predators

Encouraging natural predators of mice may assist with the control of mice in the area surrounding orchards, hulling/shelling and processing facilities. Natural predators of mice include foxes, snakes, hawks (black shouldered kites, kestrels etc) and owls. There are few studies that convincingly demonstrate the benefits of providing perching or nesting sites for avian predators (hawks or owls). One of the few examples was a study conducted in an irrigated cropping area of NSW, Kay *et al*. (1994). Artificial perches increased the number of raptors feeding on mice in crops and reduced the rate at which the mouse population increased and the peak abundance of mice in the fields (Kay *et al*. 1994). Perches were constructed from 3 m lengths of 90 mm PVC pipe with a small wooden perch attached to the top. Each perch was placed at 100 m intervals around the perimeter of crops. There are ample perching locations already within the orchards.

Perches or nesting sites might increase the number of avian predators, but it is generally considered that these animals do not eat enough mice to have an effect on the population. That is, the number of mice they eat is fewer than the reproductive potential of the mice. Once mouse population densities are high, predation will have little effect.

There would be little point in encouraging natural predators within the boundary fence of the facilities, because there is a high chance that mice would have come in contact, or possibly have eaten a sufficient dose, of the rodenticide baits. There would therefore be a secondary-poisoning risk if a natural predator eats a sick or dying mouse.

5.3.11 Sonic deterrents

There have only been a few studies conducted on these devices. The devices fall into two broad categories:

1. Ultra-sonic devices that emit a high-frequency sound.

2. Magnetic pulses device.

There is no convincing evidence that any of the machines available are effective and therefore would not be appropriate for almond hulling/shelling or processing facilities. They may repel rodents for a short time, but rodents generally become accustomed to them rapidly. The main shortcomings of the devices are:

1. High-frequency sounds and magnetic pulses do not reflect around solid objects, they are absorbed.

2. Initial aversion by rats and mice is rapidly overcome.

5.3.12 Repellents

There has been some success in situations where repellents have been applied to reduce rodent damage repellents applied to trunks of orchard trees (eg apple trees) to prevent attack and subsequent death through damage by rodents. These mostly relate to situations where rodents cause direct damage to the bark or trunks of the trees. There are various types of repellents available including capsaicin (very hot taste – a derivative of hot chillies) and predator urine. In both cases, rodents have to sample the repellent and then learn to avoid it in the future. Most mouse damage is directly on the almond nuts, so a repellent sprayed on the trunk of a tree is unlikely to be effective.

5.3.13 Decoys (diversionary feeding)

There are few examples where decoys or diversionary feeding have been successful in preventing or reducing damage. Where diversionary feeding has been successful was to protect young tree seedlings in northern America. Young pine seedlings need to be protected only for a short time or during winter before they are not attractive to voles (small rodent). Diversionary food can provide some protection to pines, although some damage still occurred (Sullivan *et al*. 2001).

5.3.14 Staff training

A key to a successful rodent control strategy is to train specific staff in these methods (staff involved in setting and checking bait stations and traps). It is also important to change some of the behaviour of all staff at the orchards and processing facilities (eg forklift drivers). Such training would make staff aware of rodents, enlist their help to keep an eye out for signs of rodents, enable monitoring of Occupational Health and Safety (OH&S) issues relating to rodents, and importantly, provide an understanding of the effect of routine tasks on rodent populations.

5.4 Management actions during a mouse plague

During the extreme circumstances that may be encountered during mouse plagues, more effort will be required to keep mice from entering the warehouses/storage sheds and processing facilities. In addition to the preventative actions already described, the following actions should be considered.

1. Store valuable products in shipping containers immediately after they are packaged, wrapped and placed on pallets. The shipping containers can be mouse-proof. However, care should be taken when moving pallets in and out of the shipping containers that mice do not inadvertently gain access to the containers.

2. Lift pallets off the ground, particularly the valuable products and store on mouse-proof racks.

3. Bait adjacent fields with zinc phosphide to reduce the potential population abundance of mice. Reinvasion of the wheat fields may occur after a period of time, so baiting does not provide complete protection. When population abundance is high during mouse plagues, mice will also be inhabiting sub-optimal habitats such as areas of land between the fields and the hulling/shelling and processing facilities where there is some ground cover but it may not be possible to bait such habitats.

4. Keep external access doors shut at night to limit entry by mice to the storage areas.

5.5 Activity monitoring and record keeping

A well-designed monitoring system will allow a manager to determine the progress and success of any control operation and to relate the benefits of the strategy to the costs of the operation.

Monitoring can be in the form of number of mice captured in snap traps, amount of poison baits consumed, number and proportion of census cards eaten (information provided below), and presence of rodent faeces in set areas. These techniques are all relatively simple to conduct. It is important to keep good records, so that when activity increases, control efforts can be implemented accordingly.

The current practice of measuring amount of wax block consumption by rodents once a week is excellent. This is valuable data that can be analysed to determine areas of high mouse activity.

A census card (canola square) is a piece of paper with a 10 x 10 cm grid marked on it, which is soaked in canola oil and pegged into the ground (Figure 14). On cereal farms, these are set 10 metres apart on the edge of the crop in lines of 10 or in a crop in a 5 x 5 grid. In almond orchards, they could be set in lines through the orchard, on perimeters and in adjacent crop fields. In hulling/shelling and processing facilities, they could be set along the boundary fence, inside the warehouse or adjacent to the wheat fields. The census cards are left overnight. The percentage eaten on each card is recorded, then averaged over all cards to give an average amount of card eaten. This technique provides a rough indication of relative abundance of mice.

The ultimate success of the rodent control program will be the decline of rodent-related complaints.

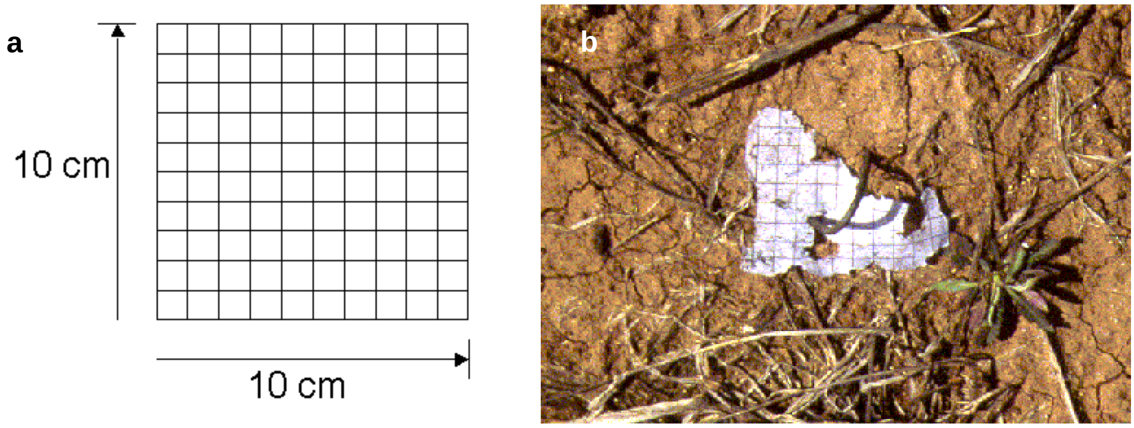


Figure 14. (a) Design of census card and (b) a census card that has been set out in the field overnight and held in place by a piece of bent wire: approximately 40% of this card has been chewed by mice.

6. RECOMMENDATIONS FOR MANAGING MICE IN ORCHARDS

6.1 Existing practices in orchards

There are a range of activities and management practices being conducted in and around almond orchards, which are discussed below. Overall, management appeared to be largely reactive. Some monitoring was conducted, but appeared to be largely ad-hoc. Management, particularly “broadacre” baiting with zinc phosphide and perimeter baiting using bait stations containing anticoagulants, appeared to be reactive to the damage that was becoming evident. It seems the mouse plague has caught many by surprise. There hasn’t been a good mouse plague for many years, and there are many new almond growers who have not experienced a mouse problem before.

- *Matrix of mouse habitat*: Almond orchards are set within a range of mouse habitats, which include wheat crops, other broadacre crops, horticulture crops and other activities – each of which were also affected by mice over the last 2 years or so. Almond orchards are therefore affected by what mouse populations are doing in surrounding fields. Mice have built up in wheat fields, almond crops and other horticulture crops and have readily moved between these habitats as food and cover requirements change.

- *Zinc phosphide baiting*: There has been some ad-hoc baiting of mice in small pockets of land. Baiting using zinc phosphide has occurred in almond orchards and there has been baiting with zinc phosphide in neighbouring wheat fields (both aerial application and ground-based application of zinc phosphide). There were a few instances where baiting of mice has occurred concurrently on almond orchards and surrounding fields, but this seems to be rare. Mouse damage was clearly the motivator for undertaking the baiting, but the timing for this in relation to almond crop development was not clear. Many baiting operations appeared to be successful, but some growers reported that the baiting was not successful and resorted to re-baiting of orchards. The reasons for the lack of baiting success could be related to:

    - The small areas being baited which meant that re-invasion occurred rapidly;
    - High mouse densities meaning that many mice still remained after baiting occurred; or
    - Mice ate sub-lethal doses of the zinc phosphide bait because of the availability of other high quality food sources thus reducing the effectiveness of the baiting operation and also the unsuccessful re-application of zinc phosphide baits.

  To ensure baiting is successful, management needs to be conducted over a large area (eg 1,000 ha) covering surrounding fields (with relevant agreements and permissions) to minimise the chance of reinvasion. Baiting also needs to be conducted at a time when little alternative high quality food is available, so monitoring should be conducted at key times to determine whether baiting is warranted.

- *Additional zinc phosphide baiting*: Some additional baiting using zinc phosphide sprinkled on the ground was practiced in some orchards. This practice should be avoided and contravenes the registered product label. Clumps of poisoned grain near potential bird perches must be avoided.

- *Perimeter baiting*: Additional baiting using perimeter baiting using anticoagulant baits in bait stations has been implemented in many orchards. Many of the bait stations were “hand-made” using 90 mm PVC pipe, but were adequately constructed for their use (Figure 15). In most cases, a single bait station was positioned at the end of a row of trees and every 10 m or so along perimeter fences. This is considered adequate coverage.

Figure 15. *Left*: A bait station set on the edge of an orchard. Small holes are located at the ends of the tube. *Right*: A close-up of the anticoagulant bait inside the bait station with the top cover removed.

- *Undisturbed habitats*: In almond orchards, the ground surface is largely undisturbed which means mouse burrows are not disturbed. Some weed spraying is conducted to clean the ground surface to assist with clean harvesting of the almonds (Figure 16). This can help removing potential cover and food sources for mice that the weeds provide. Mice seemed to be constructing mouse burrows near the base of the almond trees, and this may be a result of the shaking process to knock the almonds off the tree at harvest which loosens the soil. This enables mice to easily dig in the loosened soil near the tree trunk (Figure 16). Mice are unlikely to cause damage to the roots of the trees.

Figure 16. *Left*: the floor of the orchard is relatively clean because of the spraying that is conducted to control weeds; this can benefit mouse control because there is little food and cover provided by weeds. *Right*: Many mouse burrows were constructed near the base of trees, presumably because the soil was loose as a result of the shaking to drop the almonds to the ground during harvesting.

6.2 What still needs to be done

Some recommendations for improving the monitoring and management of mouse populations and damage are provided here, specifically for the almond industry.

- *Monitoring*: Regular monitoring of mouse populations needs to be conducted to define whether a problem exists before applying control. It is recommended to undertake monitoring in early spring (eg September) to get an idea of mouse activity at the commencement of the main breeding season (at the time when mouse population abundance is at their lowest). If activity and numbers appear to be relatively high, then management should be considered to knock the population down early so that the starting population is lower. A second round of monitoring should then be conducted during January (prior to tree shaking and harvesting) to see whether further management of mice is warranted. Mouse numbers normally peak in autumn, so another round of monitoring may be required in March/April if harvesting of almonds is delayed.

  Monitoring is necessary not just in the orchard, but also in the surrounding habitats (Figure 17). Monitoring should be conducted in a number of habitats and with at least 2 lines of census cards (canola squares; see Section 5.5) in each habitat type (to gauge the level of variation within each habitat and across the whole area). This allows a better understanding of the level of mouse activity and mouse abundance within the orchard and in surrounding fields to enable better planning and implementation of management to reduce damage caused by mice. If using census cards (canola squares), then the following monitoring strategy is suggested (Figure 17):

- 2 lines of 10 cards (each set 10 m apart) should be set within the orchard (say 5 rows in from the edge),
- 2 lines of 10 cards (each set 10 m apart) should be set along the edge of the orchard, and
- 2 lines of 10 cards (each set 10m apart) should be set in neighbouring fields (eg wheat fields, horticulture crops) to get an idea of mouse activity near the orchards.

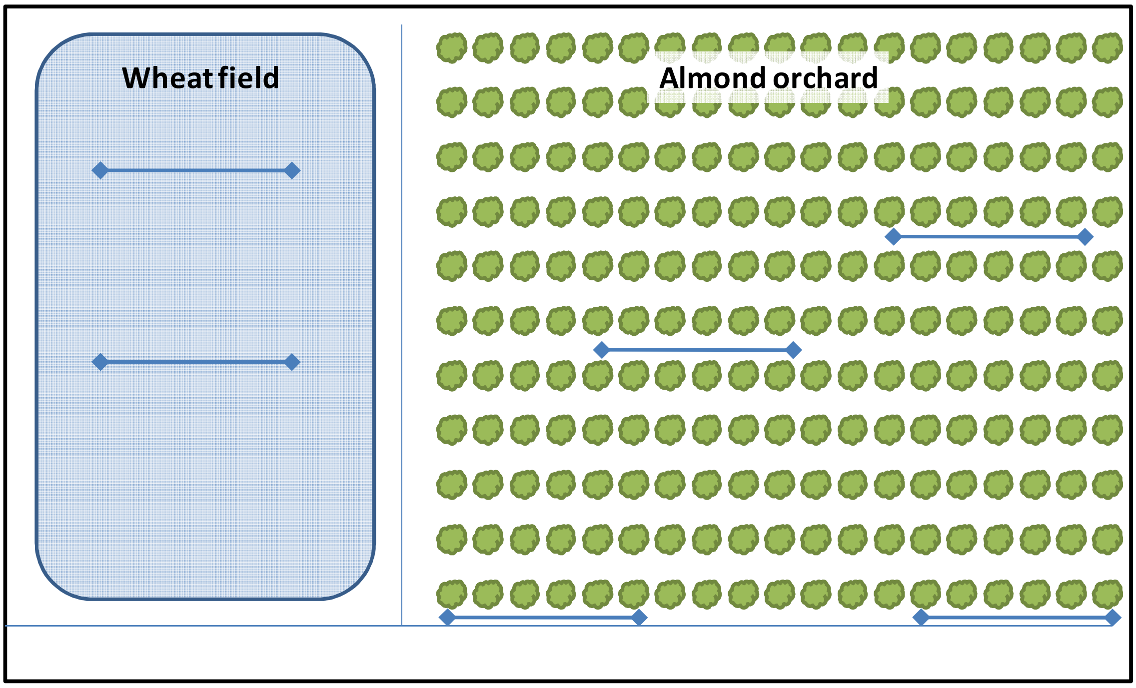


Figure 17. Schematic layout of lines of census cards (canola squares) in and around almond orchards to monitor the activity of mice. Two lines of 10 cards (each card spaced 10 m apart) should be set (a) within the orchard, (b) on the perimeter of the orchard and (c) in neighbouring habitats such as wheat fields.

There is little science behind the level of “take” of the census cards. There are many factors at play here, including hunger, inquisitiveness, behaviour etc. There is no hard and fast rule, but the card chewing results will help with a “gut feel” for the situation. It is also good to look around through the orchard while setting and checking the cards the next day to help with understanding the level of mouse activity present. As a rough guide:

- *If < 10%* of the cards have significant chewing evident, then it is likely that activity levels of mice are reasonably low.
- *If > 20%* of the cards have significant chewing evident, then there are moderate levels of mice present.
- *If > 50%* of the cards have significant chewing evident, then there is high levels of activity.

Another form of monitoring is to look for active mouse burrows throughout the orchard. Conduct a walk transect through the orchard (say 100 m), and loosely cover over any mouse burrow that is found. On the following morning, walk over the same area and take note of how many burrows have re-opened. This can give a rough idea of activity of mice.

Key issues for management are set out in Table 3. Some other considerations are:

- Management should be conducted over > 1,000 ha to minimise reinvasion of mice from surrounding areas.
- If mouse activity is high and mice are seen running around in the orchards and in the trees causing damage directly to the nuts, then consider baiting with zinc phosphide. Many growers indicated they had good success with zinc phosphide treatments.

Table 3. Summary of management practices to control mice in almond orchards.

Time of year	Mouse activity low	Mouse activity moderate	Mouse activity high
Spring	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources • Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions)
Summer	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources	• Manage habitat using weed spraying and slashing of grasses and weeds to remove cover/shelter • Remove potential food sources	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources • Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions) (beware of withholding period before harvest)
Autumn	• Management may not be necessary	• Remove potential food sources	• Remove potential food sources • Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions) (beware of withholding period before harvest)
Winter	• Management may not be necessary	• Remove potential food sources	• Remove potential food sources • Apply rodenticide over entire orchard and surrounding fields (obtain necessary approvals and permissions)

7. RECOMMENDATIONS FOR MANAGING MICE IN HULLING/SHELLING AND PROCESSING FACILITIES

7.1 Existing practices

Much mouse control is already being practiced in the hulling/shelling and processing facilities. The key activities that were observed are outlined below.

- *Bait stations*: Bait stations were set up containing anticoagulant rodenticides in areas surrounding the facilities (spaced every 10 m) (eg boundary fences and internal fences) and on external walls and internal walls of sheds and buildings. Bait stations are checked every 1-2 weeks by facility staff or by commercial pesticide companies. Information on activity and amount of baits consumed is recorded and information has been used to monitor activity.

- *Trapping*: Sticky traps and live traps are being used in some facilities to capture mice in internal buildings where the food-processing is occurring (it is not possible to use poison baits in these situations because of the risk of contamination with food products). It is strongly recommended that sticky traps should not be used simply from an animal welfare perspective. Live traps are entirely suitable and their practice should continue. The disposal of live mice seems to be normally done by drowning, and fumigation in chambers could also be considered.

- *Management of vegetation and general site hygiene*: Areas of vegetation surrounding the facilities were regularly mown or slashed to keep ground cover down. Piles of rubbish were cleaned up and spills of almonds were cleaned up.

- *Remedial work to prevent access by mice into facilities*: Seals were fitted to the bottom of doors to prevent access by mice. Roller doors were converted into new rapid shutter doors. Gaps at the bottom of wall panels were covered up with angled metal, caulked up with gap filler or the wall panels were unscrewed and pulled down and re-fitted so that there were no gaps. Small metal “termite” shields were inserted into the air circulation gaps between bricks. Some small gaps around the sheds and facilities still remained, but most were too small for mice to access the facilities.

- *Stacking of pallets and crates*: Some considerable effort was taken to be careful about where and how pallets and crates were stacked so that they were well stacked. This allows inspections between and surrounding the stacks. Most mouse activity seemed to occur in areas where pallets and crates had not been moved for some time.

- *Salmonella sampling*: Samples of almonds are checked for Salmonella contamination. There is a slight delay in getting results back from the lab, but contaminated samples can be traced back to batch numbers and these can be recalled before they reach shelves. The source of the Salmonella contamination is not known, but it is likely to be from mice. Other potential sources of contamination could be from the workers themselves in the facility, but also from birds roosting in the facility.

7.2 What still needs to be done

A few activities could be done to improve the rodent management in the hulling/shelling and processing facilities. These include the following:

- Sticky traps should not be used. Consideration should be given to replacing sticky traps with live traps or kill traps (eg snap traps; Figure 5).
- Bait stations and live capture traps are sometimes not set appropriately. They need to be well positioned and in contact with walls to maximise the chance that mice will enter the bait station or trap.
- Consider connecting a low shade cloth fence/silt fence (approx 30 cm high) along the external boundary chain link fences to help guide mice into the bait stations placed on the perimeter fences.
- Carefully look at external access points, for example where pipes or conveyors entered the buildings higher off the ground (Figure 18).
- Ensure poorly fitting wall panels are fixed up so that mice cannot climb up them and gain access to buildings at a higher location (Figure 18).
- Ensure drains inside buildings have mouse proof covers (< 6 mm hole size) to prevent access by mice.

Figure 18. *Left*: If mice can grab hold of the edge of corrugated iron, they can climb up and climb through small gaps around elevators such as this. *Right*: Mice can climb up poorly fitting wall panels. These need to be fitted together with no overhang.

Key issues for management for processing facilities are set out in Table 4.

Table 4. Summary of management practices to control mice in hulling/shelling and processing facilities.

Time of year	Mouse activity low	Mouse activity moderate	Mouse activity high
Spring	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources • Set and check anticoagulant bait stations at least every month • Ensure floors are swept and kept clean	• Manage habitat using weed spraying and slashing of early spring grasses and weeds to remove cover/shelter • Remove potential food sources • Set and check anticoagulant bait stations at least every 2 weeks • Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) • Ensure floors are swept and kept clean	• Apply rodenticide over surrounding fields to reduce resident mouse population abundance (obtain necessary approvals and permissions) • Set and check anticoagulant bait stations at least every 1 week • Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) • Ensure floors are swept and kept clean
Summer	• Remove potential food sources	• Remove potential food sources	• Apply rodenticide over surrounding fields (obtain necessary approvals and permissions)
Autumn	• Remove potential food sources	• Remove potential food sources	• Apply rodenticide over surrounding fields (obtain necessary approvals and permissions) • Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors)
Winter	• Ensure grasses and weeds are managed • Remove potential food sources • Set and check anticoagulant bait stations at least every month • Ensure floors are swept and kept clean	• Manage habitat using weed spraying and slashing of grasses and weeds to remove cover/shelter • Remove potential food sources • Set and check anti-coagulant bait stations at least every 2 week • Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) • Ensure floors are swept and kept clean	• Apply rodenticide over surrounding fields to reduce resident mouse population abundance (obtain necessary approvals and permissions) • Set and check anticoagulant bait stations at least every 1 week • Set live/kill traps inside facilities and check every day (set 1 every 10 m, and on each side of doors) • Ensure floors are swept and kept clean

REFERENCES/BIBLIOGRAPHY

Brown, P.R. and Singleton, G.R. (1997). *Review of rodent management for pig production units*. Unpublished report to the Pig Research and Development Corporation. CSIRO Wildlife and Ecology, Canberra. pp. 45.

Brown, P.R. and Singleton, G.R. (2001). Impacts of rodent pests on crops in Australia - costs and damage. In *Human-Wildlife Conflicts: Economic Considerations*. (Ed. L. Clark.) pp. 27-40. (United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center: Colorado State University Press, Fort Collins, CO, USA.)

Brown, P.R. and Singleton, G.R. (2001). *Mouser Version 1.0*. Canberra, CSIRO Sustainable Ecosystems and the Centre for Pest Information Technology and Transfer, The University of Queensland.

Brown, P.R., Davies, M.J., Croft, J.D., and Singleton, G.R. (2004). Can farm management practices reduce the impact of house mouse populations on crops in an irrigated farming system? *Wildlife Research* **31**, 597-604.

Brown, P.R., Singleton, G.R., Pech, R.P., Hinds, L.A., and Krebs, C.J. (2010). Rodent outbreaks in Australia: mouse plagues in cereal crops. In '*Rodent Outbreaks: Ecology and Impacts*.' (Eds Singleton, G.R., Belmain, S.R., Brown, P.R. and Hardy, B.) pp. 225-238. (International Rice Research Institute: Los Baños, Philippines) [download at: http://books.google.com/books/irri?id=yaI0NFQb36UC&printsec=frontcover&dq=rodent+outbreaks&cd=1#v=onepage&q&f=false]

Buckle, A.P. (1994). Rodent control methods: chemical. In *Rodent Pests and Their Control*. (Eds. A.P. Buckle and R.H. Smith.) pp. 127-160. (CAB International: Wallingford, UK.)

Buckle, A.P. (1999). Rodenticides - their role in rodent pest management in tropical agriculture. In *Ecologically-based Management of Rodent Pests*. (Eds. G.R. Singleton, L.A. Hinds, H. Leirs, and Z. Zhang.) pp. 163-177. (Australian Centre for International Agricultural Research: Canberra.)

Buckle, A.P. and Smith, R.H. (1994). *Rodent Pests and Their Control*. (CAB International: Wallingford, Oxon, UK.)

Caughley, J. and Croft, D. (1994). A survey of the MIA mouse plague. *IREC Farmers Newsletter* **144**, 28-33.

Caughley, J., Bomford, M., Parker, B., Sinclair, R., Griffiths, J., and Kelly, D. (1998). *Managing Vertebrate Pests: Rodents*. 130 pp. (Bureau of Resource Sciences and Grains Research and Development Corporation: Canberra.)

Caughley, J., Monamy, V., and Heiden, K. (1994). *Impact of the 1993 mouse plague*. GRDC Occasional Paper Series No.7. (GRDC: Canberra, Australia.)

Chambers, L.K., Singleton, G.R., and Krebs, C.J. (2000). Movements and social organization of wild house mice (*Mus domesticus*) in the wheatlands of Northwestern Victoria, Australia. *Journal of Mammalogy* **81**, 59-69.

Kay, B.J., Twigg, L.E., Korn, T.J., and Nicol, H.I. (1994). The use of artificial perches to increase predation on house mice (*Mus domesticus*) by raptors. *Wildlife Research* **21**, 95-106.

Kenney, A.J., Krebs, C.J., Davis, S.A., Pech, R.P., Mutze, G.J., and Singleton, G.R. (2003). Predicting house mouse outbreaks in the wheat-growing areas of south-eastern Australia. In *Rats, Mice and People: Rodent Biology and Management*. (Eds G.R. Singleton, L.A. Hinds, C.J. Krebs and D.M. Spratt) ACIAR Monograph 96. pp. 325-328. (ACIAR: Canberra)

Mason, G., and Littin, K.E. (2003). The humaneness of rodent pest control. *Animal Welfare* **12**, 1-37.

Pech, R.P., Hood, G., Singleton, G.R., Salmon, E., Forrester, R., and Brown, P.R. (1999). Models for predicting plagues of house mice (*Mus domesticus*) in Australia. In *Ecologically-based Management of Rodent Pests*. (Eds. G. R. Singleton, L. A. Hinds, H. Leirs, and Z. Zhang.) pp. 81-112. (Australian Centre for International Agricultural Research: Canberra.)

Prakash, I. (1988). Bait shyness and poison aversion. In *Rodent Pest Management*. (Ed. I. Prakash.) pp. 321-329. (CRC Press: Boca Raton, Florida.)

Prakash, I. (1988). *Rodent Pest Management*. (CRC Press: Boca Raton, Florida.)

Singleton, G.R. and Brown, P.R. (1999). Management of mouse plagues in Australia: integration of population ecology, bio-control and best farm practice. In *Advances in Vertebrate Pest Management*. (Eds. D. P. Cowan and C. J. Feare.) pp. 189-203. (Filander-Verlag: Berlin.)

Singleton, G.R. and Redhead, T.D. (1989). House mouse plagues. In *Mediterranean Landscapes in Australia: Mallee Ecosystems and their Management*. (Eds. J. C. Noble and R. A. Bradstock.) pp. 418-433. (CSIRO: Melbourne.)

Singleton, G.R., Brown, P.R., Pech, R.P., Jacob, J., Mutze, G.J., and Krebs, C.J. (2005). One hundred years of eruptions of house mice in Australia - a natural biological curio. *Biological Journal of the Linnaen Society* **84**, 617-627.

Singleton, G.R., Hinds, L.A., Leirs, H., and Zhang, Z. (1999). *Ecologically-based management of rodent pests*. (Australian Centre for International Agricultural Research: Canberra.)

Singleton, G.R., Krebs, C.J., Davis, S., Chambers, L.K., and Brown, P.R. (2001). Reproductive changes in fluctuating house mouse populations in Southeastern Australia. *Proceedings of the Royal Society of London Series B* **268**.

Singleton, G.R., Smith, A.L., and Krebs, C.J. (2000). The prevalence of viral antibodies during a large population fluctuation of house mice in Australia. *Epidemiology and Infection* **125**, 719-727.

Singleton, G.R., Smith, A.L., Shellam, G.R., Fitzgerald, N., and Muller, W.J. (1993). Prevalence of viral antibodies and helminths in field populations of house mice (*Mus domesticus*) in southeastern Australia. *Epidemiology and Infection* **110**, 399-417.

Sullivan, T.P., Sullivan, D.S., and Hogue, E.J. (2001) Influence of diversionary food on vole (*Mictotus montanus* and *Microtus longicaudus*) populations and feeding damage to coniferous tree seedlings. *Crop Protection* **20**, 103-112.

Twigg, L.E. and Kay, B.J. (1994). The effects of microhabitat and weather on house mouse (*Mus domesticus*) numbers and the implications for management. *Journal of Applied Ecology* **31**, 651-663.

APPENDIX A – MOUSE PROOF FENCE

The specifications for building a mouse-proof fence is provided in Figure 19. These barriers have been used around grain storages and other facilities. The fence should be carefully constructed to keep mice out.

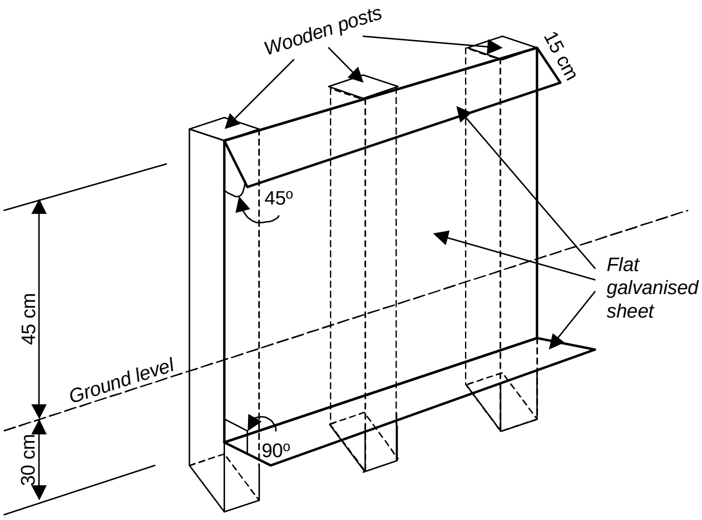


Figure 19. Design of mouse-proof fence. Redrawn from Saunders and Robards (1982) Mice and their control. Department of Agriculture NSW, Agfact A9.0.1.

1. Barriers should be at least 45 cm high and be made of material such as tin or galvanised iron (not corrugated iron).

2. The barrier should have at least 30 cm buried underground, or set in the concrete.

3. There should be a minimum of joints and rough edges on the outside so mice cannot climb over.

4. If the fence is set in concrete, there is no need to have 90° lip under ground, but there should be at least 1 metre of concrete around the outside of the fence that gently slopes away from the fence so that no water can pool.

5. If posts are used to support the fence, they must be placed on the inside of the fence, and secured (using a fastener) to the fence so that no part of the fastener can extend beyond the fence. This will make it difficult for mice to climb over the fence.

6. Care needs to be taken in designing a door so that forklift trucks and large vehicles can gain access to the area. There are two options: (a) a rolling door with snug fitting edges (b) hinged doors that have a snug fit (<4 mm gap underneath and at the sides) when closed.

7. A protocol should be developed so that the gate is closed at all times except when shipping containers are moved in or out. Furthermore traps and/or bait stations could be set inside the fence in case any mice do gain access to the area.

Contact Us

Phone: 1300 363 400
+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au

Your CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

Appendix 4 – Review of Australian Almond Processing Industry

University of South Australia

REPORT: REVIEW OF AUSTRALIAN ALMOND PROCESSING INDUSTRY

Prepared for	Almond Board of Australia 9 William Street, PO Box 2246, BERRI South Australia 5343 ABN 31709079099 Attention: Ben Brown bbrown@australianalmonds.com.au
Prepared by	Associate Professor John Fielke Director, Agricultural Machinery Research and Design Barbara Hardy Institute Mawson Lakes Campus, SA Telephone (61) 8 8302 3119 Email john.fielke@unisa.edu.au Contact details for notices: Mr Sebastien Hebert Business Development Manager Division of Information Technology, Engineering and the Environment University of South Australia 5095, SA Telephone (61) 8302 3973 Email sebastien.hebert@unisa.edu.au
Date of issue	20 June 2011

Important Notice

This report is confidential and was prepared exclusively for the Almond Board of Australia. It is not intended for, nor do we accept any responsibility for its use by any third party.

This report is copyright of University of South Australia and may not be reproduced. All rights reserved.

This project has been facilitated by HAL in partnership with the Almond Board of Australia (ABA). It has been funded by the Australian almond industry levy through project AL09021 (Australian Almond Industry, Industry Liaison and Extension Project). The Australian Government provides matched funding for all HAL's R&D activities.

Table of Contents

1

PROJECT BACKGROUND AND OBJECTIVES

The Almond Board of Australia has recently released their Strategic R&D plan 2011-2106 which has highlighted the following relevant areas:-

- Harvest
  - Harvest systems
  - On-farm product storage
- Primary processing
  - Product storage
  - Hulling &shelling
  - Product sizing
  - Logistics
- Secondary Processing
  - Product classification
  - Product development
  - Product packaging
  - Distribution

The Australian almond industry is preparing itself for:

- A large increase in production from around 35,000 tonnes of kernels in 2010 to over 80,000 tonnes in 2015.
- Ever increasing needs for improved quality.
- Investigating better methods for harvest, dehydration, storage and processing.

The aim of this project was to familiarise Associate Professor John Fielke with the Australian almond industry and to provide some recommendations for further R&D activities to help achieve the above aims.

2

PROJECT VISITS

Date	Visitors	Company
Friday 18 March 2011	John Fielke Andrew Burge Fei Tang (student) Samuel Tok (student) Ben Brown	Jubilee Almonds (grower)
	As above	Almondco (packer)
	As above	Simarloo (huller and sheller)
Monday 11 April 2011	John Fielke Sang-Heon Lee Fei Tang (student) Samuel Tok (student)	Riverland Almonds (packer)
	As above	Laragon Almond Processors (huller and sheller)
Tuesday 12 April 2011	As above	Select Harvests (grower only visited, but they also hull, shell and pack)
	As above	Nut Processors Australia - Pistachio (grower, processor, packer)
Wed 13 April 2011	As above	Mark Stoeckel (grower)
	As above	Omega Orchards (grower)
	As above	Almondco (packer)
Wed 15 June 2011	John Fielke Fei Tang (student) Samuel Tok (student)	Costa Almonds (huller and sheller)

3 INDUSTRY OVERVIEW, IMPRESSIONS AND R&D DIRECTIONS – ON FARM

The almond industry was observed to be highly mechanised and driven by Californian style equipment for both on farm operations and the processing of almonds.

During the visits it was pointed out that the Australian industry is different to California:-

1. Australian trees are unpruned and more compact; hence the equipment does not fit down the row as easily.

2. Australian farmers achieve a higher yield per ha and machines such as sweepers cannot blow the quantities of almonds as well. Sandy textured soils also make sweeping and pick-up operations more difficult

3. Australian trees are mainly drip irrigated with dripper lines generally running on the surface, about 1m out from the trees and consequently interfere with harvesting equipment. California uses micro-sprinkler and flood irrigation which do not interfere with harvesting equipment.

4. The Australian climate is different. Australia has more likelihood of summer rainfall events during harvest and hence orchard operations such as sweeping and pickup need to be responsive to possible rain. This means that Australian growers do not want to sweep large volumes of almonds ahead of the time of pickup. The issues are not wanting swept almonds to become wet as they may spoil and/or require respreading to redry the almonds.

5. Australian growers would like to have the option of being able to pick up almonds at a moisture content greater than final storage moisture content ahead of a rain event and use efficient and cost effective dehydration techniques to dry down the almonds. Some US and Spanish experiences also indicate hulling and shelling efficiencies increase following pre-cleaning and dehydration of all product, regardless of the starting moisture content.

6. The industry desires to eliminate health risks associated with dropping the almonds on the ground. There may become two classes of almond product, those caught from tree shaking and those collected from the ground. In California pasteurising of kernels exists to control health risks. Australia wants to keep its clean-green image and ideally avoid pasteurisation.

7. If product collected from the ground is minimised, opportunities become available to use soil management techniques that improve soil health, increased yields and reduced input costs.

8. Skilled orchard labour is hard to find and retain. The situation would be helped by de-skilling many of the orchard tasks.

In order to achieve the industry aims it was seen that R&D is required to investigate new types of equipment that:-

1. Provides automatic steering down rows (GPS and obstacle avoidance based). This will increase work rates and minimise equipment and tree damage.

2. Improves efficiency of tree shaking – removing more kernels quickly. Thus increasing work rate and eliminating carryover of crop into the next season by remaining on the tree (i.e. mummies) and therefore potentially being collected with the following season's harvest or providing a source of fungal contamination on the tree for the following season's crop. This could include different shaker technologies and the use of a continuously moving shaker vehicle with only the shaker head grabbing onto the tree as the vehicle continually moves along the row. This has been successfully achieved in Spain.

3. Does not need multiple passes of sweeping of kernels and is more tolerant of soil types and ground undulations. This could include integrating the sweeping with the pick-up operating, and using vacuum pickup which could work over dripper lines and small surface undulations. This reduces the number of workers and reduces risk of rain on swept almonds.

4. Better pre-cleans the almonds of sticks and soil at the time of: pickup, placing in the stockpile and loading onto a truck.

5. Dehydrates the almonds when they are in bunker or other storage without darkening the kernel from too high a temperature.

6. Removes the hull on-farm to increase transport/handling efficiency and potentially retain valuable nutrients or alternatively a fueld source for dehydration.

7. Minimises raised dust that carries fungal spores into canopies and almond fruit. In addition, dust can reduce photosynthesis and transpiration capability of the trees.

8. Collect windfalls as they remain a key issue in addressing shake and catch systems, quality deterioration and food safety risks.

4 INDUSTRY OVERVIEW, IMPRESSIONS AND R&D DIRECTIONS – PROCESSING

All processors have invested considerably in their facilities with the various almond processors taking quite different approaches and different set-ups of:

- On site storage of almonds in bunkers versus daily deliveries of almonds for processing.
- Large emphasis on dust extraction versus emphasis on multiple sorting machines.
- Single flow of kernels into processing line versus multiple tanks of almonds that can be blended into the line.
- Use of plastic bins versus use of wooden bins for the shelled kernels.

Of particular note is the large amount of equipment used for conveying around the almonds and the removal and storage of waste (hulls, shells and dust) in comparison to the actual equipment involved in the processing activities.

In the facilities visited, the hulling and shelling was conducted by modules of equipment with much back and forth/up and down movement of the product on a very complex path through the processing line. Also the flow was often one of spreading out, drawing in to load into an elevator and spreading out again.

In all cases the equipment has evolved over the years to quickly process almonds. New customer and food safety demands are requiring the processors to do an ever increasingly better job to; not damage the kernels, remove all contaminants, insect damage, rodent damage and mouldy kernels plus ensure food safety.

5 TOWARDS AN IMPROVED HULLING AND SHELLING PROCESSING LINE

An improved hulling and shelling processing line will be based on the following equipment principles, in the following order:

1. Uniform flow rate of kernels into the line (t/hour).
2. Early removal of sticks.
3. Removal of any metal and large contaminants before entering the processing line and causing damage/inefficiency.
4. Accurate screening with large deck (intermittent jumping screen) to remove all small stones (much smaller than almonds in shell but are of similar size once shelled) prior to hulling and shelling.
5. Hulling and shelling without damage to kernels (repeated multiple times with cleaning).
6. Cushioning of impacts of kernels to eliminate chipping.
7. Size grading of kernels (small, medium and large) and removal of splits using intermittent jumping screens
8. Use of gravity tables to remove stones, shell and shrivelled kernels on size graded product. They will work better with similar size kernels.
9. Final air separation.
10. Final size grading.
11. Laser scanning to remove mouldy kernels (this could be run off line, prior to storage of hulled and shelled product).

Chipped and scratched almonds are an inefficiency of the processing line and these must be minimised or preferably eliminated.

As mouldy kernels can be a large percentage of the crop, these should be removed prior to storage and accumulated for use in alternative products.

Hence, following the hulling and shelling stage there is the opportunity to produce a product that does not contain:-

- Foreign material (stones and other material).
- Chips and scratches as their sources have been eliminated.
- Mouldy, discoloured kernels that have a higher risk of spreading more mould and food safety issues.

This will eliminate the need for the packers to search for and remove contaminants plus mouldy, chipped and scratched almonds and will leave them with a final check and removal of any insect/rodent damage and ensuring food safety.

Intermittent jumping screen

The above mentions an intermittent jumping screen. This is an alternative screening technology developed to improve upon the bouncing ball screen sizing method. The intermittent jumping screen works on the principle of using the optimum screening motion for maximum material passage through the screen and allows a portion of the screen to become blinded by near size material resting in the screen deck holes. After a period of about 10 seconds (up to 20% of screen blinding is allowed to occur) the screen jumps vertically to release any material trapped in the screen deck holes. This provides more accurate and space efficient sizing of product. This technique has been used successfully for sizing products which are easily damaged and hard to screen such as flower bulbs (Israel flower industry) and sunflower seeds (Manoora Seeds, SA) and would be very applicable for almonds. A research screen using this principle is located at the UniSA, Mawson Lakes.

The following R&D is required to achieve the above aims:

1. Develop an understanding of the sources of chipping and scratching of almonds in the hulling and shelling process. As shown in the Appendix, a random sample of product leaving a huller and sheller showed it to contain 32% chipped almonds and 7% scratched kernels.

2. Develop methods to eliminate all chipping and scratching of kernels.

3. Determine the optimum screening parameters with respect to removal of stones and contaminants prior to hulling and shelling and size grading after shelling of:-

    a. screen deck apertures such as round or slot

    b. screen amplitude and direction

    c. screen acceleration (speed)

    d. screen length

4. Demonstration of the improvement in performance of gravity tables and destoners when using size graded product.

5. Integration of the above technologies into a new design of a hulling and shelling processing line which can produce size graded kernels that are free of contaminants.

6 TOWARDS AN IMPROVED PACKING LINE

The packers must be receiving size graded product that is free of contaminants. The packing line will consist of:

1. Multiple laser scanning to find multiple defects.

2. Repeat laser scanning to achieve required quality for specific defects.

3. Only with a low amount of chipped and scratched kernels will laser scanning be able to efficiently find and remove small areas of insect and rodent damage. Both insect and rodent damaged kernels must be totally removed from the final product.

4. Visual inspection for any non-kernel material (not to be used as a contaminant removal stage).

5. Final metal detection to remove any metal present.

6. Packing.

When using electronic sorting it is not good enough to just have one attempt to try and remove all defects. With a large number of defective kernels in the product, multiple attempts of high efficiency equipment will be required to get close to zero defective kernels remaining.

In order to have good detection of insect and rodent damage the kernels need to be free of chipping and scratching which have a similar appearance of the white kernel being exposed through the brown skin. As chips and scratches are avoidable and the elimination of the chips and scratches in the hulling and shelling stage is vital.

<u>The following R&D is required to achieve the above aims</u>

1. Undertake the work listed in the previous section so as to provide packers with a product that is free of contaminants and chipped and scratched kernels.

2. Rate the performance of various electronic sorting devices for both product checking and defect removal.

3. Determination of the number of electronic sorting machines required in series to provide the required level of contaminant removal.

Shaking of almonds (1 pass).

Sweeping of almonds (3 passes are undertaken).

The sweepers both comb the almonds to the centre of the row (front of machine) and blow almonds near the drip line and along the row of tree trunks into the next row (rear of machine).

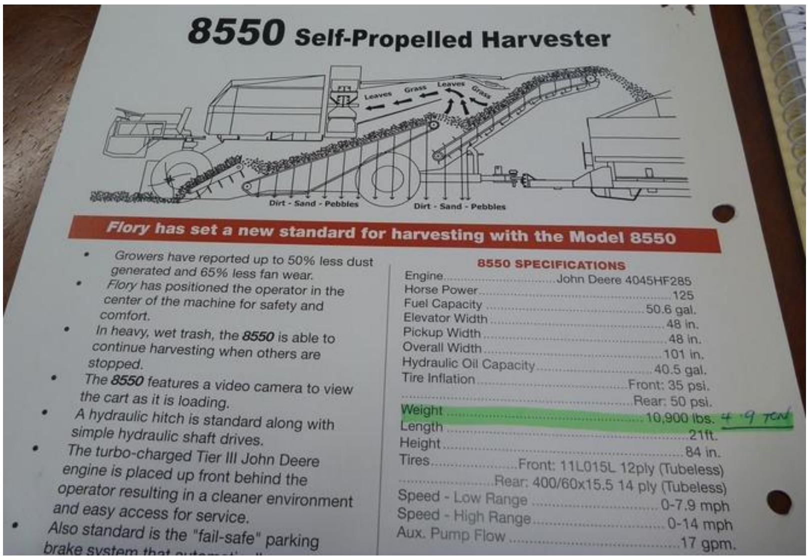
Final pass of sweeping (ready for pickup).

Note drip lines about 1m from the tree trunk.

A new style (Exact) sweeper has an additional rotary brush to help gather kernels. One of the 2 brushes was removed as it was too difficult for the operator to control.

Pick up of almonds (1 pass). Machines can have a stick remover fitted.

The pick up uses a rotating flap to lift the almonds onto a cleaning and transfer chain.



8550 Self-Propelled Harvester

Flory has set a new standard for harvesting with the Model 8550

- Growers have reported up to 50% less dust generated and 65% less fan wear.
- Flory has positioned the operator in the center of the machine for safety and comfort.
- In heavy, wet trash, the **8550** is able to continue harvesting when others are stopped.
- The **8550** features a video camera to view the cart as it is loading.
- A hydraulic hitch is standard along with simple hydraulic shaft drives.
- The turbo-charged Tier III John Deere engine is placed up front behind the operator resulting in a cleaner environment and easy access for service.
- Also standard is the "fail-safe" parking brake system that

8550 SPECIFICATIONS

Engine	John Deere 4045HF285
Horse Power	125
Fuel Capacity	50.6 gal.
Elevator Width	48 in.
Pickup Width	48 in.
Overall Width	101 in.
Hydraulic Oil Capacity	40.5 gal.
Tire Inflation	Front: 35 psi.
	Rear: 50 psi.
Weight	10,900 lbs. 4·9 TON
Length	21ft.
Height	84 in.
Tires	Front: 11L015L 12ply (Tubeless)
	Rear: 400/60x15.5 14 ply (Tubeless)
Speed - Low Range	0-7.9 mph
Speed - High Range	0-14 mph
Aux. Pump Flow	17 gpm.

Specification for pick up.

Haul out of almonds (note rear bumper which pushes against a lever on pickup to start transfer of almonds into the haul out vehicle).

Extra operation (i.e. Prepa-Jack) to lift almonds above swept row (undertaken following rain on swept row) plus undertakes removal of sticks.

Bunkers for storage of almonds awaiting dispatch to huller and sheller. Bunkers are generally within 2km of almond harvest.

Elevators can have a stick remover fitted and thus sticks are removed at the point of transfer to the bunker.

Almonds stored in sheds save the labour to place and remove large tarpaulins and eliminates sweating under the tarpaulin if the almonds are too wet.

APPENDIX – ALMOND PROCESSING

Almonds are brought to huller and shellers by trucks and emptied onto concrete pads or into an underground hopper.

Almonds are precleaned and placed in a silo prior to hulling.

The flow from the silo is regulated by the gate height.

Hulling and shelling is undertaken using shear rollers (upper) and a shear roller running over a belt (lower).

Following shelling, screening is used to remove the kernels with uncracked almonds being returned for shelling on a machine with a smaller clearance.

Air separation is used to remove pieces of broken hull and shell.

Destoners are used to separate stones from kernels. Air is blow up through a vibrating screen with the lower mass kernels moving down the screen and the heavier stones being lifted by friction up and over the top of the screen.

Gravity tables are used to separate various mass and density particles. Each chute represents a slightly different physical property.

Kernels are size graded and placed in plastic bags in a bin.

The final size graded product is not free of contaminants. Note mouldy kernels (dark) and small melons remaining.

Dehydration of almonds with excess moisture content is undertaken using:-

- Bins with a mesh floor with heated air blown up through the bin, or
- Placed in a heated tunnel previously used for prunes, or
- A wrapped vertical stack of four bins with a suction fan fitted on top that pulls ambient air through the base of the bottom bin (as used in garlic industry).

Both plastic and wooden bins are used for storage of shelled almonds.

Dust extraction and air cleaning forms a major part of process.

The hulls and shells are placed in stockpiles for later sale (primarily as a stock feed).

Fumigation of almonds on receival.

Fumigation in boxes is also undertaken with spear going into the sealed plastic liner.

A pre-cleaning line to remove foreign material using a laser scanner.

Colour sorters are used to remove chipped (light patches) and mouldy (dark) kernels. The settings determine the size detected and hence the number removed. Good kernels are ejected alongside each reject removed. These lane based machines use a portion of the lanes to rework the discharged material.

Kernels rejected by a colour sorter.

Cascades to reduce damage to falling almonds.

Typical contaminants delivered with kernels from huller and sheller (mainly stones that are smaller than the almond in a shell).

Hand sorting is still used but plays only a checking role.

The electronic sorting machines are not removing all of the defects.

Many of the chips are caused by impacts with other almonds.

Automatic sample collection is used.

Processing is undertaken up high and needs many elevators and platforms.

APPENDIX – ALMOND DAMAGE/ SORTING EFFICIENCY – BACK OF THE ENVELOPE REVIEW

During the visits a sample of almonds was collected at the start and end of a packing line.

Analysis of the sample of almonds, as delivered from the huller and sheller showed:-

	Number	%
Good kernels	455	58.1%
Scratched kernels	34	7.5%
Chipped	253	32.0%
Insect	36	4.6%
Deformed	5	0.6%
Total	783	

Following the final sorting and being ready to pack, a sample of the same batch of almonds showed:-

	Number	%
Good kernels	588	70.3%
Scratched kernels	52	8.8%
Chipped	193	23.1%
Insect	3	0.4%
Deformed	0	0.0%
Total	836	

Knowing that the total number of undamaged kernels cannot increase from processing (only defective almonds are removed but there is a possibility that more chipped and damaged kernels can be created) a trial and error analysis showed that the samples could be balanced if the following sorting efficiencies occurred:-

	Efficiency	% kernels in starting sample	No. removed from a batch size of 100 kernels	% kernels in end sample
Removal of good kernels	0%	58.1%	0	69%
Increase in scratched kernels	0.8%	7.5%	0.8	9%
Removal of chipped kernels	45%	32.0%	14.4	21%
Removal of insect damaged kernels	94%	4.6%	4.3	0.4%
Removal of deformed kernels	100%	0.6%	0.6	0.0%
Total			20.1	

The method of collecting samples and analysing them was crude as an accurate test needs to examine the finished product and the contaminants removed for a more precise result.

Despite this the results indicate the following:-

1. Nearly one third of the kernels were chipped and 7.5% were scratched.

2. A small number of kernels had insect damage.

3. The cleaning process at the packer had many product movements and resulted in just less than 1% of kernels being scratched.

4. Approximately 45% of the chipped kernels were removed (this was evidenced by the large number of chipped kernels removed by the hand sorters).

5. There was a very large percentage of the kernels that were removed and downgraded in the final cleaning process.

6. There was a high level of efficiency (94%) for removing insect damaged kernels. However many insect damaged kernels remain. (4 in every 1000 kernels still had insect damage).

The implication from these results are:-

1. The source of the high number of chipped kernels needs to be identified and eliminated. This will give a higher quality product, reduce downgrading/segregation and increase yield as the chipped pieces are not lost from the product.

2. The sources of the scratched kernels must also be identified and eliminated.

3. By reducing the white portions of kernels from chips and scratches the electronic sorters (colour and laser) will be able to be more finely tuned to detect and eject the kernels with insect damage.

4. If the sorting of insect damage can be repeated from 94% ejection to 94% x 94% this will then result in a change :-

   from 460 insect damaged kernels/10,000 kernels

   to 27 insect damaged kernels /10,000 kernels (94% removal)

   to 1.7 insect damaged kernels /10,000 kernels (94% x 94% removal)

Appendix 5 – Samuel Tok, Identifying sources of mechanical damage in almond processing.

UNIVERSITY OF SOUTH AUSTRALIA

School of Advanced Manufacturing and Mechanical Engineering

Bachelor of Engineering

in

Mechanical Engineering

Identifying sources of mechanical damage in almond processing

By Samuel Kwang Ming Tok

2011

ABSTRACT

Almonds that are damaged or blemished fetch a lower price on the commodities market. A significant portion of the damage that is inflicted on the almonds may be caused by processing. This is an area of concern for the Almond Board of Australia as the processing of the almonds may be destroying some of the value of the crop. This study aims to identify the sources of mechanical damage in almond processing.

A series of site visits were carried out in order to understand the whole process flow of almonds from harvest to the final packaging. The probable sources of mechanical damage identified were the primary processing and secondary processing facilities. It was found that there was negligible damage whilst the kernel remained in the shell. A sampling study and data analysis further narrowed down the source to the primary processers.

The primary process of removing almond hulls and shells known as hulling and shelling was studied in detail in order to understand the mechanical processing involved. Samples were taken from each stage of the hulling and shelling process and examined to identify and quantify the mechanical damage present in the almonds. The data was then studied and analysed to find the forms of damage and the percentage of the almonds that are damaged at each stage. Machine settings data such as roller and belt speeds and diameters were obtained and used to extimate the velocities that the almonds are subject to when going through the machines.

The study also measured the thickness and width of the in-husk almonds, in-shell almonds and kernels to obtain size distribution data. It was found that the size of the in-shell almonds and its kernel did not increase in thickness or depth proportionally with the thickness and depth of the whole in-husk almond. As the thickness and depth of the in-husk almond increased, the thickness and depth of the in-shell almonds increased at a reduced rate and the thickness and depth of the kernels stayed within a narrow range.

The study determined the impact energy and velocity required to cause mechanical damage in almonds.

The almond kernels were subjected to impact tests from a pendulum impact tester. Almond kernels were impacted with a steel anvil, with the pointed end of another almond and with the pointed end of another almond with the targeted almond at an offset in order to produce a glancing impact affecting mainly the surface of the almond. The tests showed that impacting the almonds with an almond point required less energy to produce damage and even less energy with higher incidences of damage when the impact was offset. The energy levels required to produce damage by anvil, almond point and almond point with offset were 46.7mJ, 11.5mJ and 7.1mJ, respectively. The 46.7mJ required to produce damage in almond kernels using the anvil corresponds to dropping an almond kernel from a height of 3.9 m.

The almond kernels were then subjected to impact tests using a rotary arm impact tester. The study found that an impact velocity of 5.5 m/s will damage 1 in 10 kernels and at 19 m/s all of the tested almond kernels were damaged.

The study has produced results that identify the shear rollers and belts of the hulling and shelling machines to be a significant source of mechanical damage to the almonds. It has also identified energy levels and velocities that damage almonds and information on the anatomy of almonds. The study also found that the almond kernels are mechanically damaged after removal from its shell by the hulling and shelling process.

The results of this study imply that the almond kernels should be kept inside of their shells until ready for the hulling and shelling process in order to prevent damaging them. The shear rollers and belts of the hulling and shelling machines are causing damage to the almond kernels and further studies should be carried out to improve the hulling and shelling process in order to reduce mechanical damage to the kernels.

DECLARATION

I declare that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

22 November 2011

Samuel Kwang Ming Tok

ACKNOWLEDGEMENT

I would like to thank my project supervisor Associate Professor John Fielke for his supervision, guidance and support throughout the project. I especially appreciate Associate Professor John Fielke's patience with guiding me in the technical writing aspects of a thesis and his guidance from his extensive experience in research and in the agriculture industry.

I would also like to thank the Almond Board of Australia for initiating this study and giving me the opportunity to work with the local almond industry. I wish to thank Ben Brown, the Industry Liaison Manager of the Almond Board of Australia, for arranging the industry site visits, without which the project would not have been possible. A word of thanks also to everyone who assisted in the project during our site visits at AlmondCo, Jubilee Almonds, Laragon, Riverland Almonds, Simarloo and Select Harvest Orchards.

I thank Mr. Tony Costa of Costa Almonds who was most helpful during my site visits, process and sampling study. The involvement of Costa Almonds in this study was crucial to its success and is most appreciated.

Most of all, I would like to thank my family who have always stood by me and for their support especially during this period. I thank my wonderful wife Karine who literally handled most of our family's affairs so that I could complete my studies. I thank my sons, Shann and Cornelius for understanding that their Papa was working during the times that I was glued to my laptop analyzing data or writing my thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

1.1 Health benefits of consuming almonds

Almonds have been consumed since ancient biblical times. They were a valuable commodity transported from Asia into the Mediterranean, into Greece, Turkey and the middle east on the Silk Road (Almond Board of Australia, 2009). Since ancient times, many have believed that consuming almonds are beneficial to them. This has been endorsed by the National Heart Foundation of Australia as almonds and other nuts are listed on their Healthy Tick list of foods (National Heart Foundation of Australia, 2011). They are a natural source of healthy unsaturated fats. It has also been concluded that the consumption of almonds lowers LDL cholesterol (Abbey et al., 1994; Kris-Etherton et al., 2009). Obesity and Diabetes Week (NewsRx, 2003) reports on a study that proves almonds can help individuals to achieve weight loss goals. Another study conducted by the Institute of Food Research (IFR) has found that finely ground almonds are a potential prebiotic (Nutraceutical Business & Technology, 2009).

1.2 The Australian market share of almonds

The top three almond producers in the world are California, Spain and Australia. The market share of these three producers are 82% for California, 8% for Spain and 3% for Australia (Almond Board of Australia, 2010). In 2010, Australia produced an estimated 45,400 tonnes of almonds (Fell et al., 2011) compared with California's production of 748,427 tonnes (Western Farm Press, 2010). The total estimated amount of Australian almond plantings have increased by 5% from 2009 to 2010 and as these plantings mature, it is forecasted that Australia will overtake Spain to be the second largest producer of Almonds within the decade (Almond Board of Australia, 2010).

The Australian Nut Industry Council president, Brenton Woolston told the Advertiser in March 2008 (Austin, 2008), that the almond industry will grow to produce 77,000 tonnes in 2015. The Almond Board of Australia (2009) provided an updated forecast of 80,000 tonnes of almond production by 2015. This appears to be a valid prediction as three quarters of the Australian almond plantings have yet to reach full maturity (Almond Board of Australia, 2010; Almond Board of Australia, 2011).

1.3 The Australian almond industry

Australia does enjoy some advantages compared to the Californian almond industry. For a start, Australia produces a higher almond yield per hectare than USA (Almond Board of Australia, 2009; Olam, 2009). The Australian almonds also fetch a premium of about 7% more than the USA almonds due to better process management (Olam, 2009). However, the rainy season in Australia coincides with the harvesting of almonds. This presents some challenges for the industry as the rain will interfere with the harvesting process and exposes the almonds to increased moisture levels and the risk of mold growth (Brown, 2011).

As the production quantities are forecasted to increase, the Almond Board of Australia is also increasing its investment in research and development. It is especially important to consider if the industry has the technology and facilities to cope with the anticipated quantities that will pass through the processing plants.

The Almond Board of Australia has initiated this project by requesting the University of South Australia to assist in industry improvements. The main concern is the efficiency, capacity and ability of existing facilities to process the almonds. As the production quantities increase up to 2015, the processing capacity has to be increased to cope with the future growth.

The Almond Board of Australia would like to see research and developments in several areas. These can be broadly classified into the areas of harvesting, dehydration techniques, damage prevention and secondary processing improvements (Brown, 2011).

In order to understand the almond industry, a number of visits to almond orchards and processors were conducted with the support of the Almond Board of Australia. The information that follows was gathered from these visits to AlmondCo, Jubilee Almonds, Laragon, Riverland Almonds, Select Harvests, Simerloo and Costa Almonds.

1.3.1 Growing and harvesting almonds

The almonds are a tree nut and grown in an orchard. When it is time to harvest the nuts, the nuts are shaken off the trees, collected and stored awaiting delivery to the primary processing facilities.

1.3.2 Primary processing of almonds

The primary processing of almonds is known in industry as hulling and shelling. This is the process of removing the hulls and shells of the almond so that only the edible kernel remains. The kernels are size graded at this stage before being sent to the secondary processors.

1.3.3 Secondary processing – sorting and packing almonds

The secondary processing of almonds involves sorting and grading the almonds. The process uses machine vision systems. The almond kernels go through the sorting machines that pick out the bad or lower quality almonds from the good ones. The kernels which have color differences, chips, scratches, mold or insect damage are removed from the good ones by air ejectors.

1.4 Objectives and scope of project

The removal of the hull and shell of the almonds is a necessary process and without doubt adds value to the product. The general public is used to buying almonds that have been shelled and are ready to eat (or used in recipes). Therefore, the process of removing the hulls and shells makes the almonds marketable.

Since visual presentation plays a part in the price of almonds, it is important to prevent damage to the almond kernel. Mechanical damage in the form of chips or scratches to the kernel will obviously be recognized as defects. Excessive mechanical damage would cause the price of the almonds to be downgraded. This is highly undesirable and mechanical damage has become a necessary evil that reduces some of the product's value.

The scope of this project is to find the sources of mechanical damage and to develop ways to minimize them in order to retain the product value.

1.4.1 Identify and rank sources of mechanical damage

The process from harvest to packing uses a variety of machinery which is possibly inflicting mechanical damage to the almond kernels. In order to reduce mechanical damage as much as possible, the first part of this project aims to find the sources of mechanical damage to almonds. After ascertaining the sources of mechanical damage, future studies can be carried out based on the results of this study to intervene and find solutions to minimize the damage.

In order to identify the source of mechanical damage, product samples were collected at inputs and outputs of all primary and secondary stages of processing. The almonds from each stage were then examined for mechanical damage, in order to narrow down the sources of mechanical damage.

1.4.2 Finding out the dimensional characteristics of almonds

The next step of the project was to measure and record the dimensions of the almonds. The information obtained will be useful for understanding the anatomy of almonds and proposing future machine settings.

In order to do this, a random sample of almonds was taken from the orchard for data collection. Data was collected on the dimensions of in-husk almonds, in-shell almonds and almond kernels.

The information was sorted, to provide the size distribution and range of in-husk almonds, in-shell almonds and almond kernels. This information will provide important information in determining the suitability of existing equipment and for further studies in improving the equipment and processes.

1.4.3 Rate current sorting capability

The almond kernels are sent to the secondary processors after they have been shelled. This stage of processing concentrates on removing foreign objects such as sticks and stones as well as blemished almonds. Almonds that are blemished are rejected from the lot.

There are two issues to be considered in this area. The first issue is that there is anticipated growth in the industry. The equipment in use has to be able to cope with the demands of the industry growth. The almonds being processed have to be sorted quickly and efficiently in a single pass if possible. If multiple passes are required, the equipment would be tied up with sorting the same batch of almonds multiple times. This means that the plant will not be able to operate effectively. Time will be wasted sorting the same almonds over and over again.

The second area of concern is that the standards required by the customers are getting more stringent. The customers are expecting almost zero defects in the delivered products. This has proved to be a challenge with the present equipment. In order to satisfy customer demands, the equipment has to be capable of sorting to a standard that is acceptable to the customer.

The objective of the second part of the project is to study the efficiency of the present machines. There are various machines using different sorting techniques available.

The main principle is that the machines will analyze light that is reflected off the product to determine color conformity to specifications (Antosh, 1985). Every machine will have its strengths or weaknesses.

The existing machines can be rated by taking product samples from both the “accept” and “reject” streams of the machines. The samples can then be inspected for the quantity of blemished almonds in the accepted stream and the quantity of good almonds in the reject stream. This will provide data on the accuracy of the machines.

The project findings on the accuracy of the machines can then be presented to the Australian almond industry for further review. It is anticipated that the findings will aid the Australian almond industry to better understand the capabilities of the machines. This will also help the industry to determine if further studies will be required with regards to future plant equipment upgrades.

2. Literature review

2.1 Anatomy of almonds

The fruit of the almond tree consists of a kernel encased by a shell and a hull (Esfahlan et al., 2010). When the fruit is dry enough, the hull splits open to reveal the shell as shown in Figure 2.1. The almond has to have the hull removed and the shell cracked in order to get to the edible kernel.

Figure 2.1 Almond in split hull, in shell and kernel.

Almonds can also be catagorized into hard shelled and soft shelled varieties. In today's market, the soft shelled varieties are more valuable with the Nonpareil variety fetching the highest prices (Western Farm Press, 2009).

2.2 Mechanical properties of almonds

Hard and soft shelled varieties of almonds possess different mechancial properties. A comparison study was done on the mechanical properties of Gulcan and Nonpareil almonds. Gulcan is a hard shelled variety and Nonpareil is a soft shelled variety which has a shell that is soft enough to be broken by hand. The study found that there are very big differences in the force required to crack open hard or soft shell varieties of almonds (Aktas et al., 2007).

Their study was focussed on the Southeast Anatolia region in Turkey. In this region, the almonds are cracked when they are fresh, dried or after being stored according to the market conditions. Thus, the study conducted experiments at three different moisture levels of 7.2%, 22.9% and 33.6% of in-shell moisture level. In order to attain the exact moisture levels required for the experiment, the almonds were dried or had distilled water added to them in a sealed glass jar. The almonds were then left for storage at 5°C in the sealed glass jar and thoroughly mixed at regular intervals to ensure equilibration.

The dimensions and weight of the Gulcan cultivar was compared to the Nonpareil cultivar before the almonds were cracked. The Gulcan cultivar was found to be bigger and heavier than the Nonpareil. Increasing the moisture level also caused a significant increase in the length and sphericity of the almond dimensions for both cultivars.

The moisture level also caused significant variation in the force required to crack the almond shells. It was found that increasing the moisture content of the in-shell almonds reduced the force required to crack open the shells of both varieties. This was supposedly because the shell becomes soft and weak when it has absorbed water. The results of Aktas et al's (2007) study was in agreement with the results of another study carried out by Aydin (2003) which came to the conclusion that increased moisture levels decreased the compressive force required to rupture almond nuts and kernels.

Aktas et al's (2007) study found during experiments that the shell had to be compressed and deformed by 2mm to 3mm before the maximum rupture force was reached. The amout of compressive force required to rupture the in-shell almonds was minimum along the x-axis and maximum along the y-axis as defined in Figure 2.2. The amount of force required to rupture the in-shell almonds was also substantially lower for the Nonpareil cultivar compared to the Gulcan cultivar. The maximum and minimum energy absorbed by the in-shell Gulcan cultivar before rupture was 831.57mJ along the y-axis at 7.2% moisture level and 190.40mJ along the x-axis at 33.6% moisture level respectively. The Nonpareil cultivar's maximum and minimum energy absorbed along the same loading axes and moisture levels were significantly smaller at 79.86mJ and 11.21mJ.

The energy absorbed by the in-shell Gulcan cultivar along the z-axis before rupture was 755.28mJ at 7.2% moisture level, 466.19mJ at 22.9% moisture level and 221.02mJ at 33.6% moisture level respectively. The energy absorbed by the in-shell Nonpareil cultivar along the z-axis before rupture was 75.62mJ at 7.2% moisture level, 57.57mJ at 22.9% moisture level and 24.26mJ at 33.6% moisture level respectively.

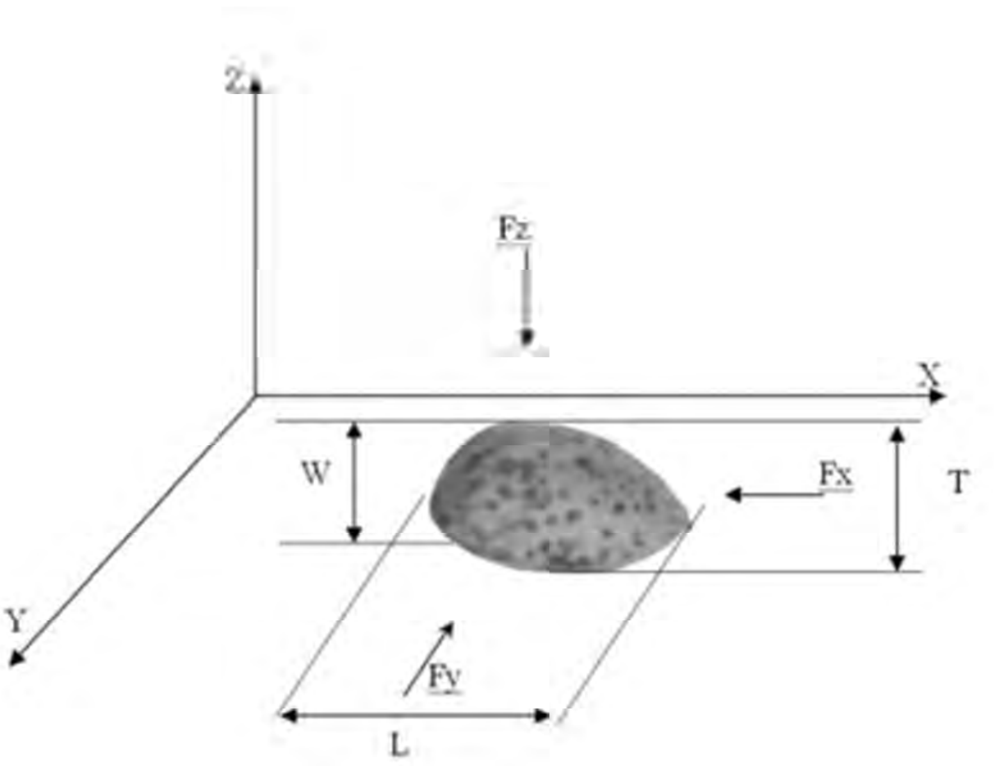


Figure 2.2 Definitions of axis used by Aktas' study (Aktas et al., 2007).

2.2.1 Mechanical properties of other nuts

Studies on other nuts was used to compare the results obtained by Aktas et al's (2007) study.

A study on the fracture resistance of pine nuts under compression determined that increased moisture levels resulted in a reduction in the compressive force required to fracture the pine nuts (Vursavus and Özgüven, 2005). The study also found that the pine nut shells required the lowest rupture force, deformation and required power when the compressive load is in the vertical orientation as shown in Figure 2.3. When the shape profile of the pine nut is compared with the almond, compression force in the vertical orientation of the pine nut corresponds to compression in the x-axis of Aktas's almond.

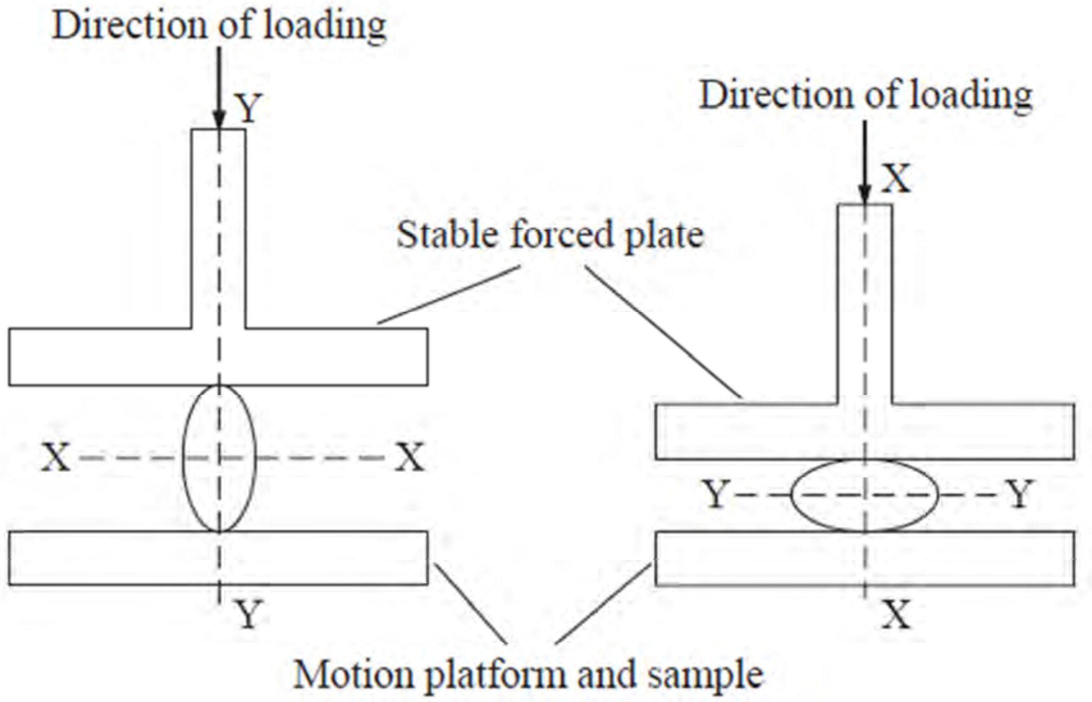


Figure 2.3 Pine nut compression load in vertical orientation (left) and horizontal direction (right) (Vursavus and Özgüven, 2005).

A study on the cracking characteristics of walnuts concluded that the least amount of force is required to crack the walnut along its length as defined in Figure 2.4 (Koyuncu et al., 2004). When the shape profile of the walnut is compared with the almond, applying a compression force along the length of the walnut corresponds closely to compression in the x-axis of Ak-tas's almond.

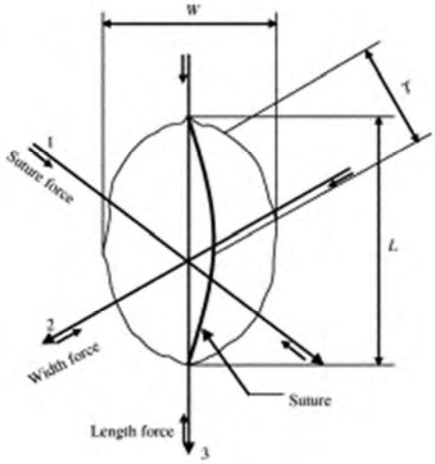


Figure 2.4 Definitions of walnut length, width and suture (Koyuncu et al., 2004).

A study on the behavior of pistachio nuts under compression loading also found that increasing the moisture level in the nuts resulted in reduction in the force required for rupture. However, the study found that the highest level of energy was required when attempting to rupture the pistachio along the x-axis as shown in Figure 2.5 (Galedar et al., 2009).

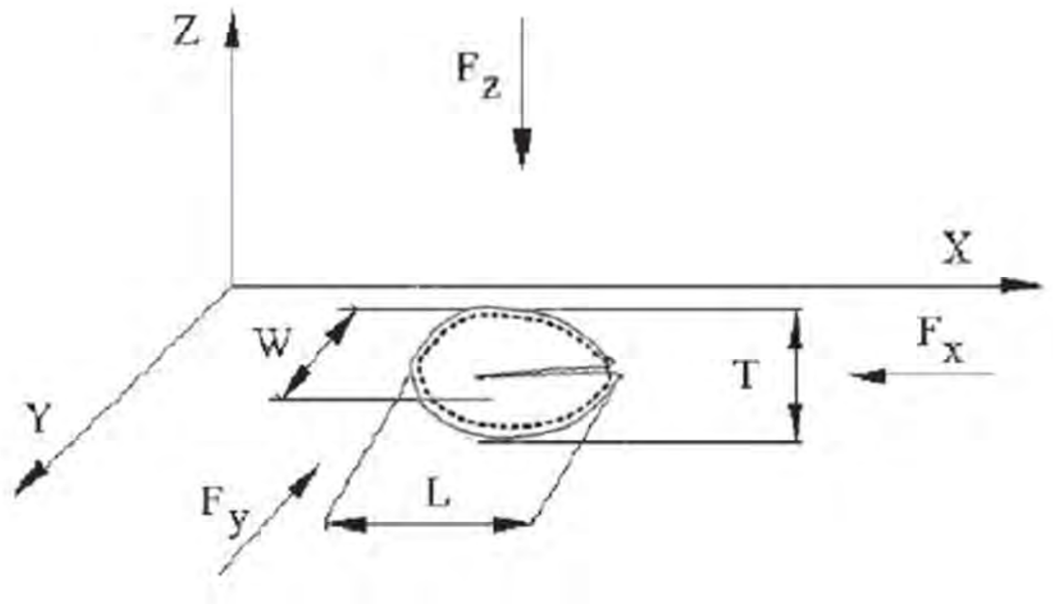


Figure 2.5 Definitions of pistachio nut axis by Galedar et al (2009).

2.2 Almond growing and harvesting

Almonds are grown in an orchard and harvested using a variety of machines. A visit to Jubilee Almonds' Orchard organized by the Almond Board of Australia was pivotal to understanding the growing and harvesting processes as described here.

2.2.1 Pollination of almond trees

Almond trees are not self-pollinating by nature. Several varieties need to be planted in close proximity of each other in order for the almond flowers to be pollinated by bees so that the trees can bear fruit (The Fresno Bee, 1995; Cline, 2010). The growers will hire bees from beekeepers during the pollination period so that the bees can pollinate the almond flowers (Goddard, 2007; Western Farm Press, 2010).

2.2.2 Almond varieties

The major varieties presently grown in Australia according to a 2010 survey are Nonpareil (50%), Carmel (32%) and Price (12%) plus others such as Fritz and Mission (Almond Board of Australia, 2010). Figure 2.6 shows these almond varieties and the differences in the kernel appearance.

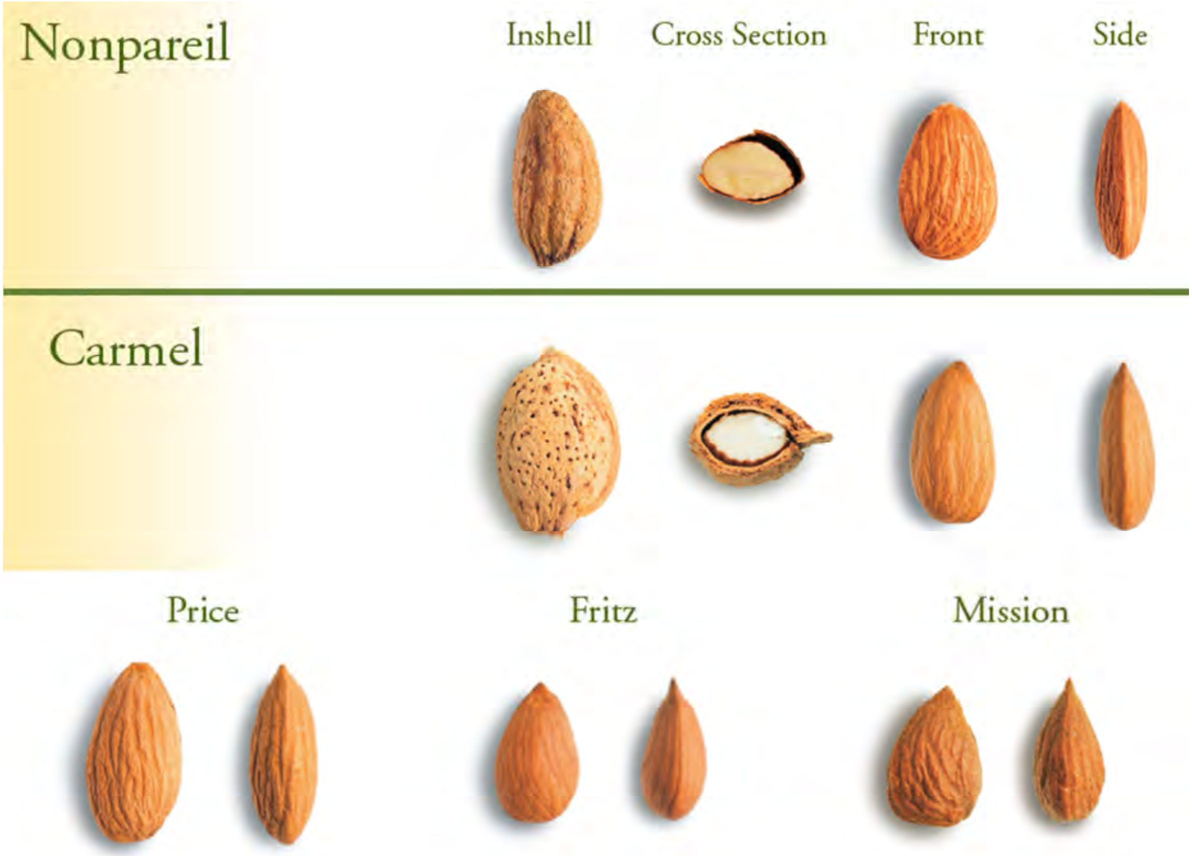


Figure 2.6 Almond varieties grown in Australia (Almond Board of Australia, 2009).

2.2.3 Segregation of almond varieties in the orchard

The need for different varieties to be planted in the same orchard poses a problem for the growers. Almond varieties fetch different market prices and mixed varieties of nuts are sold at marked down prices. This means that the growers have to maintain segregation of the harvested nuts in order to fetch the highest possible prices for their produce.

Segregation of variety is achieved firstly by planting each almond tree variety in a row as shown in Figure 2.8. Each row is dedicated to that one particular variety. The most valuable variety is the Nonpareil (Western Farm Press, 2009); thus the Australian growers usually have this variety on every other row. The rows of trees are also spaced far enough to avoid mixing of any fruit that falls onto the ground.

2.2.4 Almond harvesting process

Almonds are harvested using a mechanical shaker (The Fresno Bee, 1995). The almonds have to be dry enough in order to be harvested. If the almonds are too green, the shaker will not be able to shake them off the tree. The shaker is driven up to the tree and padded hydraulic clamps clamp onto the tree trunk. The tree is then shaken and the almonds, leaves and sticks fall to the ground as shown in Figure 2.7.

Figure 2.7 Almonds being harvested with a mechanical shaker.

After drying, the almonds are swept into windrows with a sweeper machine. Once the almonds (and leaves) are in windrows, they are left on the ground to further dry out. Figure 2.8 shows the almonds in a windrow.

Figure 2.8 Almond trees planted in rows and an almond windrow in the middle .

The almonds are then picked up with another machine called a 'pickup'. The pickup has an integrated desticker to remove sticks from the almonds. The desticker is effective only for the larger sticks and smaller sticks and twigs are still present in the harvested almonds. Figure 2.9 shows the pickup in operation.

Figure 2.9 A pickup with an optional integrated desticker in operation.

The almonds collected by the pickup are transferred into a bankout which transports the almonds to the storage facilities. This allows the pickup to keep doing its job of collecting almonds off the ground. The bankout’s tray can be tipped to the side to unload the almonds into the tray of the elevator. Figure 2.10 shows a bankout and the elevator into which it unloads the almonds. The elevator hooks the sticks off from the main conveyer with a desticker and deposits them onto a different conveyer. The main conveyer deposits the almonds into the bunker and the sticks are deposited into the bin on the left.

Figure 2.10 Picture of a bankout and elevator.

The harvested almonds are then stored until the primary processors are ready to receive them for processing.

2.2.5 Post harvest almond storage

In the Australian almond industry, the growers have to store the almonds until the hullers and shellers are ready to receive them for processing. Most Australian hullers and shellers do not have storage facilities for the almonds. Therefore, if the processing capacity of the hullers and shellers does not keep up with the increased quantities produced by the orchards, the almonds will have to be stored for longer periods of time before the hullers and shellers and packers are ready to receive them.

While some growers may have purpose built sheds, most of the almond growers store their almonds in tarpaulin covered bunkers. Figure 2.11 shows an almond storage shed and bunker. The storage bunker presents a cost effective solution as it is simply an open concrete enclo-sure to contain the almonds in the area. The almonds are covered by a tarpaulin to protect them from the rain. The tarpaulin affords protection from the rain, but has the problem that almonds ‘sweat’ under it as the moisture is trapped. The shed does not have the problem of trapped moisture under a tarpaulin but requires a higher investment.

Figure 2.11 Storage shed for almonds (top) and storage bunker (bottom).

2.3 Primary processing – hulling and shelling of almonds

The primary processing of almonds involves the removal of its husk and shell. This process is accomplished by shearing the almonds between a pair of rollers and then between a roller and belt that rotate with a speed differential. The shearing effect breaks the hulls and shells from the kernel. The almonds are then passed over a screen to remove the loose kernels before re-peating the process on the next stage. The space between each subsequent stage of rollers is reduced to hull and shell increasingly smaller almonds. Throughout each stage, the kernels are separated from the hull and shell remnants using gravity tables or vibrating screens as seen in Figure 2.12. The final step of the process is to grade the almonds by size through a series of sizing screens as seen in Figure 2.13.

Figure 2.12 Vibrating screens with round holes separate kernels from husk and shell remnants

Figure 2.13 Overhead vibrating screens size grade and drop kernels into the respective bins below.

2.3.1 Patents related to hulling and shelling

The technique of using rollers to shear off the husk and break the shells of almonds has existed since 1917 when an inventor patented a machine that hulled almonds and cracked their shells by shearing them between a roller and a stationary bow shaped member, then separated the loose kernels with reciprocating screens (Vaughn, 1917). Figure 2.14 shows part of a drawing of the invention with the roller labeled item 26 and the bow shaped member labeled item 28, items 14 and 17 are the reciprocating screens.

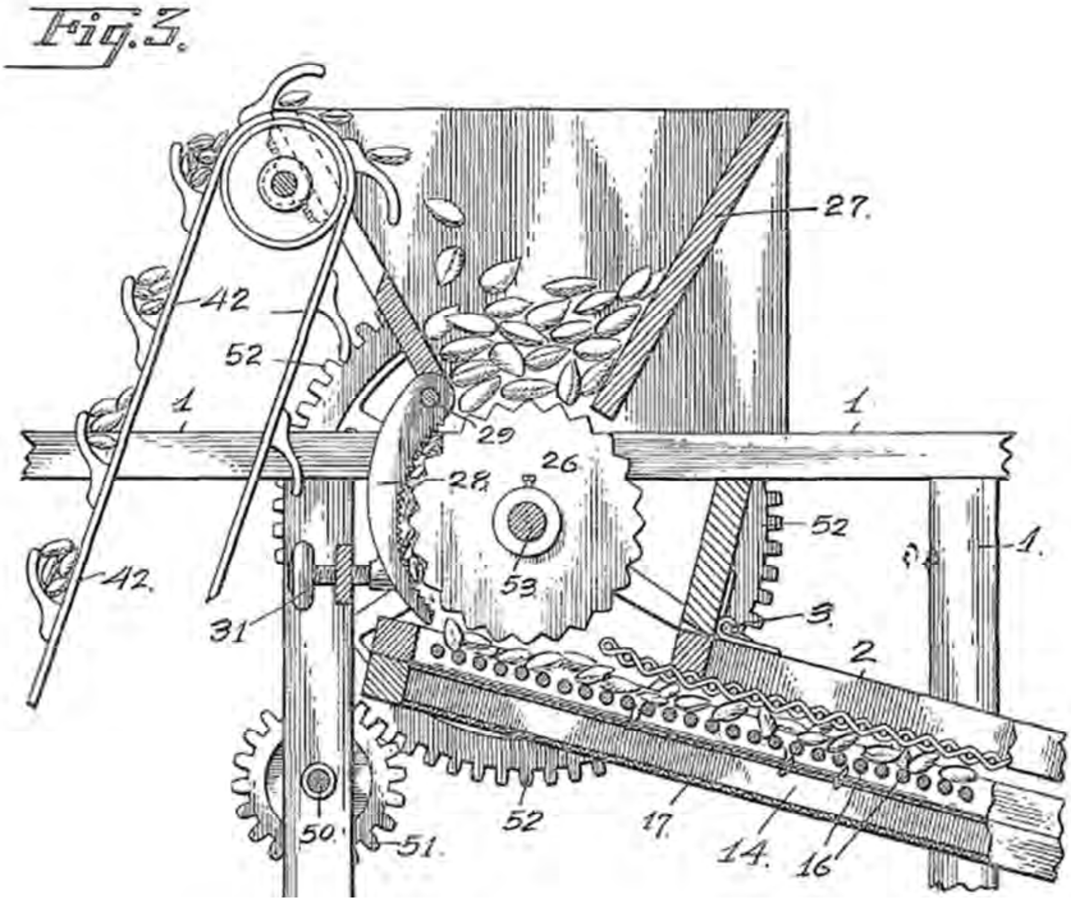


Figure 2.14 Machine patented in 1917 for hulling and cracking almonds (Vaughn, 1917).

The same inventor also patented an improved machine based on his previous patent with improved screens and a vacuum device to separate the unwanted husk and shell remnants from the kernels (Vaughan, 1925). Figure 2.15 shows the patented invention with the screens labeled as items 76 and 82.

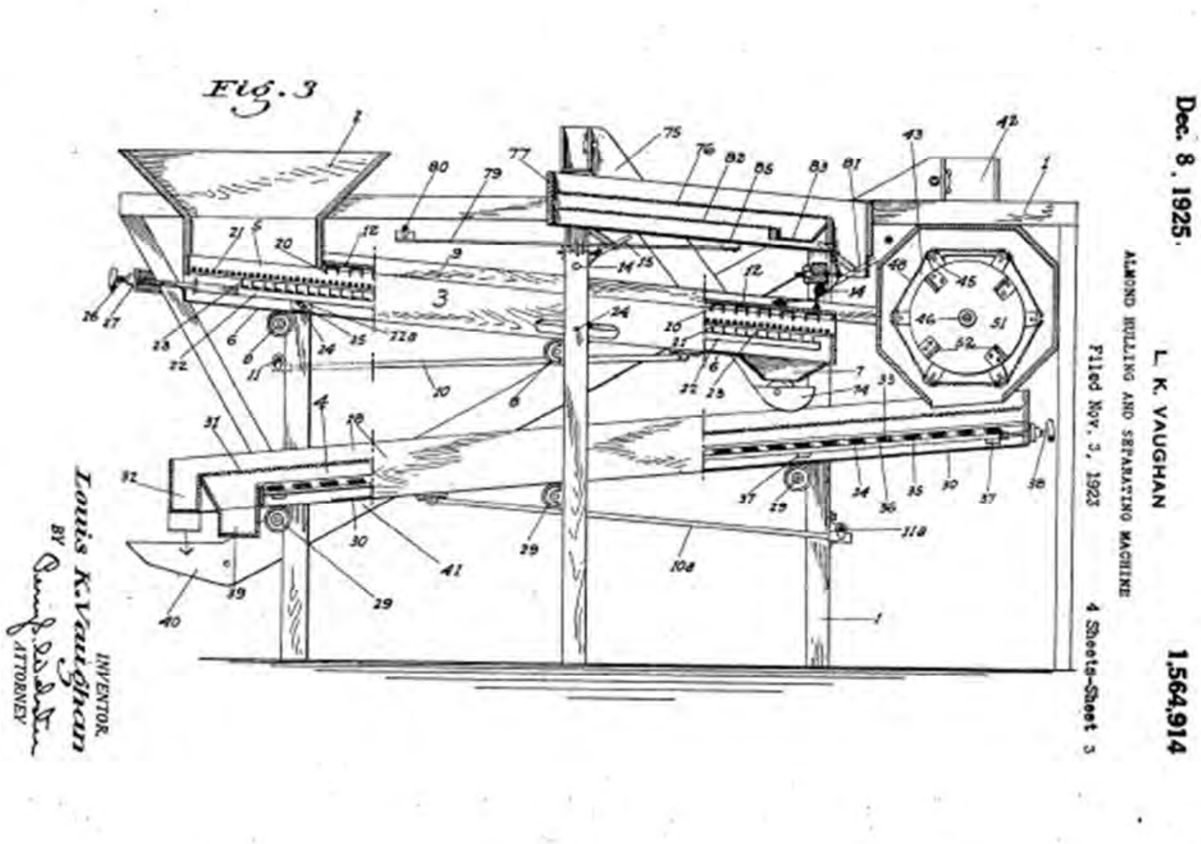


Figure 2.15 Vaughan's patented machine with screens (items 76 and 82) for separating husk and shell remnents (Vaughan, 1925).

An invention for hulling pistachio nuts as shown in Figure 2.16 was patented in 1981 (Volk, 1981). This invention uses a roller with projections and a stationary member with slots in order to hull the pistachio nuts. The design is similar to Vaughn's 1917 invention which uses a roller and stationary member to hull and shell almonds. The method of hulling in both inventions essentially uses the same means of imposing a shear force on the nuts.

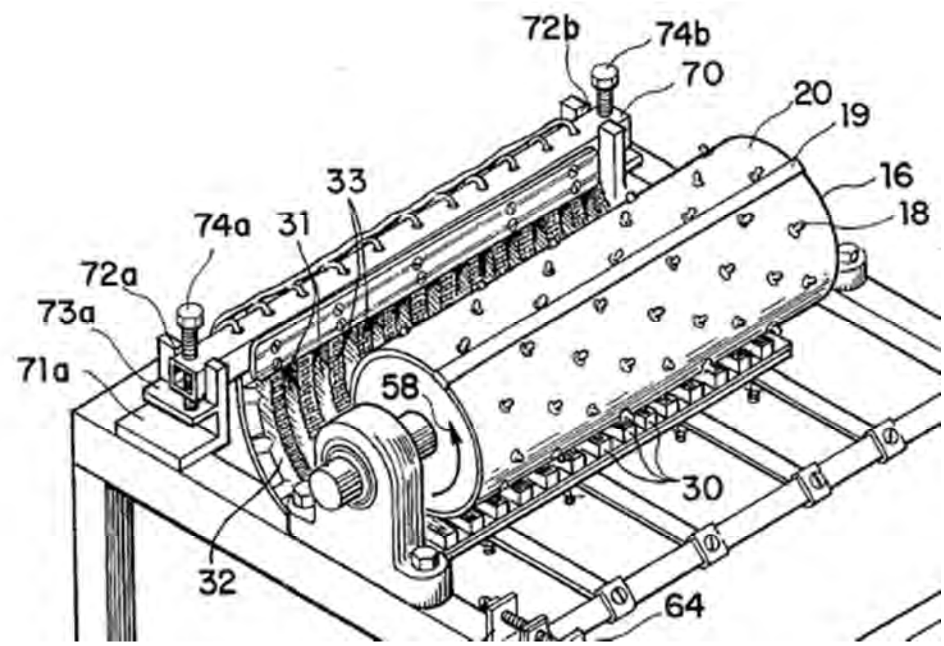


Figure 2.16 Patent for pistachio nut huller (Volk, 1981).

2.3.2 Moisture level parameters of almonds for efficient hulling and shelling

The moisture content of the almonds is important for efficient hulling and shelling. According to Don McKinney, Chairman of the Central California Almond Growers Association, the almond kernels should not have more than 5% moisture content (Cline, 2006). High moisture content not only promotes mold growth but also causes the hull to be rubbery. The almond would not be hulled effectively with a rubbery hull as the hull will compress rather than split under the rollers. The Australian industry guideline for almond kernel moisture content is 6% moisture content and 15% moisture content for the hull (Brown, 2011). If the moisture content is significantly above these values, the delivery of the almonds will be rejected by the primary processor (Stoeckel, 2011).

2.3.3 Size grades of almond kernels

The final part of the hulling and shelling process is to size grade the almond kernels.The USDA (1997) standards of specifying the range in number of whole almond kernels per ounce is an internationally recognized method. The USDA count range per ounce standards is:

- 16 to 18, inclusive.
- 18 to 20, inclusive.
- 20 to 22, inclusive.
- 22 to 24, inclusive.
- 23 to 25, inclusive.
- 24 to 26, inclusive.
- 26 to 28, inclusive.
- 27 to 30, inclusive.
- 30 to 34, inclusive.
- 34 to 40, inclusive.
- 40 to 50, inclusive.
- 50 and smaller.

There is no tolerance allowed when a range is specified. Therefore, if the range specified is 16/18, there has to be no less than 16 and no more than 18 kernels in an ounce.

The Australian almonds are sized graded as per international and USDA standards (Almond Board of Australia, 2010).

2.4 Secondary processing – colour sorting and packing almonds

The secondary processing of almonds subjects the almonds to a colour sorting process before packing them.

As with most other products, almonds are sorted and graded by its quality and appeal. The fewer defects the product has, the higher the price it can fetch on the market. As with any agricultural product, it is to be expected that there will be some variation in the product quality, appearance and size.

Almonds are graded according to standards established by a recognized authority such as the United States Department of Agriculture (USDA) or the Almond Board of Australia. A third party or independent authority is required as the third party will not be deemed as having a direct interest in the selling price of the product. Buyers are able to refer to the standard and know what to expect for the price that they are paying.

2.4.1 Almond grade categories

The USDA has defect tolerances for each almond grade. The USDA standard categorizes almonds into seven grades. The grades in descending order of value are U.S. Fancy, U.S. Extra No. 1, U.S. No. 1, U.S. Select Sheller Run, U.S. Standard Sheller Run, U.S. No. 1 Whole and Broken and U.S. No. 1 Pieces (USDA, 1997).

The Almond Board of Australia uses slightly different terms to grade the almonds. The Almond Board of Australia categorizes almonds into grades known as Fancy, Extra Supreme, Supreme and Manufacturing (Almond Board of Australia, 2010).

The defect categories for almonds are: dissimilar varieties, doubles, foreign material, kernels damaged by chipping or scratching, particles and dust, split and broken kernels, bitter almonds, serious damage and other defects (USDA, 1997).

2.4.1.1 Almond pricing by grade

Almonds are graded according to their size and visual presentation (Axelrod, 2011). The best grades are called 'fancy' grade. Naturally, there is a small percentage of defects allowed, beyond which the almonds will be downgraded to a lower grade (USDA, 1997). Lower grading means that a lower price would be paid for the almonds. Typically, the wholesale price of almonds starts from $5 a kilogram and drops by about 50 cents per kilogram for each grade that it is lowered.

2.4.2 The food safety standpoint for colour sorting

It is important for almonds to be of high quality and safe for consumption. There have been two separate incidences of salmonella contamination of almonds from California (Gary Gentile, 2004; The Cornucopia Institute, 2007). The two incidences were serious enough for the US government to legislate the pasteurization of almonds (Raine, 2007). There was also an Australian almond product recall in April 2011 due to the possible presence of salmonella (FSANZ, 2011).

In order to prevent food contamination, the Central California Almond Growers Association recommend proper rodent control and non-usage of manure or compost as fertilizer (Cline, 2006). This is because salmonella contamination usually occurs from contact with fecal matter, poor employee hygiene or sanitization practices (The Cornucopia Institute, 2007).

A study was done to find out if there is a correlation between aflatoxin contamination and the USDA grade of shelled almonds. The study found that high quality almonds only accounted for 3.2% of the aflatoxin mass while damaged grades of almonds accounted for 96.8% of the aflatoxin mass (Whitaker et al., 2010). The study concluded that the use of sorting techniques have the potential to effectively remove aflatoxin-contaminated kernels thereby reducing overall aflatoxin content of the lot to acceptable levels.

There have been other similar studies carried out. A study on brazil nuts found that sorting by size, density difference and Near Infra Red spectrophotometry resulted in selected nuts with no aflatoxin detected (Scussel and Mello, 2009).

Another study claims that the removal of discolored peanuts by color sorting removes most aflatoxin-contaminated peanuts as the discoloration in peanuts is primarily due to mould growth (Hocking and Pitt, 2006).

2.4.3 Colour sorting for removal of foreign matter found in almonds

There is a variety of foreign matter found in the almonds and these will all have to be removed from the final product. These include sticks, stones, dried peaches and even tiny melons that are picked off the ground of the orchard during harvesting as shown in Figure 2.17.

The harvesting process uses a mechanical shaker to shake the almonds off the tree. This process will also shake off any weak bits on the tree such as leaves and sticks. When the almonds are collected off the ground by the machines, sticks and other foreign material will also be picked up in the process. The pickup machines have destickers and screens to separate foreign matter from the almonds. Some orchards have another desticker to remove sticks before the almonds are stored in the bunkers or sheds. Despite all of these efforts, foreign matter still gets through. These are often small sticks that are too small to be picked up by the destickers or stones or melons that are about the same size as an almond.

Most hullers and shellers may have a destoner machine as part of their process. However, the destoner only removes dense material and not all of it. Some small stones may be getting through the process as they may be light in weight.

Dried peaches as shown in Figure 2.17 are another form of foreign matter in almonds. Almond trees can be grafted onto a variety of rootstocks such as peach, plum, peach/almond, and plum almond hybrids (Western Farm Press, 2011). Peach rootstock is very common and has been used for decades (Ledbetter and Sisterson, 2008). If the almond plant does not strike and the tree produces peaches or a combination of peaches and almonds, the dried peaches become a foreign material to the process.

Figure 2.17 Foreign matter removed by a laser sorter at the packers (top left); stones removed by a destoner machine at Costa Almonds (top right); tiny green melons in the product from the hullers and shellers (bottom left); dried peaches removed from almonds at hulling and shelling stage (bottom right).

2.4.3 Machine vision systems for food sorting

Food sorting can be carried out using machine vision systems. Machine vision systems are better than human inspections in terms of speed, accuracy, consistency and efficiency of food sorting (Narendra and Hareesh, 2010). It has been found statistically that machine vision measurements are more consistent than human measurement (Churchill et al., 1992; Verma, 2010). Machine vision systems have proven to be especially useful where manual sorting and evaluation of products such as raisins are costly and unreliable due to their subjective nature (Abbasgolipour et al., 2010).

Machine vision sorting has proved to be successful for objective assessment of food products such as bakery products, meat, fish, vegetables, fruit, prepared consumer foods and grain (Brosnan and Sun, 2004).

However, the variety of shapes, colours and textures of foodstuffs present a challenge for machine sorting (Sun, 2000; Connolly, 2005).

Machine vision systems were in use in all of the secondary processing facilities visited for this project. An argument for the use of such systems is that the sorting of almonds by human inspectors is unreliable as the inspector is only able to view the side of the kernel that is facing upwards (Page, 2011). Nonetheless, human inspectors were also a part of the process in all of the secondary processing facilities visited for this project. Figure 2.18 shows the use of human inspectors after the almond kernels have been through the colour sorting process. The kernels are moved past the inspectors on the green conveyor belts and the inspectors pick out any out of specification kernels before the kernels are packed.

Figure 2.18 Human inspectors at the secondary processors.

2.4.3.1 Difference between Mono, Bi and Tri chromatic systems

The main difference between mono-chromatic, bi-chromatic and tri-chromatic systems are the number of colour hues differentiated by the machine.

Mono-chromatic systems only differentiate between light and dark contrasts (Elexso, 2005). This system is unable to differentiate between a blue object and a red object if the colour shades are similar as the image is captured by the machine in gray scale (Gunasekaran, 1996).

Bi-chromatic systems are able to differentiate in the green and red spectrum of colours while Tri-chromatic systems are able to differentiate across the full colour spectrum to detect colour variations (Elexso, 2005).

2.4.3.2 Laser sorters

Laser sorters are sorting machines that use lasers as their light source. A variety of lighting sources can be used including incandescent, fluorescent, lasers, X-ray tubes and infrared lamps (Brosnan and Sun, 2004). The Elexso colour sorters use halogen lamps as a light source (Elexso, 2005).

2.4.3.2.1 Laser sorting efficiencies

A laser sorting system was developed to separate almonds having embedded shells from normal kernels. The study used near infrared lasers and line scan cameras to inspect both sides of the kernels simultaneously. This method of sorting resulted in 88.5% of normal almonds and 82% of almonds with embedded shell being correctly identified in a single pass (Pearson and Young, 2002). When a two-pass test was carried out on almonds with 0.1% embedded shell content, it resulted in 0.025% of embedded shell almonds in the accept stream with 6.2% of normal almonds in the reject stream. Therefore, multiple passes or machines may be required to attain high sorting efficiencies.

2.5 Project plan

This project requires a number of site visits for sample collection, sorting and process studies. The visits that have already been conducted to the orchards, primary and secondary processors provided important information on the process flow of the almonds from harvest to packaging.

A few more visits will be carried out in order to understand the primary and secondary processes and to collect samples.

In order to find the sources of mechanical damage in almonds, the following tasks will be completed:

- Analyze processes of primary and secondary processors.
- Carry out sampling at primary and secondary processor to gather data on kernel damage.
- Measure almond dimensions to find the size distribution of almonds.
- Carry out pendulum impact tests to find the effect of impact energy on almond kernels.
- Carry out velocity tests to find the effect of velocity on almond kernels.
- Carry out shear rolls test to find the effect of roller clearances on almonds.

A Gantt chart scheduling all of these tasks is shown in Figure 2.19.

2.5.1 Sampling and analysis for mechanical damage

In order to identify the source of mechanical damage, the process flow of all primary and secondary stages of processing will be studied. This requires prior coordination and agreement with the primary and secondary processors. To ensure that the study is conducted in a safe manner, all OHS requirements of the site being visited will be complied with.

After understanding the process, the sampling points in each process can be determined. Samples will be taken at the sampling points and inspected for mechanical damage. The data will then be analyzed and the sources of mechanical damage identified.

Samples will be requested from each processor being studied. As the study is being carried out in conjunction with the Almond Board of Australia, it is anticipated that there will not be a cost imposed for the samples taken.

2.5.2 Determining size distribution of almonds

A sample lot of almonds will be measured in order to find the size distribution of almonds while in-hull, in-shell and kernel. This information can be used in further studies to minimize damage in almond processing.

2.5.3 Finding the effects of impact energy, velocity and shear rolls on almond damage

The effects of impact energy, velocity and shear rolls on almond damage can be found out by carrying out the relevant tests. All of these tests will be carried out subject to the availability of the testing equipment.

The impact testing will be carried out on a pendulum impact tester, the velocity testing will be carried out on a rotary arm velocity tester and the shear rolls testing will be carried out on a shear rolls tester. All of the machines are available at the University of South Australia's Mawson Lakes campus.

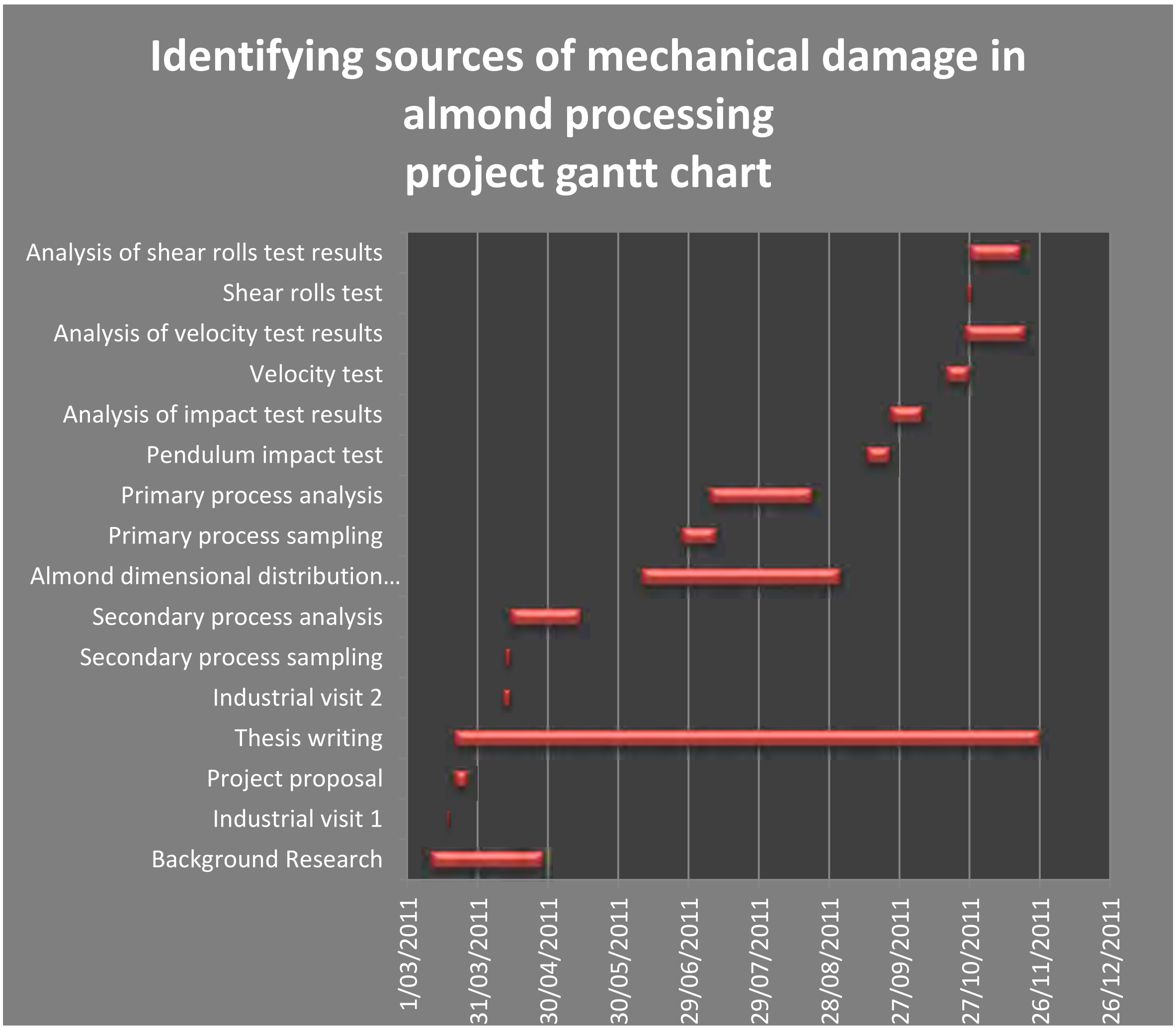


Figure 2.19 Gantt chart for project plan.

3. Determination of damage by processors

A number of site visits were conducted to understand the primary process of hulling and shelling and the secondary process of sorting and packing. Samples were taken in order to study the damage being inflicted on the almonds at each processor.

Samples were taken from the packer, Riverland Almonds before and after the almonds were sorted. Samples were then taken from Costa Almonds at various stages of the hulling and shelling process to study the damage from hulling and shelling machines.

3.1 Determination of damage at secondary processor

3.1.1 Sorting process of Riverland Almonds

The Riverland Almonds process begins with the receipt of the almonds. The almonds are brought from the hullers and shellers in wooden crates lined with large plastic bags as shown in Figure 3.1. The large plastic bags protect the almonds and prevent foreign material from getting mixed into the kernels.

Figure 3.1 Wooden crates for almonds (left). Almonds in large plastic bags (right).

The almond kernels then go through a fumigation process with a food grade fumigant in order to kill any insects, eggs or larvae.

The first stage of Riverland Almonds' process is the removal of foreign matter from the almond kernels using a laser sorter. This process is new to Riverland Almonds and is a dedicated laser sorter used solely for the removal of foreign matter.

The next stage of the process uses a series of color sorters to reject out of specification kernels and foreign material. The color sorters reject kernels that have white on them or are of a darker or lighter shade of color. The kernels that are chipped, scratched or broken will have white spots where the brown skin is damaged to reveal the white almond meat inside. The kernels that are of a different shade of color may be from another variety or have mold growth. Any foreign material that is not the exact same color as the almond kernel will also be picked out.

The almond kernels are flung off a belt through the air for the cameras to capture the color of the kernels. When cameras of the color sorters pick out an out of specification almond, a jet of air knocks the kernel out in mid-stream into the reject stream. The remaining kernels then repeat the process at the next stage until the last machine. There is some wastage generated as good almonds that are beside the bad ones will sometimes get knocked out by the air burst, therefore, any increase in the rejection rate will also result in an increase in good almonds in the waste stream (Antosh, 1985).

The kernels are sent through a final stage of visual inspection before being packed into bulk bags or carton boxes as shown in Figure 3.2.

Figure 3.2 The almond kernels go through a final visual inspection (left). Almonds packed into bulk bags (right foreground) or carton boxes (right background).

3.1.2 Foreign material removal by laser sorter

Riverland Almonds find a lot of foreign material mixed in with the almond kernels and implemented a laser sorting stage to remove foreign material before the colour sorting process. The foreign materials removed by the laser sorter were mainly small stones as seen in Figure 3.3 that were smaller than an almond in a shell. Although the laser sorter is able to remove the foreign material, it would be better if the foreign matter is removed earlier at the hullers and shellers before being sent to the packers.

A customized solution to remove foreign matter could be implemented. This could be accomplished by a screen allowing small particles to pass through but sending the almonds to the next stage of processing.

Figure 3.3 Riverland Almonds' laser sorter (left) removes foreign material (right).

3.1.3 Color sorting to remove out of specification almond kernels

The almond kernels are loaded into the color sorters through a large hopper. The hopper is located up high as shown in Figure 3.4 and is loaded by a forklift. There was a hypothesis by Riverland Almonds that the dropping of the almonds through the large hoppers of the sorting machines were causing impact damage in the form of chips or scratches to the almonds. This has prompted Riverland Almonds to implement a number of cascades as shown in Figure 3.4 to prevent damage to the falling almonds.

Figure 3.4 Hopper for loading almond kernels into the color sorters (left). Cascades at Riverland Almonds (right).

3.1.4 Results from sampling for mechanical damage at packers

A sample of almond kernels was taken from Riverland Almonds before the color sorting process and after the color sorting process. These kernels were visually inspected and sorted to quantify the defects in the sample.

3.1.4.1 Analysis of secondary processing mechanical damage to kernels

Samples were taken for data collection and hand sorted into the following categories: good, chipped, scratched, insect/rodent damage and doubles.

The results obtained from the sample of almonds from Riverland Almonds are as indicated in Table 3.1. The doubles were then omitted from the final tally as they are not categorized as damaged almonds.

Table 3.1 Results of Riverland Almond's sampling

	Before		After	
	Quantity	%	Quantity	%
Good	455	58.5	588	70.33
Chipped	253	33	193	23.9
Scratched	34	7.5	52	8.84
Insect/Rodent Damaged	36	4.6	3	0.36
Doubles	5		0	

From Table 3.1, it is evident that 45.1% of the almonds arrive at the packers with some form of damage already inflicted. Collectively, 40.5% of the almonds are chipped or scratched before the product arrives at the packers. This leads to the conclusion that 40.5% of the almonds have been mechanically damaged at the hullers and shellers, during harvest or during transportation.

Figures 3.5 to 3.8 defines the defects found in the almond kernels.

Figure 3.5 Example of a 'double'. Two mating almonds (twins) in the same shell.

Figure 3.6 Examples of chipped almonds

Figure 3.7 Example of a scratched almond

Figure 3.8 Examples of insect or rodent damaged almonds

3.1.4.2 Calculating efficiency of sorting machines in removing defective almonds

After analyzing the data to quantify the mechanical damage in the sample, the data was used to work out the sorting efficiency of the process. This study was done in order to better understand the process and obtain some useful information that could be used in future studies.

The following method was used:

The quantities of almonds were balanced to account for the difference in the sample quantities taken before and after the process. In order to do this, the assumption is made that all of the good kernels passed through without being air ejected. Since the number of good kernels cannot be increased through processing, the number of good kernels in the 'after' sample was multiplied by a factor to bring it down to the exact same quantity as in the 'before' sample. The rest of the quantities were subsequently multiplied by the same factor to produce the results in Table 3.2. The sorting efficiency was worked out with formula 3.1.

$$Sorting\ Efficiency = [1 - \left(\frac{Number\ of\ defect\ remaining\ after\ sorting}{Number\ of\ defect\ before\ sorting}\right)] \times 100\% \quad \textbf{(3.1)}$$

Table 3.2 Efficiency of machines in removing defective almonds

	Before		After		Efficiency in removing defects
	Quantity	%	Quantity	%	%
Good	455	58.5	455	70.4	N/A
Chipped	253	33	149	23.1	41.1%
Scratched	34	7.5	40	6.19	-17.6%
Insect/Rodent Damaged	36	4.6	2	0.31	94.4%
Doubles	5		0	0	100%

The negative percentage for removal of scratched almonds implies that there is additional scratching caused by the sorting process itself with 6 out of 646 kernels being scratched during the process.

The sorting process is quite efficient at removing deformed and insect/rodent damaged almonds, but some still remained in the final sample. It is desirable to remove as many if not all of the insect/rodent damaged almonds as it may constitute a food safety concern. Based on the calculated rate of 94.4% efficiency of insect/rodent damaged kernels, a second pass will remove a further 94.4 % of the defect left in the lot. Taking the representative sample of 4.6% insect/rodent damage and projecting it in terms of a 10,000 kernels lot size a starting figure of 460 insect/rodent damaged kernels per 10,000 kernels is obtained. After the first pass, 94.4% of insect/rodent damaged kernels will be removed leaving 26 insect/rodent damaged kernels in the lot. After the second pass, only 1 insect/rodent damaged kernel will remain in the lot. Thus, if it is desired to eliminate insect/rodent damaged kernels as much as possible, a second pass or machine will have to be implemented. Alternatively, the sensitivity of the sorting machine could be increased. However, increasing the sensitivity of the sorting machine will also result in an increase in rejections of good almonds.

3.2 Determination of damage by secondary processor

3.2.1 Hulling and shelling process of Costa Almonds

In order to find the source of the mechanical damage, the hulling and shelling process used by Costa Almonds was studied. From the visits to facilities operated by Simerloo, Costa Almonds and Laragon, it was found that the hulling and shelling equipment is similar at all of the companies. There were differences observed in the number of stages, the adjusted gap between the rollers and the belts as well as the layout of the machinery. Overall, the machinery used by all of the companies use the same principle of shear rollers, shear roller and belt and screens with bouncing balls. Therefore, the study of Costa Almonds will provide an indication of where the mechanical damage is occurring in the hulling and shelling process.

The hulling and shelling process facility can be used for both hard and soft shell varieties of almonds. However, the machine settings have to be modified by varieties. The almond’s shell strength varies greatly among different varieties and using a hard shell setting on a soft shell variety would cause significant damage to the almond kernels (Ledbetter, 2008).

The process begins with the receival of almonds by the primary processor. The almonds are transported by trucks from the orchard to the primary processor as shown in Figure 3.9.

Figure 3.9 The truck tips its tray to pour the almonds out (right).

Costa Almonds stores the received almonds in a shed as shown in Figure 3.10. The shed has limited storage space and is meant only to provide some protection to the almonds that are being immediately processed.

Figure 3.10 Shed for temporary almond storage at Costa Almonds.

After the primary processor receives the almonds the hulling and shelling process begins with the almonds being loaded into the machines as shown in Figure 3.11. The pre-cleaning machines are shown in Figure 3.12.

Figure 3.11 Front end loader collects almonds from shed and loads them in the hopper.

Figure 3.12 Almond pre-cleaning machines at Costa Almonds.

The first stage of the process is a pre-cleaning stage where sticks and stones are removed from the almonds. The waste streams from the precleaning stages are shown in Figure 3.13.

Figure 3.13 Desticker and destoner removes sticks and stones in the pre-cleaning process.

The hulling and shelling process used by Costa Almonds is a five stage process. At each stage of the hulling and shelling process, the almonds go through a set of rollers, followed by a roller and belt, and finally through a vibrating screen. The pair of rollers runs at a speed differential in order to shear the husks off the almonds. The roller and belt are also rotating at different speeds to exert a shear force to crack the shells of the almonds. These rollers and belts work in tandem to hull and shell the almonds.

The screens are vibrating screens with bouncing balls inside to clear them. Any object (almonds, hulls, shells or foreign) that gets lodged in the screen will be hit by the bouncing ball, thereby dislodging it and clearing the screen. The screen vibrates and ‘throws’ the almonds in a forward direction. Any kernel that is small enough will pass through the screen onto a conveyor and transferred to the end of the processing. The rest of the almonds go to the next stage of the hulling and shelling process where the process is repeated.

3.2.2 Sampling for mechanical damage caused by the hulling and shelling process

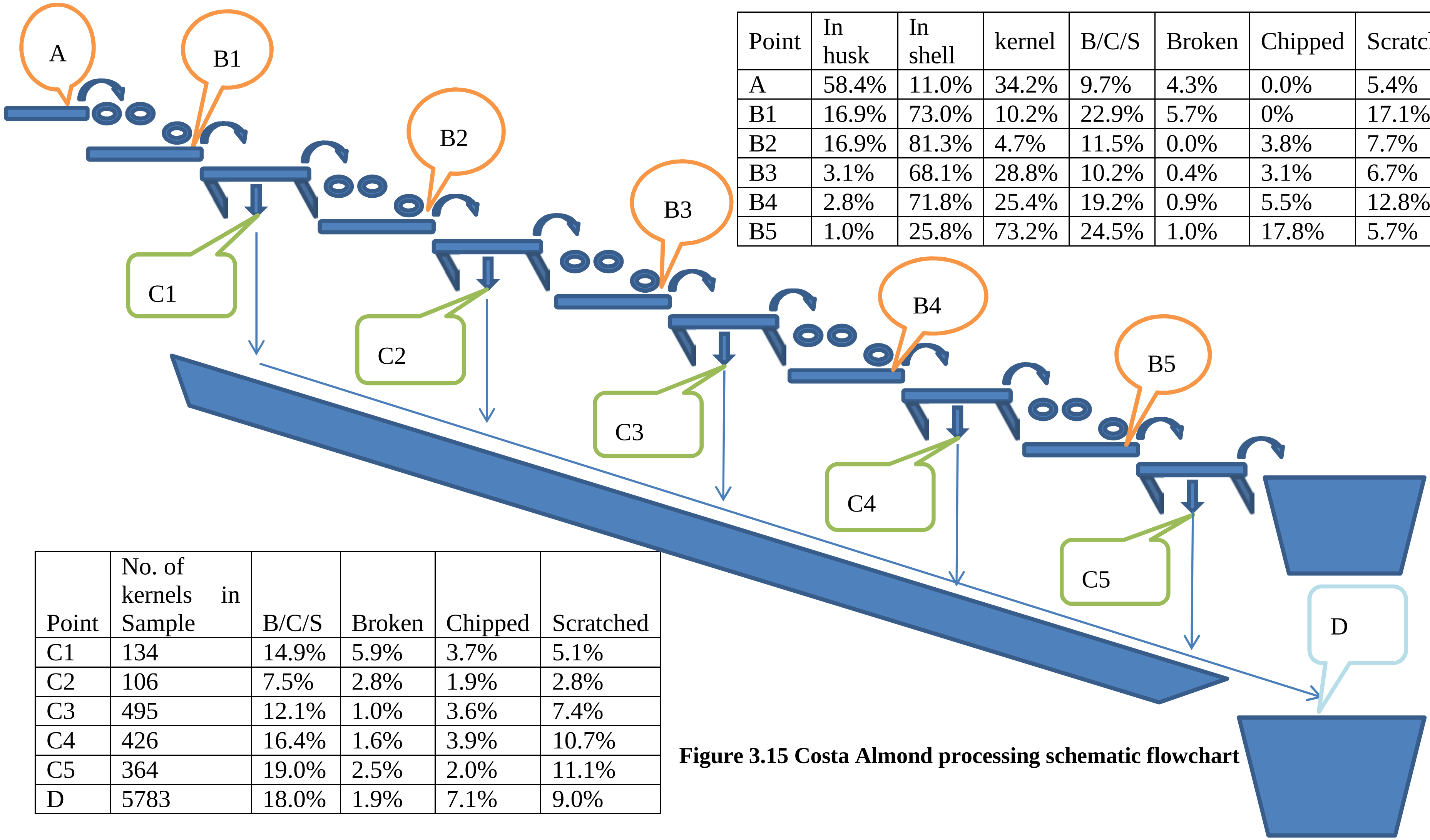
In order to determine the mechanical damage of almonds from the hulling and shelling process, samples were taken and examined at every feasible point. The samples were sorted into lots of in-husk almonds, in-shell almonds and kernels as shown in Figure 3.14 before being checked for signs of mechanical damage.

Figure 3.14 Samples segregated by in-husk, in-shell and kernels.

A schematic flowchart of Costa Almond’s hulling and shelling process is shown in Figure 3.15; it shows the five stages and labels the points where samples were taken.

Point A is the end of the pre-cleaning process where sticks, stones as well as foreign objects are removed before the hulling and shelling process. Points B1 to B5 are at the end of the respective stage of processing after the almonds have gone through the rollers and belt. Points C1 to C5 are the respective stages of screening, thus the sample taken consists of the kernels that have passed through the screen. Point D is the end of the process where the almond kernels are collected.

Samples were taken from the stockpile before processing, at the end of pre-cleaning (point A), at all five stages of the process (points B1-B5 and points C1-C5), and at the end of the process (point D). The samples were checked for signs of mechanical damage and the results recorded. The sample numbers for in-hull and in-shell almonds as well as kernels were recorded and the results analyzed to work out the hulling and shelling efficiency of the processing plant.



Point	In husk	In shell	kernel	B/C/S	Broken	Chipped	Scratched
A	58.4%	11.0%	34.2%	9.7%	4.3%	0.0%	5.4%
B1	16.9%	73.0%	10.2%	22.9%	5.7%	0%	17.1%
B2	16.9%	81.3%	4.7%	11.5%	0.0%	3.8%	7.7%
B3	3.1%	68.1%	28.8%	10.2%	0.4%	3.1%	6.7%
B4	2.8%	71.8%	25.4%	19.2%	0.9%	5.5%	12.8%
B5	1.0%	25.8%	73.2%	24.5%	1.0%	17.8%	5.7%

Point	No. of kernels in Sample	B/C/S	Broken	Chipped	Scratched
C1	134	14.9%	5.9%	3.7%	5.1%
C2	106	7.5%	2.8%	1.9%	2.8%
C3	495	12.1%	1.0%	3.6%	7.4%
C4	426	16.4%	1.6%	3.9%	10.7%
C5	364	19.0%	2.5%	2.0%	11.1%
D	5783	18.0%	1.9%	7.1%	9.0%

Figure 3.15 Costa Almond processing schematic flowchart

3.2.3 Results of sampling for mechanical damage caused by the hulling and shelling process

The samples were checked for signs of mechanical damage and the results recorded. The sample numbers for in-hull and in-shell almonds as well as kernels were recorded and the results analyzed to work out the mechanical damage caused at each stage as well as the hulling and shelling efficiency of the processing plant. The results of these findings are summarized in Table 3.3.

Table 3.3 Percentage of mechanical damage caused by each point in the hulling and shelling process and the hulling and shelling efficiency of the machines.

Point	In husk	In shell	kernel	B/C/S	Broken	Chipped	Scratched
A	54.8%	11%	34%	9.7%	4.3%	0.0%	5.4%
B1	16.9%	73.0%	10.2%	22.9%	5.7%	0%	17.1%
B2	16.9%	81.3%	4.7%	11.5%	0.0%	3.8%	7.7%
B3	3.1%	68.1%	28.8%	10.2%	0.4%	3.1%	6.7%
B4	2.8%	71.8%	25.4%	19.2%	0.9%	5.5%	12.8%
B5	1.0%	25.8%	73.2%	24.5%	1.0%	17.8%	5.7%
	Remaining Kernels	Kernels Removed	No. of kernels in sample	B/C/S	Broken	Chipped	Scratched
C1	89.8%	10.2%	134	14.9%	5.9%	3.7%	5.1%
C2	85.6%	4.2%	106	7.5%	2.8%	1.9%	2.8%
C3	60.9%	24.7%	495	12.1%	1.0%	3.6%	7.4%
C4	45.4%	15.5%	426	16.4%	1.6%	3.9%	10.7%
C5	12.2%	33.3%	364	19.0%	2.5%	2.0%	11.1%
D	N/A	N/A	5783	18.0%	1.9%	7.1%	9.0%

The results have been expressed as percentages of kernel to ensure that the information is uniform. For example, Table 3.3 shows that 10.2% of the kernels at point B3 have some form of mechanical damage, and this can be further broken down into 0.4% broken, 3.1% chipped and 6.7% scratched almonds.

Figure 3.16 shows mechanically damaged samples from the study that has been defined as scratched, chipped and broken.

Figure 3.16 Clockwise from top: Scratched, chipped and broken almonds from the Costa Almonds hulling and shelling process.

3.2.3.1 Mechanical damage as a percentage of kernel content in sample

There is a possibility that the almonds may be damaged by the rollers and belts while they were still in their husks and shells. The compressive forces could possibly crush the kernels while they are still in their husks.

In order to determine if the damage was done to the kernels before or after they were removed from their husk and shells, almonds that were still in their husks or shells were carefully removed and examined for signs of mechanical damage.

The study found that the kernels that were removed from their husks and shells by hand had no signs of mechanical damage at all. This leads to the conclusion that the almonds do not get damaged mechanically by the Hulling and Shelling machines if they are still in their husk or shell. Only the loose kernels in the sample bore signs of mechanical damage.

The amount of mechanical damage percentage increases with the kernel content percentage in the sample as shown in Figure 3.17.

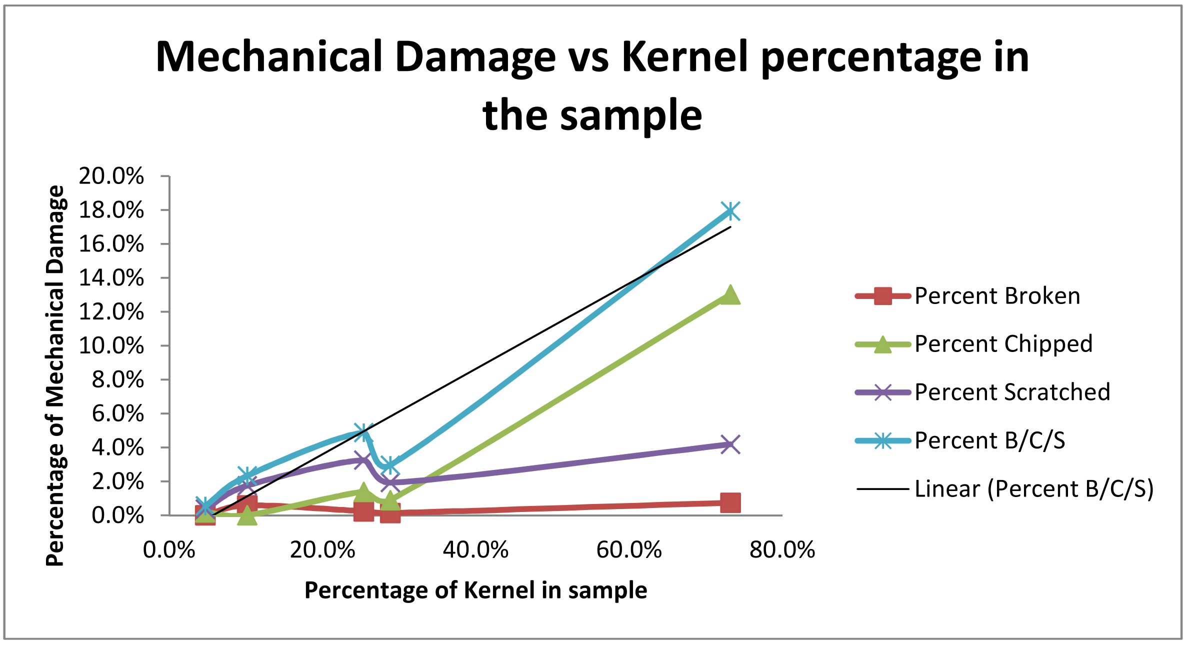


Figure 3.17 The relationship between kernel content in the sample and mechanical damage.

3.2.3.2 Results of study of secondary processing

When the kernels were removed from their husks and shells by hand, no sign of mechanical damage was found. This leads to the conclusion that the almond kernels are being damaged by the hulling and shelling process.

The result shown in Table 3.3 indicates that the amount of mechanical damage varies at each stage of the hulling and shelling process. The difference in the amount of damage at each stage is possibly due to the different almond sizes and machine settings at each stage of the process.

4. Determine the size distribution of almonds

A sample batch of in-husk almonds were obtained from Mark Stoeckel's almond orchard. These almond samples were used for data and statistical collection.

In order to find the range of the almond sizes, two measurement templates shown in Figure 4.1 were designed and fabricated. The templates were made from a perspex sheet and had round holes and slots cut into them. These templates were used to size the almonds. The round hole template sizes the width of the almonds and the slotted template sizes the thickness of the almond.

The almond industry currently uses screens with round holes to separate the almond kernels from the husk and shell. Various other agricultural industries may also use slotted screens in their machinery.

.

Figure 4.1 Round hole template (left) and slotted template (right)

4.1 Size distribution for width and thickness of in-husk almonds

An initial sample of 377 in-husk almonds were randomly selected using a sample divider. These in-husk almonds were then measured and sorted using the templates.

An in-husk almond that can fit through a 15 mm diameter hole but not through a 14 mm diameter hole is catagorized as a 15 mm wide almond. Similarly, an in-husk almond that fits through a 15 mm slot but not a 14 mm slot is catagorized as a 15 mm thick almond. This method of measuring the almonds was carried out for the whole measuring process. The almonds were maneuvered into positions that allowed them to drop through the templates without being forced. Figure 4.2 and 4.3 show the size grading process.

Figure 4.2 Top row, grading the in-husk almonds width. Middle row, grading the in-shell almonds width. Bottom row, grading the kernels width.

Figure 4.3 Top row, grading the in husk almonds by thickness. Middle row, grading the in-shell almonds by thickness. Bottom row, grading the kernels by thickness.

The in-husk almond samples were measured and Figure 4.4 shows the size distribution of the width of the almonds. The resulting distribution shows a bell shaped distribution curve. The highest percentile of the in-husk almonds had a width of 21 mm. The in-husk almonds ranged in width from 15 mm to 28 mm diameter. 92.3% of the sample had a width between 19 mm to 25 mm.

Since the distribution of in-husk almonds begins from a minimum width of 15 mm, a pre-cleaning process can be used to remove stones or other foreign matter under the size of 15 mm. Any existing loose kernels and shelled almonds under 15 mm width will also be removed in the pre-cleaning process and will have to be reclaimed.

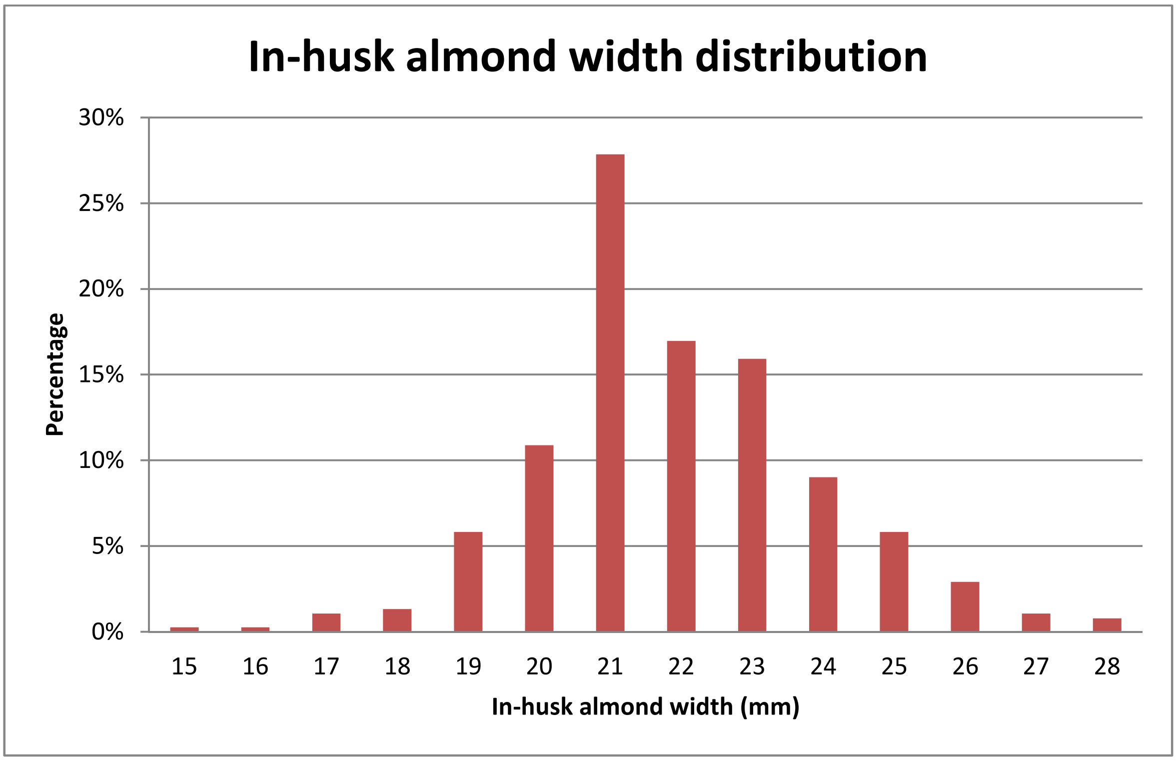


Figure 4.4 In-husk almond width size distribution

The in-husk almonds were then measured using the slotted template. The resulting bell shaped distribution curve is shown in Figure 4.5. The highest percentile of the in-husk almonds would fit through an 18 mm slot. The almonds ranged from a thickness of 12 mm to 23 mm. 95.7% of in-husk almonds were in the range of 15 mm to 21 mm thickness.

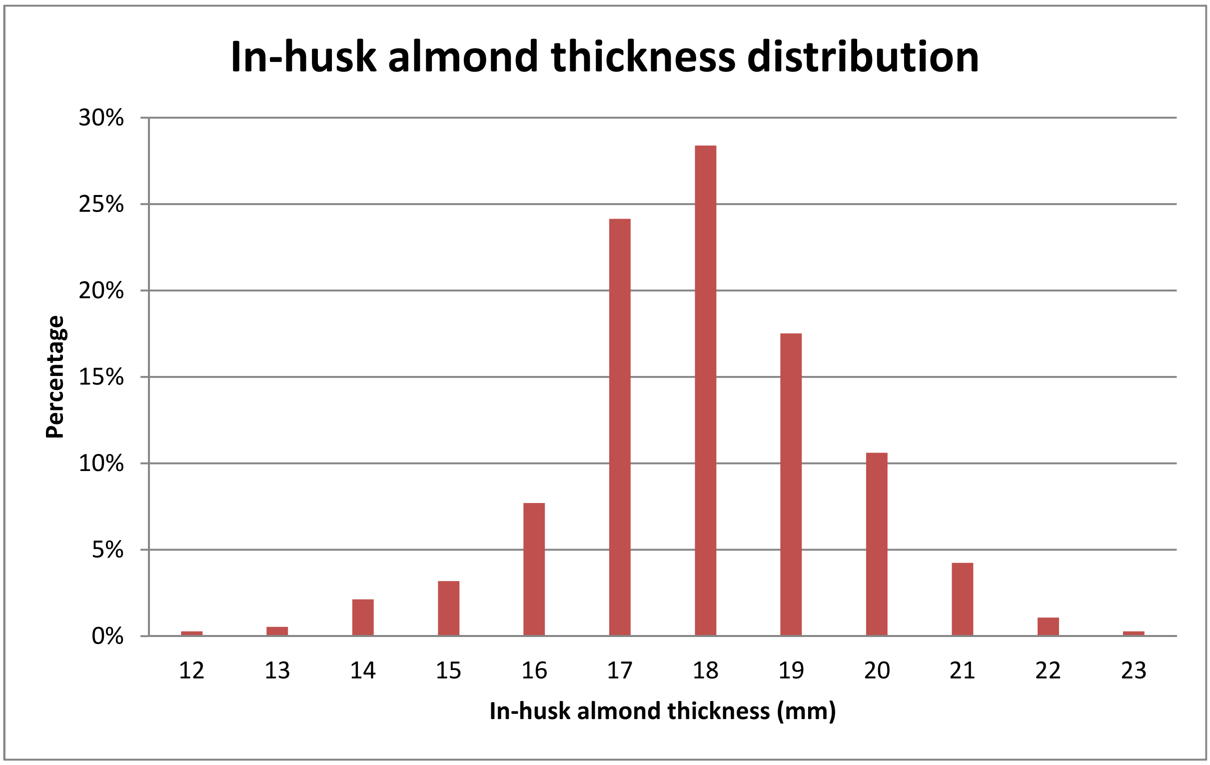


Figure 4.5 In-husk almond thickness size distribution

4.2 Relationship between the mass and width of the almonds

The in-husk almonds were weighed and the mass averaged out in order to find the average mass of almonds in comparison with their width. There was a linear relationship between the width of the almond and the mass of the almond as shown in figure 4.6.

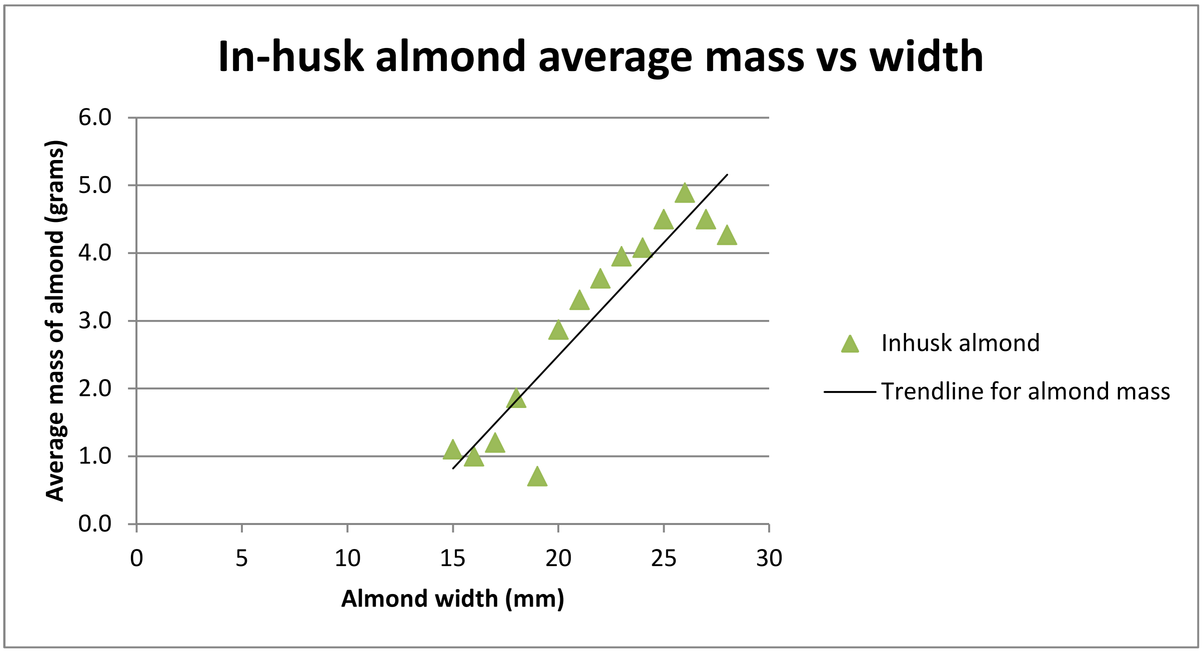


Figure 4.6 Averaged mass of in-husk almonds plotted against width.

4.3 Size distribution for width and thickness of in-shell almonds

After the in-husk almonds were measured and sorted, the almonds were carefully removed from their husks and the in-shell almonds were measured and sorted.

The round holed and slotted templates were used to measure the in-shell almonds. The same method was used whereby an in-shell almond that can fit through a 15 mm diameter hole but not through a 14 mm diameter hole is catagorized as a 15 mm wide almond and likewise for the slots. As before, the almonds were moved into a position so that they could drop through without being forced through.

Figure 4.7 shows the resulting bell shaped width distribution of in-shell almonds. The largest percentile of in-shell almonds had a width of 18 mm. The in-shell almond widths ranged from 14 mm to 23 mm. 97.3% of the in-shell almonds were in the range of 16mm to 21 mm width.

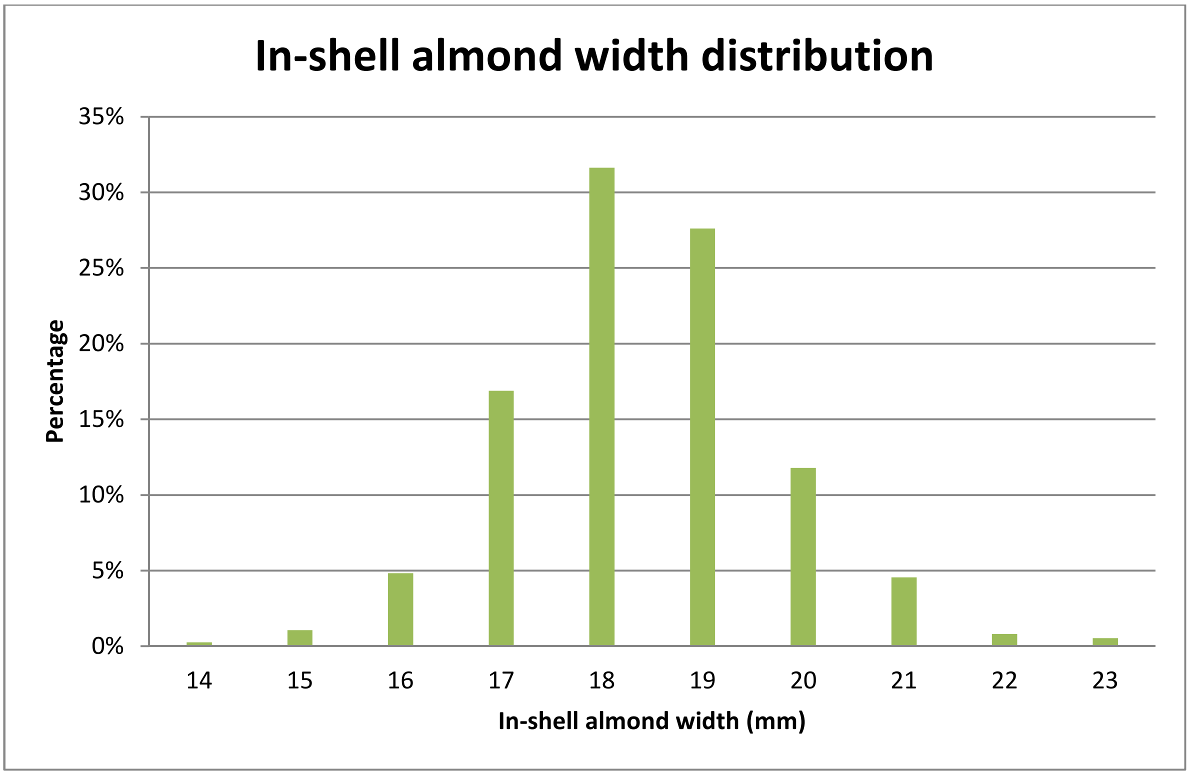


Figure 4.7 Width distribution of in-shell almonds.

The in-shell almonds were then measured using the slotted template and the resulting bell shaped distribution curve is shown in Figure 4.8. The highest percentile of the in-shell almonds would fit through a 14 mm slot. The almonds ranged from a slot width of 11 mm to 19 mm. 97.8% of in-shell almonds were in the range of 12 mm to 16 mm thickness.

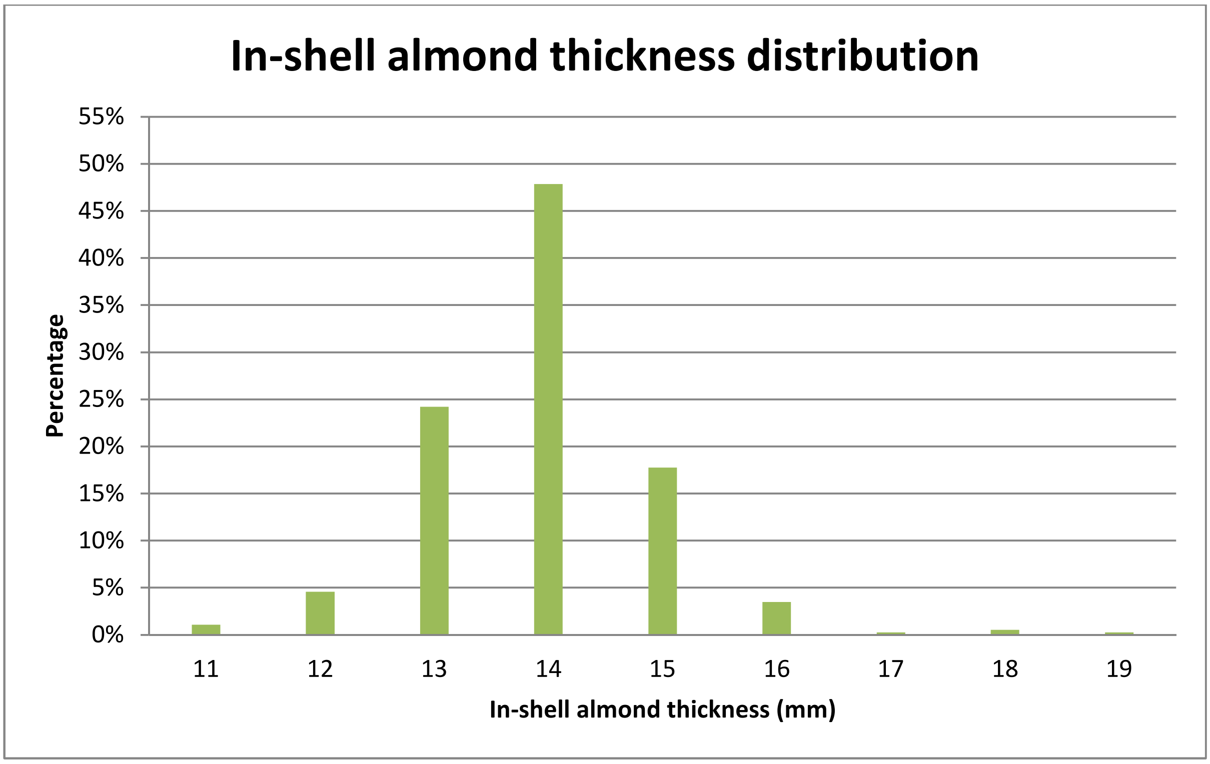


Figure 4.8 Thickness distribution of in-shell almonds.

4.4 Size distribution for width and thickness of almond kernels

The final part this exercise was to measure and sort the almond kernels. The almond kernels were carefully removed from their shells and the kernels were then measured and sorted.

The same method was used with the templates as in the previous two exercises with the in-hull and in-shell almonds. As before, the kernels were moved into a position so that they could drop through without being forced.

The resulting normal bell shaped distribution is presented in Figure 4.9. The largest percentile of kernels in the sample had widths of 13 mm. The almond widths ranged from 9 mm to 16 mm. 98.3% of the kernels were in the range of 11 mm to 15 mm width.

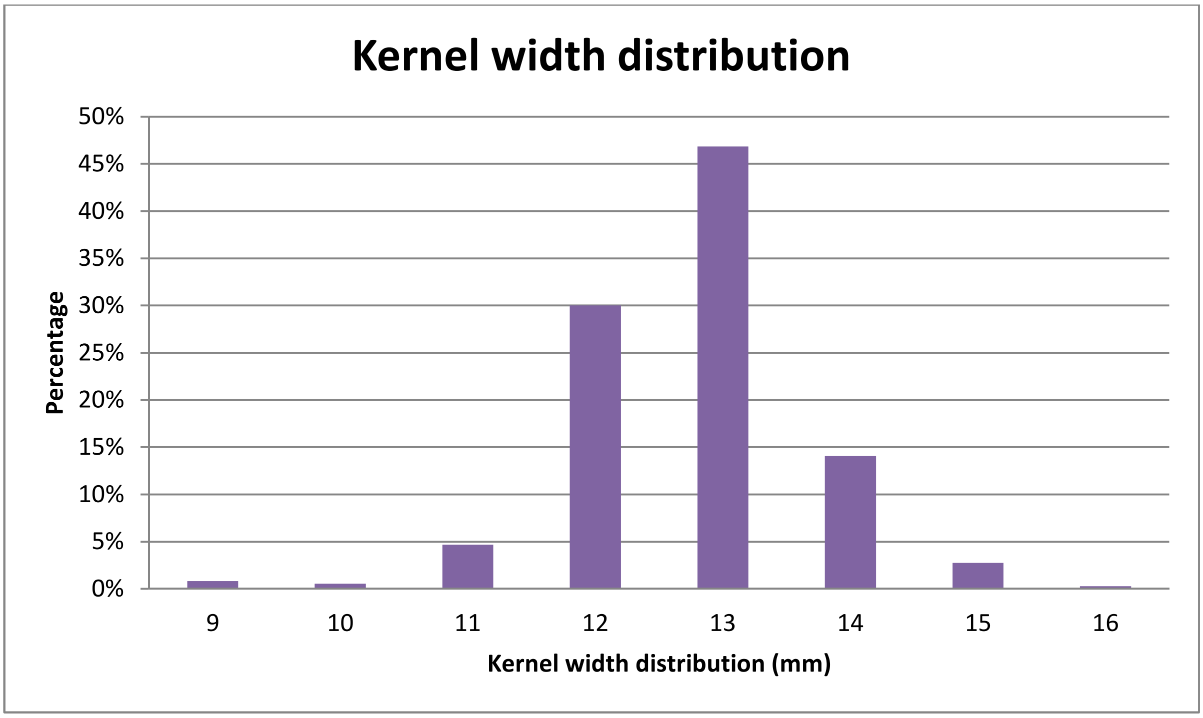


Figure 4.9 Width distribution of almond kernels.

The almond kernels were then measured using the slotted template and Figure 4.10 shows the resulting bell shaped distribution curve. The highest percentile of the kernels were 9 mm thick. All of the kernels fell within the range of 7 mm to 11 mm.

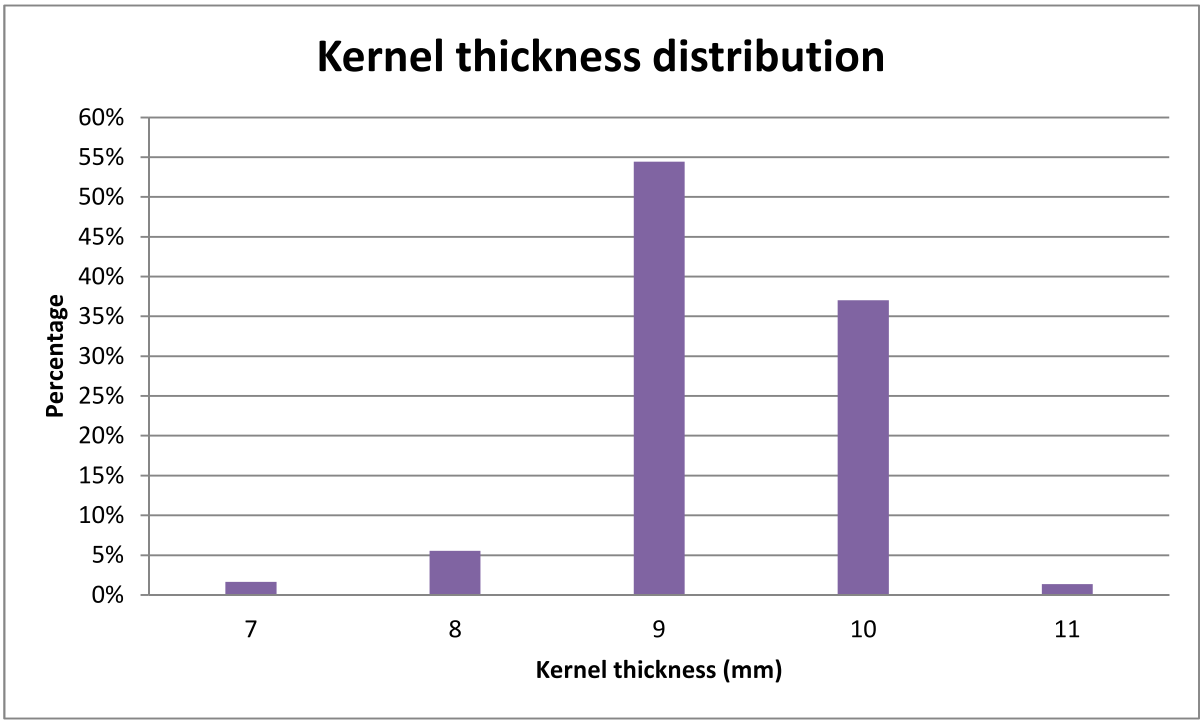


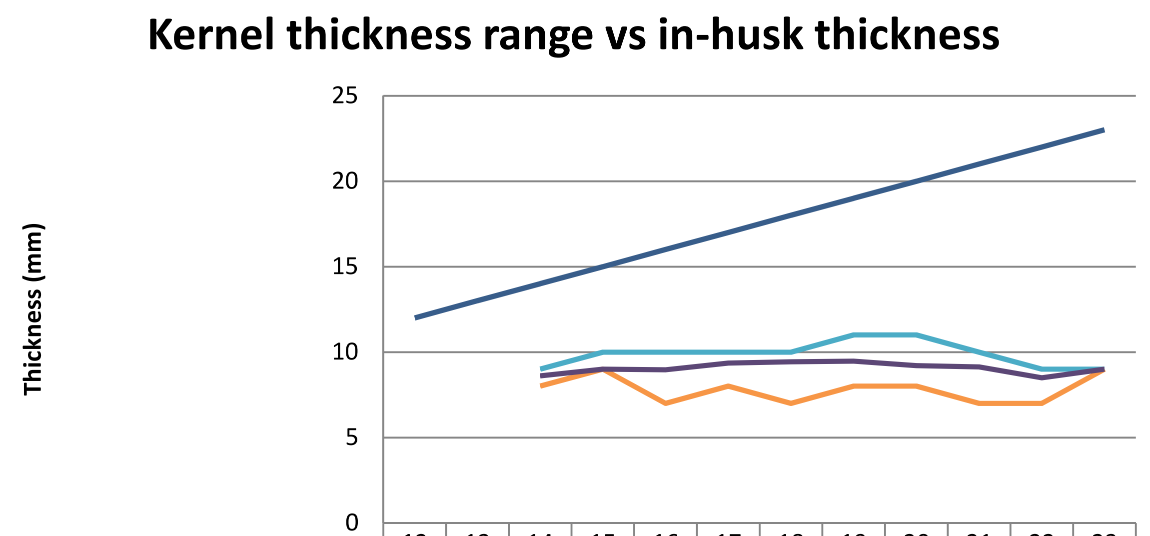
Figure 4.10 Thickness distribution of almond kernels measured using sizing template

4.5 Comparing in-husk, in-shell and kernel size

A study was carried out to find out if the kernel and in-shell size of the almonds increases proportionally with the in-husk size of the almond.

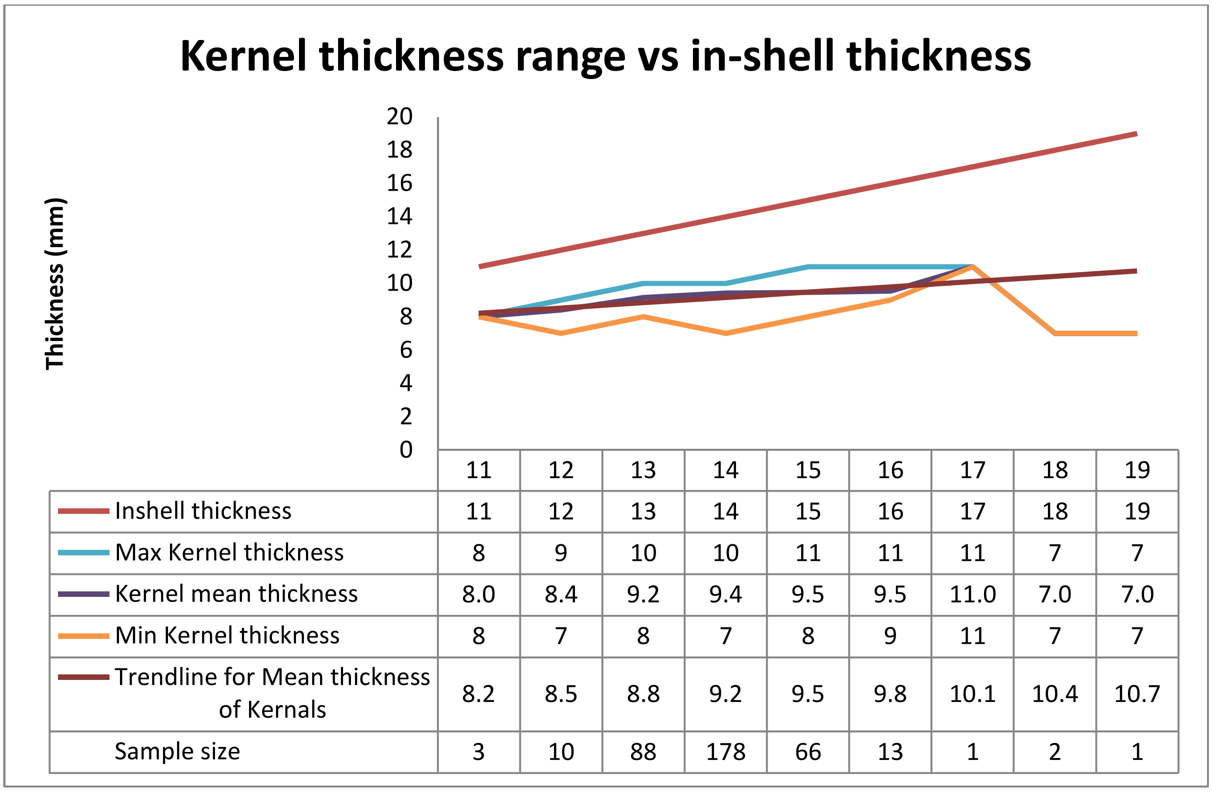
The method used was to measure the almond while it was still in its husk, remove the husk and measure the almond in its shell, and finally, remove the shell and measure the kernel inside. By following through on the whole process, data was obtained on the thickness ranges of each individual almond while in-husk, in-shell and kernel.

This study found that as the in-husk thickness of the almond increased, the in-shell thickness of the almond increased at a more gradual rate and the kernel size stayed within a narrow thickness range of 7 mm to 11mm as shown in figures 4.11 to 4.14. This means that even as the in-husk size of the almond increases, the kernel inside does not necessarily increase in thickness proportionally but stays within its narrow thickness range.



	12	13	14	15	16	17	18	19	20	21	22	23
Inhusk thickness	12	13	14	15	16	17	18	19	20	21	22	23
Max Kernel thickness	4		9	10	10	10	10	11	11	10	9	9
Min Kernel thickness	4		8	9	7	8	7	8	8	7	7	9
Mean thickness of Kernels	4.0		8.6	9.0	9.0	9.4	9.4	9.5	9.2	9.1	8.5	9.0
Quantity of Kernels	1	0	5	8	27	90	106	65	40	16	4	1

Figure 4.11 In-husk thickness of almond vs the thickness of the kernel inside.



	11	12	13	14	15	16	17	18	19
Inshell thickness	11	12	13	14	15	16	17	18	19
Max Kernel thickness	8	9	10	10	11	11	11	7	7
Kernel mean thickness	8.0	8.4	9.2	9.4	9.5	9.5	11.0	7.0	7.0
Min Kernel thickness	8	7	8	7	8	9	11	7	7
Trendline for Mean thickness of Kernals	8.2	8.5	8.8	9.2	9.5	9.8	10.1	10.4	10.7
Sample size	3	10	88	178	66	13	1	2	1

Figure 4.12 Kernel thickness with increase in almond in-shell thickness.

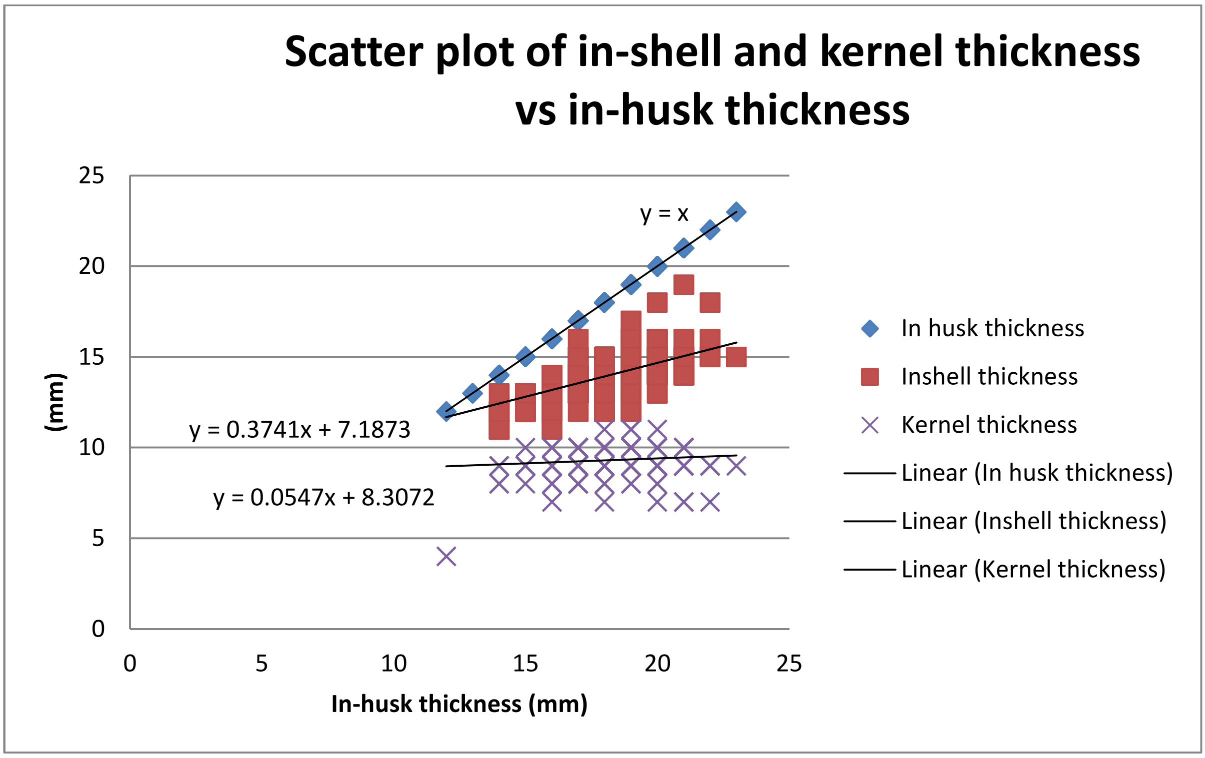
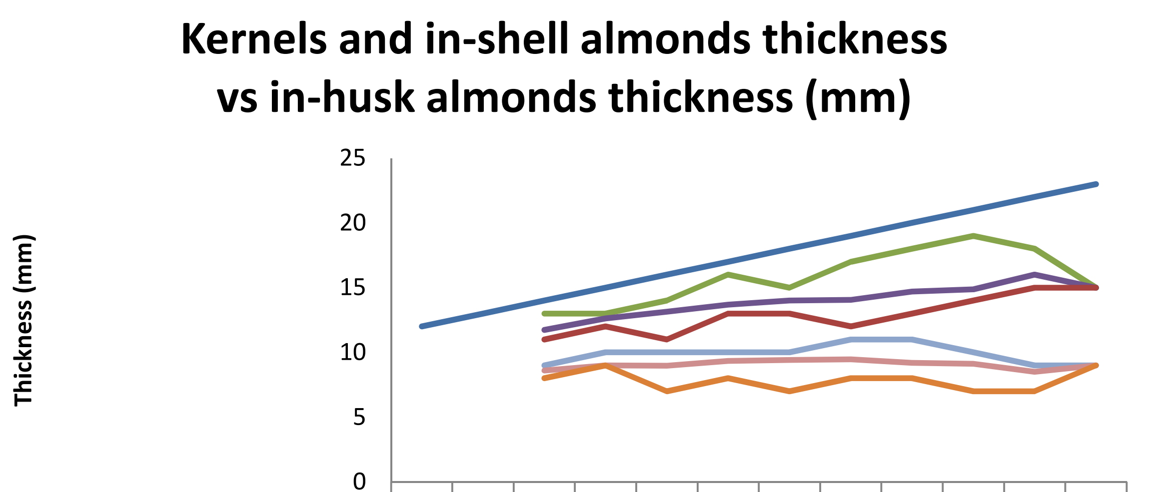


Figure 4.13 Scatter plot of the thickness of in-husk, in-shell and almond kernels.



	12	13	14	15	16	17	18	19	20	21	22	
Inhusk thickness	12	13	14	15	16	17	18	19	20	21	22	23
Max Inshell thickness			13	13	14	16	15	17	18	19	18	15
Mean thickness of Inshell Almonds			11.8	12.6	13.1	13.7	14.0	14.1	14.7	14.9	16.0	15.0
Min Inshell thickness			11	12	11	13	13	12	13	14	15	15
Max Kernel thickness	4		9	10	10	10	10	11	11	10	9	9
Mean thickness of Kernels	4.0		8.6	9.0	9.0	9.4	9.4	9.5	9.2	9.1	8.5	9.0
Min Kernel thickness	4		8	9	7	8	7	8	8	7	7	9
Quantity of Inshell Almonds	0		8	11	29	91	107	66	40	16	4	1

Figure 4.14 Results of measuring the almond thickness from in-husk, to in-shell through to kernel.

4.6 Finding the amount of clearance between the kernel and its shell

The size distribution of the almonds implied that there is a clearance between the kernel and its shell. In order to find data on the clearance between the kernel and its shell, the in-shell almond was measured, the kernel was then removed from its shell and the kernel and the thickness of its shell was measured. The in-shell almond and kernel were measured with the slotted template to find their thicknesses (as in Figure 4.3). The shell was measured with a point micrometer to find its thickness as illustrated in Figure 4.15.

Figure 4.15 Measuring the thickness of the almond shell with a point micrometer.

After data was acquired on the thickness of the in-shell almond, kernel and shell, the data was sorted. The results show that the clearance on one side between the kernel and its shell increases as the in-shell thickness of the almond increases as shown in Figure 4.16.

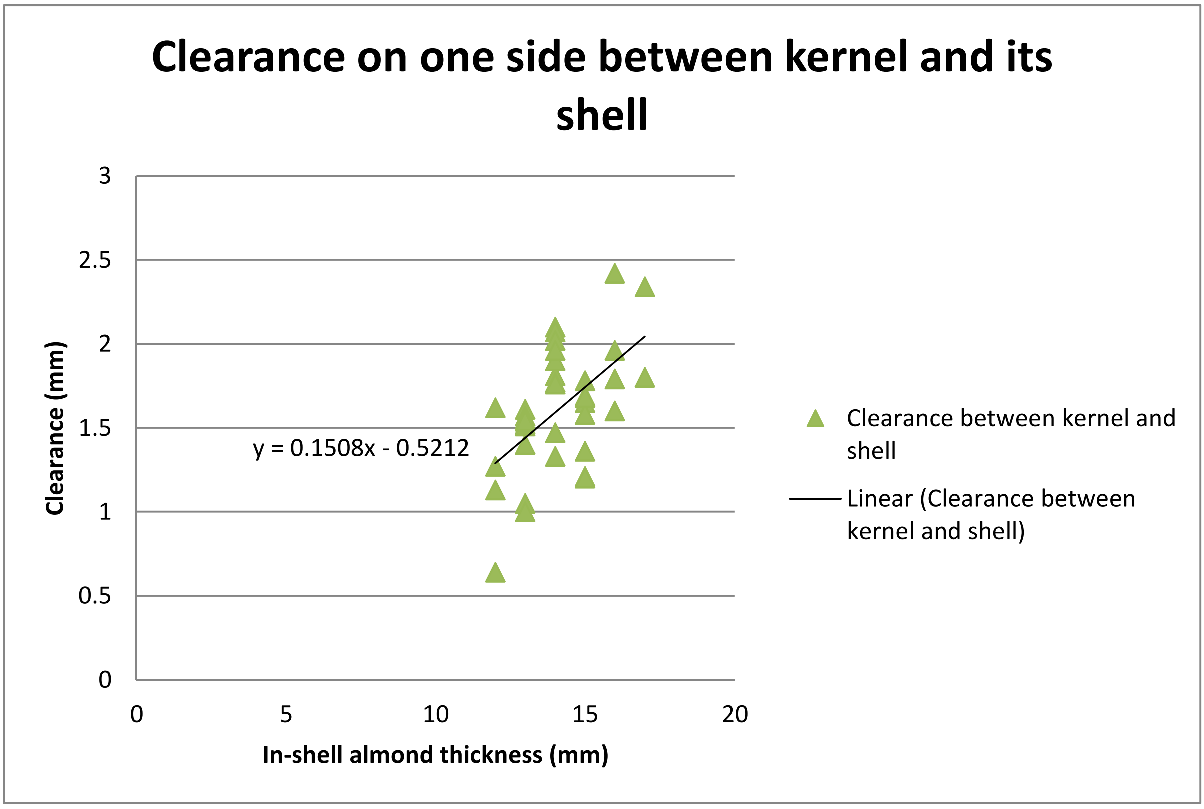


Figure 4.16 The clearance between the kernel and its shell increases as the in-shell thickness of the almond increases.

4.7 Results from size distribution study

The results of this study show that the width distribution of in-shell almonds and almond kernels has a broader range than the thickness distribution.

In-husk almonds measured had a width distribution range from 15 mm to 28 mm and a thickness distribution range of 12 to 23 mm. This is a 13 mm difference from the in-husk almond with the smallest to the largest width. There is an 11 mm difference from the in-husk almond with the smallest thickness to the largest thickness.

In-shell almonds measured had a width distribution range from 14 mm to 23 mm and a thickness distribution of 11 mm to 19 mm. This is a 9 mm difference from the in-shell almond with the smallest to the largest width. There is an 8 mm difference from the in-shell almond with the smallest thickness to the largest thickness.

Almond kernels measured had a width distribution range from 9 mm to 16 mm and a thickness distribution of 7 mm to 11 mm. This is a 7 mm difference from the in-shell almond with the smallest to the largest width. There is a 4 mm difference from the in-shell almond with the smallest thickness to the largest thickness.

There are in-husk almonds, in-shell almonds and almond kernels that have the same width sizes of between 14 mm to 16 mm as shown in Figure 4.17. If a round screen is used to collect almond kernels between the range of 14 mm to 16 mm, there will some in-husk and in-shell almonds collected along with the kernels.

There are in-shell almonds and almond kernels that have the same width of 11 mm as shown in Figure 4.18. Therefore, if a slotted screen is used to collect almond kernels there will be some in-shell almonds collected along with the kernels only for an 11 mm sized screen .

These results suggest that a smaller range of slotted screen sizes will be needed to achieve similar or better results to the round screens presently being used in the almond industry.

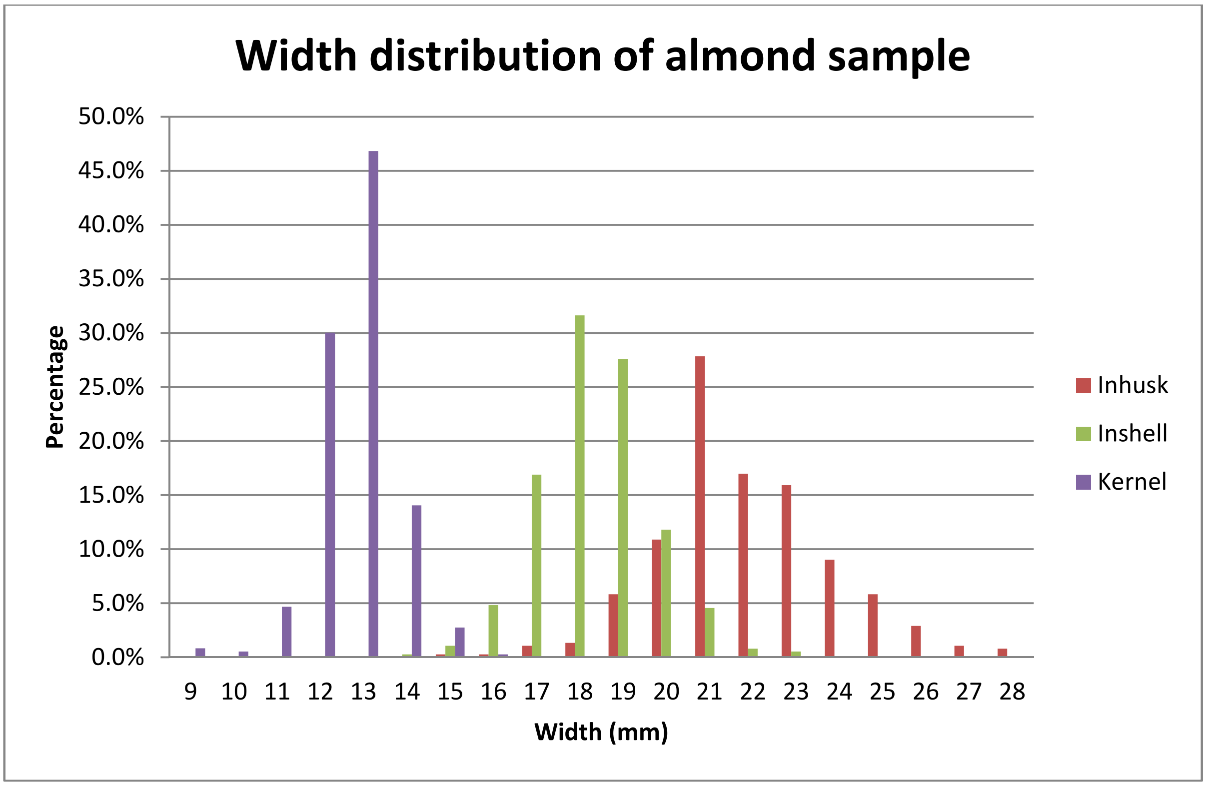


Figure 4.17 Width distribution of almond sample.

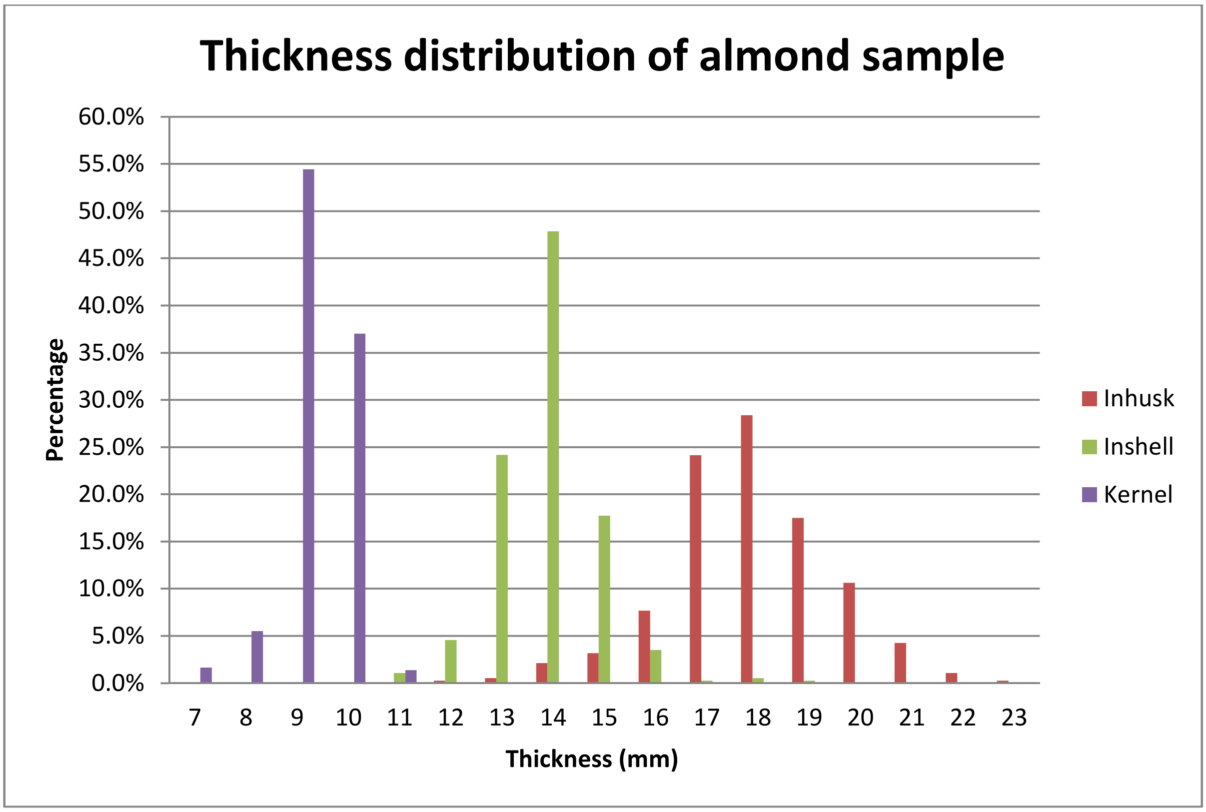


Figure 4.18 Thickness distribution of almond sample.

The comparison of in-husk, in-shell and kernel thicknesses shows that the kernel thickness does not increase proportionally to the almond's in-husk or in-shell thickness. As the thickness of the in-husk and in-shell increases, the almond kernel stays within the thickness range of 9 mm to 11 mm. The study also showed that there is a clearance between the kernel and its shell and this clearance increases with the size of the in-shell almond. This clearance starts from a minimum of 0.64 mm on one side and increases to a maximum of 2.42 mm on one side for the sample.

5. Finding the effects of impact energy/velocity and shear rolls hulling and shelling on almond damage

This part of the study produces a measured impact against an almond and obtains data on the impact energy required to create damage in almonds. The study also measured the velocities required to damage almonds. The aim of these tests is to find the impact energy and velocity that produces mechanical damage in almond kernels.

The final part of this study uses shear rolls to perform the hulling and shelling process and examines the damage caused to the almond kernels.

5.1 Damage sustained by almond from impact energy

The pendulum impact tester shown in Figure 5.1 was used to produce an impact against an almond being tested. There is an angular scale attached to the pendulum impact tester; the angle indicated on the scale corresponds to an increase in the height and potential energy of the anvil. The anvil of the pendulum impact tester was raised to specified angles before being released, so that it swings and attains kinetic energy before impacting the almond thereby producing the stated impact energy.

Figure 5.1 The pendulum impact tester used to create an impact against the almonds.

5.1.1 Damage sustained by almond from impact by a steel anvil

The first test produced an impact against an almond with the steel anvil of the pendulum impact tester. The anvil of the pendulum impact tester was raised to specified angles before being released, producing the impact energy shown as in Table 5.1.

Table 5.1 Categories and percentage of damage sustained by Nonpareil almond hit by a steel anvil

Angle (degrees)	Impact Energy (mJ)	Dent	Broken Skin	Chipped Almond	Cracked	Broken	Sample size
5	2.38	0%	0%	0%	0%	0%	30
10	11.5	0%	0%	0%	0%	0%	30
15	26.2	0%	0%	0%	0%	0%	30
20	46.7	0%	3%	3%	0%	0%	30
25	73	0%	0%	0%	10%	0%	30
30	105	0%	0%	0%	10%	0%	30
35	142.6	7%	7%	3%	13%	0%	30
36	150.9	0%	0%	0%	73%	0%	15
37	159.4	0%	0%	0%	80%	0%	15
38	168.1	0%	0%	0%	73%	0%	15
40	186.1	0%	5%	0%	60%	25%	20
45	235.3	0%	0%	0%	33%	67%	15
50	290.1	0%	0%	0%	27%	73%	15
55	350.7	0%	0%	0%	13%	87%	15
60	417.1	0%	0%	0%	0%	100%	15

The impact energy and the percentage of almonds damaged are shown in Figure 5.2. The first signs of damage appear at 46.7mJ of impact energy. There is a sharp increase in the number of cracked almonds at 150mJ of impact energy. This could be the critical point for damaging the almonds. At 186mJ of energy, the almonds that were tested start to break. At 235mJ of energy, 100% of the almonds were damaged. The test showed that as the level of the impact energy increases, the damage to the almonds becomes more extensive with more almonds being broken rather than chipped. When the energy level reaches 417mJ, 100% of the almonds tested were broken.

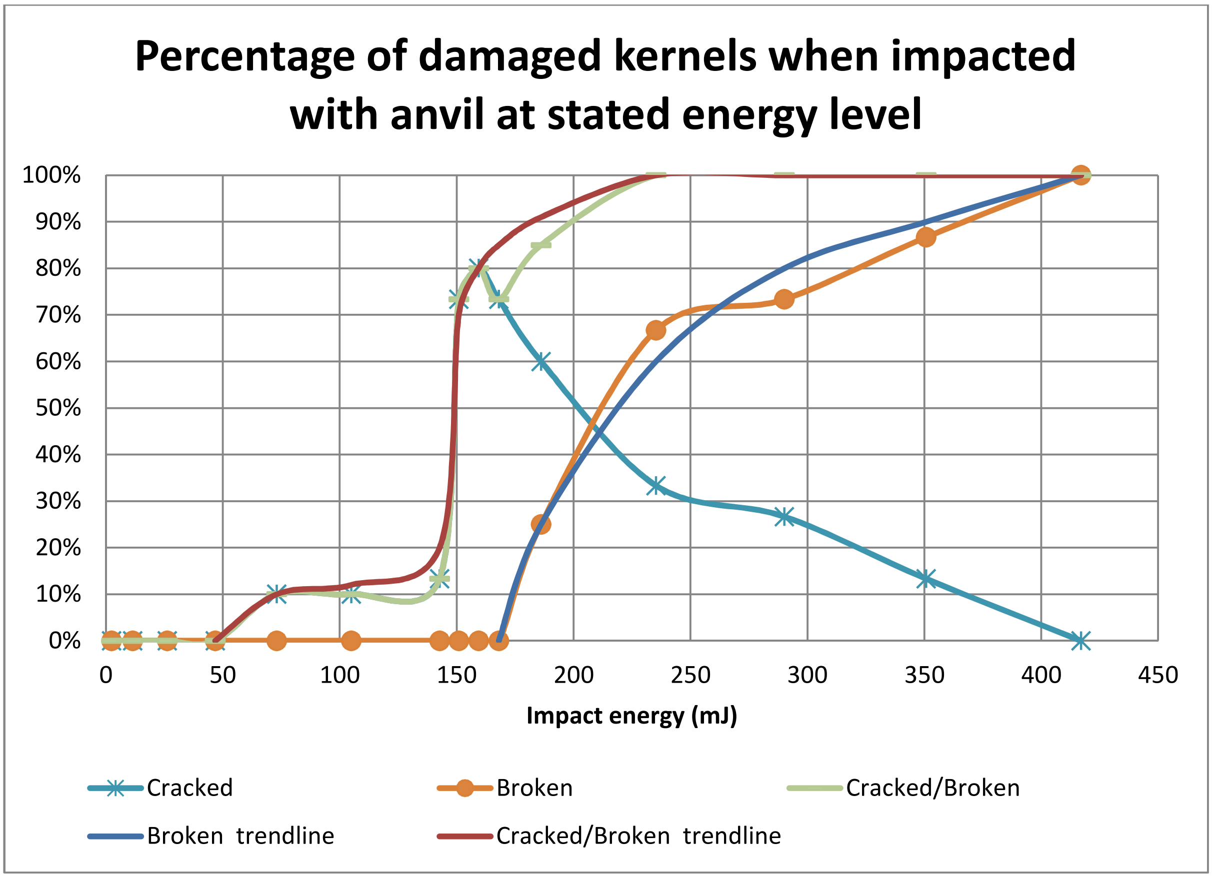


Figure 5.2 Percentage of kernels cracked or broken when hit by a steel anvil.

Figure 5.3 shows an almond kernel that was broken after being struck by the anvil of the pendulum impact tester. Figure 5.5 shows an almond kernel that was cracked after being struck by the anvil of the pendulum impact tester.

It was found that sometimes, the cracks in the kernels were not visible. The impact from the anvil caused damage to the inside of the almond kernel but the kernel skin showed no visible signs of damage from the outside. The skin remained intact and cracks could not be seen. However, when gentle pressure was applied, the almond immediately split, proving that it was not structurally sound but in fact had internal cracks. Such an almond kernel would be classified as cracked. All of the almond kernels that did not show signs of damage after impact were checked by applying gentle pressure to ascertain if there were any internal cracks in them. Figure 5.4 shows an example of the situation described.

Figure 5.3 Almond kernel that was broken by the anvil of the pendulum impact tester.

Figure 5.4 Almond kernel with no visible damage (left) shows cracks after gentle pressure was applied (right).

Figure 5.5 Almond with obvious crack after impact by steel anvil.

5.1.2 Damage sustained by almond from impact by an almond point

The next test produced an impact against an almond using the point of another almond. An almond was bonded to the anvil of the pendulum impact tester. The pointed tip of the almond was directed toward the other almond for the test to simulate the collision of an almond point at velocity against another almond. The set-up used in the experiment is shown in Figure 5.6.

Figure 5.6 Pendulum impact tester with an almond point.

The result of the test shows that signs of impact are visible from 7.13 mJ of energy and above. When the impact energy was increased to 11.5 mJ, the pointed almond tip started breaking the skin and chipping the almond kernel that was hit. As the amount of impact energy increased, the percentage of damage also increased as shown in Table 5.2 and Figure 5.7.

Table 5.2 Tabulated results of the test with almonds impacted by an almond point.

Angle (degrees)	Impact Energy (mJ)	Signs of impact	Broken Skin	Chipped Almond	Sample size
5	2.37	0%	0%	0%	50
8	7.13	52%	0%	0%	50
10	11.5		48%	12%	50
15	26.2		78%	34%	50
20	46.8		92%	72%	50

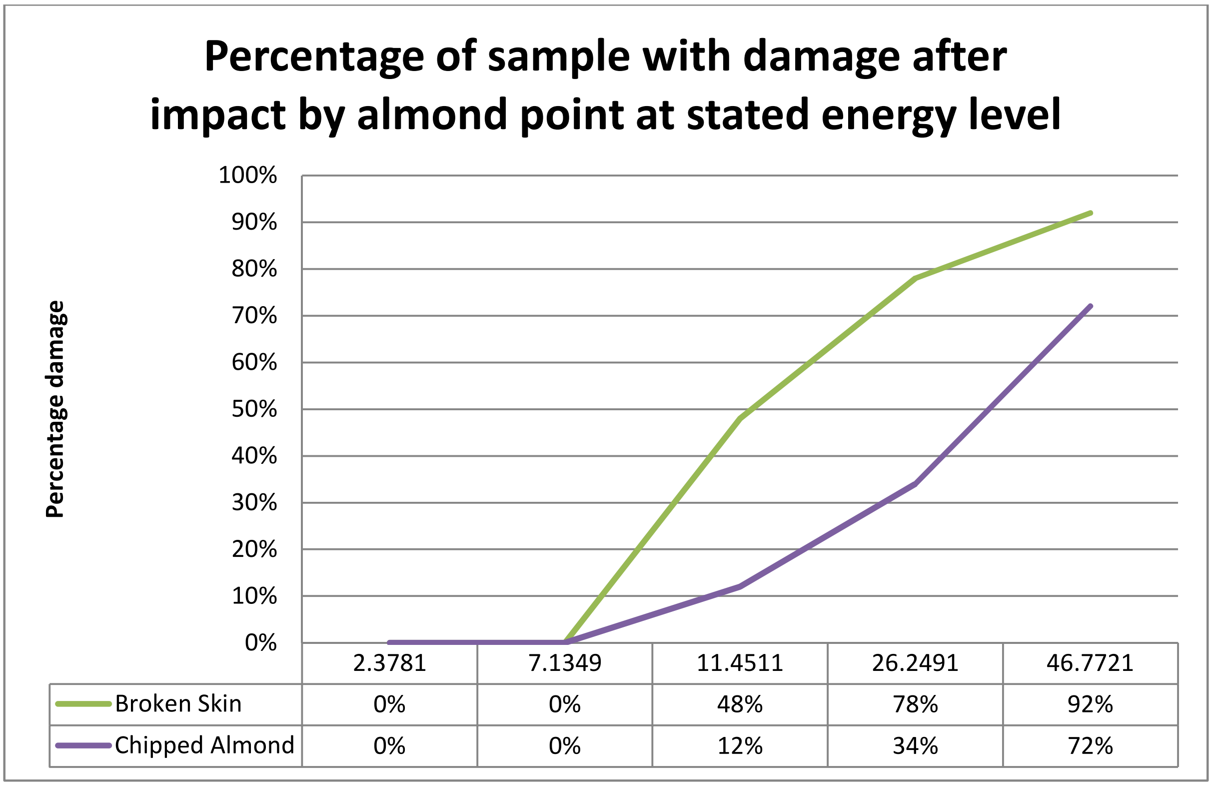


Figure 5.7 Percentage of damaged almonds increase with increase in impact energy.

5.1.3 Damage sustained by an almond with an offset from impact by an almond point

The previous impact experiment was conducted with the impact against the center of the almond kernel. This meant that the impact was directed at the thickest part of the kernel. The same experiment was attempted with the almond kernel offset so that the impact was against the taper of the almond kernel. This would result in an impact that glances off the surface. The reason for this test is to see if a glancing blow would result in damage at lower energy levels. The hypothesis is that if the impact is at an angle, the resultant force would be directed at the surface of the almond kernel rather than its internal structure. This may result in surface damage such as chips and scratches at lower impact energies.

The results of the test are shown in Table 5.3 and Figure 5.8. The first signs of damage start to occur at 7.1 mJ of impact energy. An impact at this energy level results in 50% of almond kernels with a break in the skin and 40% of the kernels being chipped. For these results, a chipped almond kernel is also considered in the tally for the percentage with broken skin as the skin has to be broken before the almond kernel is chipped.

Table 5.3 Damage to almond caused by an offset impact

Angle (degrees)	Impact Energy (mJ)	% Broke Skin	% Chipped
7	5.3	0%	0%
8	7.1	50%	40%
9	9.2	50%	30%
10	11.5	70%	50%

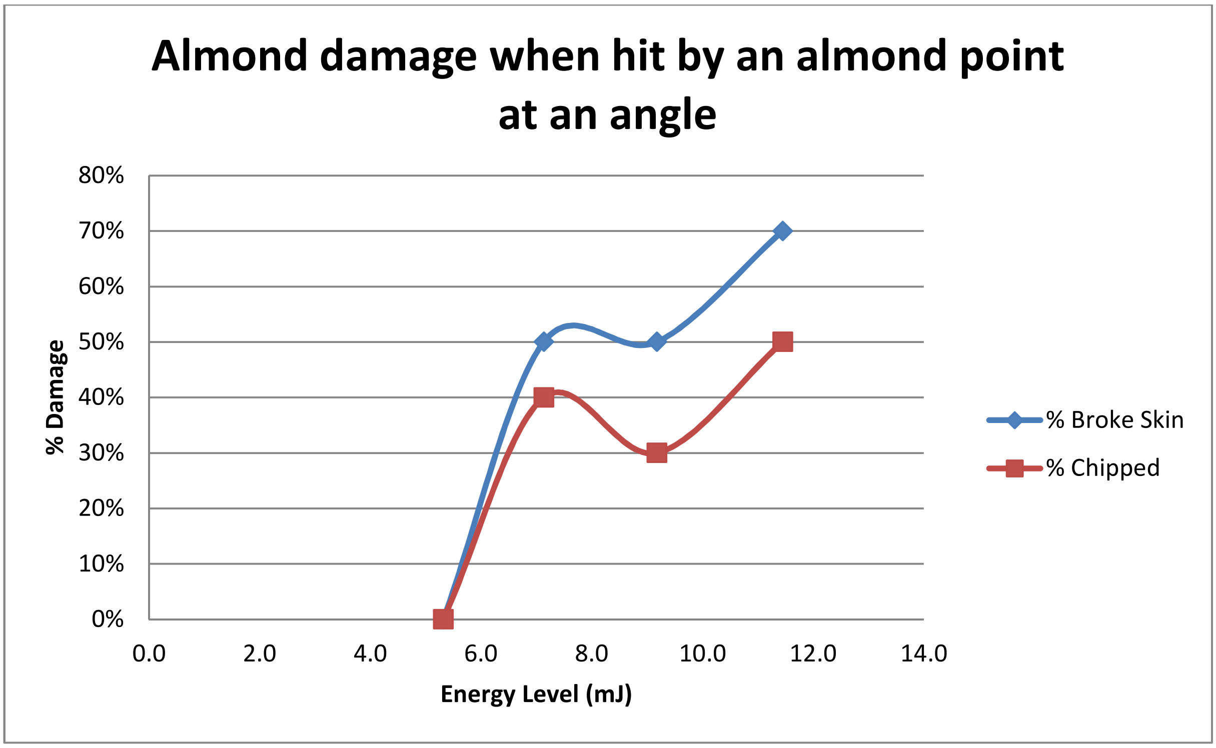


Figure 5.8 Graph showing the percentage of almonds with damage after being hit by an almond point at an offset with the stated energy level.

The results are quite consistent with expectations with the amount of damage increasing as the impact energy increases. The summarized results in Table 5.3 show that there are signs of damage from 7.1mJ onwards. When the results of Table 5.3 are compared with the results in Table 6.2, some similarities in impact energy required for damage was found. When the impact was at a right angle and absorbed by the thickest part of the almond kernel, there were signs of damage (an indentation) but no break in the skin at 7.1mJ of energy. When the test was carried out on almond kernels positioned at an offset allowing the impact to glance off the surface, 7.1mJ of energy was sufficient to cause a break in the skin in 50% of the sample. Furthermore, a 7.1mJ impact at an offset was also adequate to chip the almond kernel in 40% of the sample. This proves that less impact energy is required to cause visible damage to almond kernels if the impact is at an angle that allows the force to be directed along the surface of the almond kernel.

There was a dip in the quantity of damage at the energy level of 9.2 mJ. This could be the result of experimental errors as the test was done with a sample size of just 10 almonds at each energy level. If the test is carried out with a larger sample size, the accuracy of the results will increase.

5.2 Effects of velocity on almond damage

The next test was carried out to find the effects that velocity has on almond kernel damage. The rotary arm impact tester shown in Figure 5.9 was used to carry out the test. The rotating arm of the rotary arm impact tester can be controlled to rotate at the desired rotational velocity. This produces a controlled velocity at the end of the arm. Almond kernels are dropped into the tester through a pipe and the end of the rotating arm will hit the kernel at the controlled velocity.

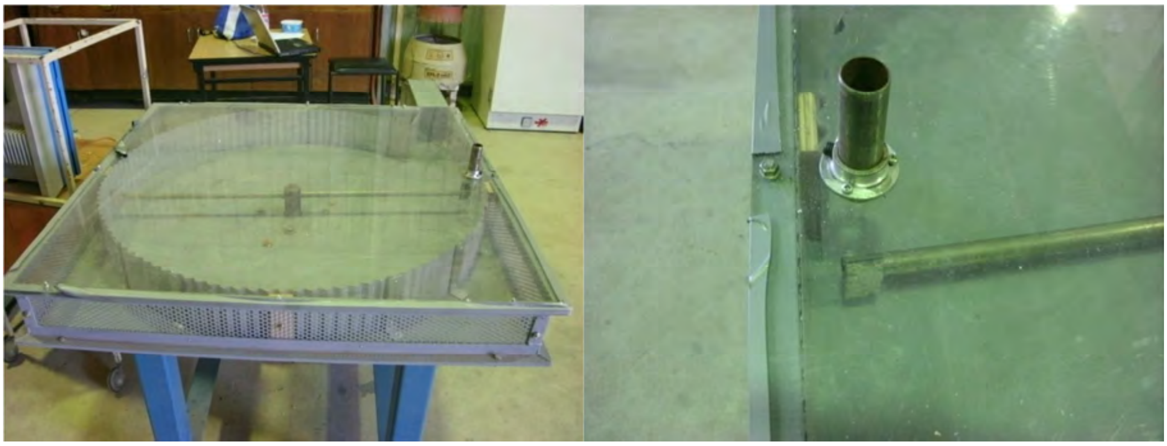


Figure 5.9 Rotary arm impact tester (left); entry point for the kernels and the end of the rotating arm (right).

The results of the test are shown in Table 5.4 and Figure 5.10. At 5.52 m/s, only 1 out of 10 almond kernels is chipped. The amount of damaged kernels and the extent of the damage increases as the velocity increases. At 11 m/s, 1 out of 30 kernels is broken into pieces, and at 13.8 m/s 7 out of 30 kernels are broken into pieces. At 24.8 m/s, all of the tested almond kernels are broken into pieces.

Table 5.4 Velocity test effect on almond kernel damage results.

Arm velocity (m/s)	Broken into pieces	Broken	Chipped	No damage	Sample size
5.5	0	0	1	9	10
8.3	0	0	11	19	30
11.0	1	2	12	15	30
13.8	7	9	11	3	30
16.5	12	8	7	3	30
19.3	7	3	0	0	10
22.1	7	3	0	0	10
24.8	10	0	0	0	10
27.6	10	0	0	0	10

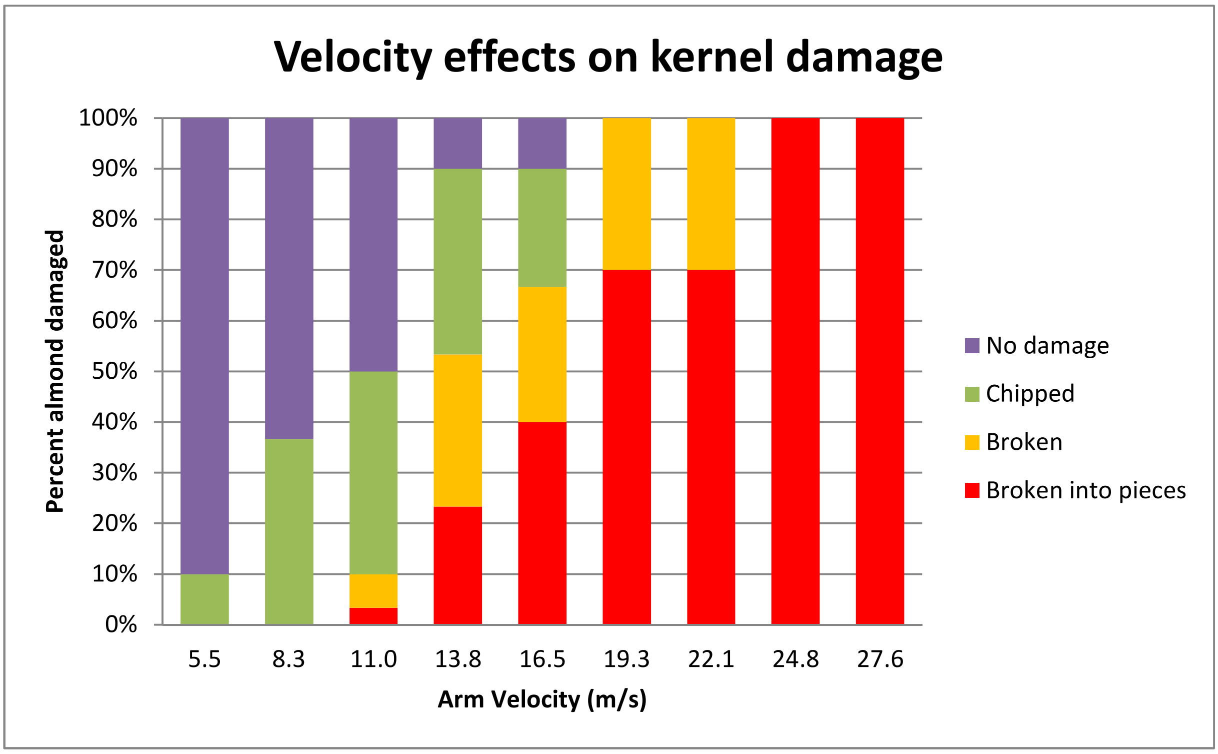


Figure 5.10 Velocity effects on kernel damage.

The damage to the kernels has been categorized into chipped, broken and broken into pieces. Figures 5.11 to 5.13 define the damage inflicted on the almonds.

Figure 5.11 Almond kernel Chipped at 5.5 m/s velocity.

Figure 5.12 Almond kernels broken at 19m/s.

Figure 5.13 Almond kernels broken into pieces at 13 m/s (left) and 24.8 m/s

5.3 Results of impact energy/velocity test compared with the machine settings used by Costa Almonds

The hulling and shelling process uses a pair of rollers and a roller and roller driven belt to hull and shell the almonds. The tangential velocity of each roller was calculated based on the machine settings data provided by Costa Almonds. The tangential velocity of the rollers gives an indication of the possible exit velocity of the almonds. The roller tangential velocity of the various stages as well as the kinetic energy calculated is shown in Formula 5.1 and 5.2.

The exit kinetic energy is worked out based on the formula of:

$$\textbf{Kinetic energy, } KE = \frac{1}{2} m\mathrm{v}^2 \qquad \textbf{(5.1)}$$

Where:

m = the mass of the almond
v = almond's assumed velocity

The actual exit velocity of the almond is unknown, The calculations were carried out using the tangential velocity of both rollers on the assumption that the almond's exit velocity is equal to the roller's tangential velocity. The mass of the almond is another variable in the equation, thus, the mean mass of the almond was used in the calculations.

The roller tangential velocity is worked out based on the formula of:

$$\textbf{Velocity, } V = \frac{N\pi d}{60} \qquad \textbf{(5.2)}$$

Where:

N = roller speed in RPM
d = diameter of the roller

The hulling and shelling machines at each stage have a pair of hard shell steel rollers and a rubber lined roller and belt pair. Figure 5.14 shows a diagrammatical representation of the hulling and shelling stage with the hard shell steel rollers labeled as ‘A’ and ‘B’ and the rubber lined roller and belt pair labeled as ‘C’ and ‘D’ accordingly. There are two directional changes in the movement of almonds. These are labeled as point ‘a’ where the almonds will be projected against the belt ‘D’ and point ‘b’ where the almonds will be projected against a guard before dropping onto a screen.

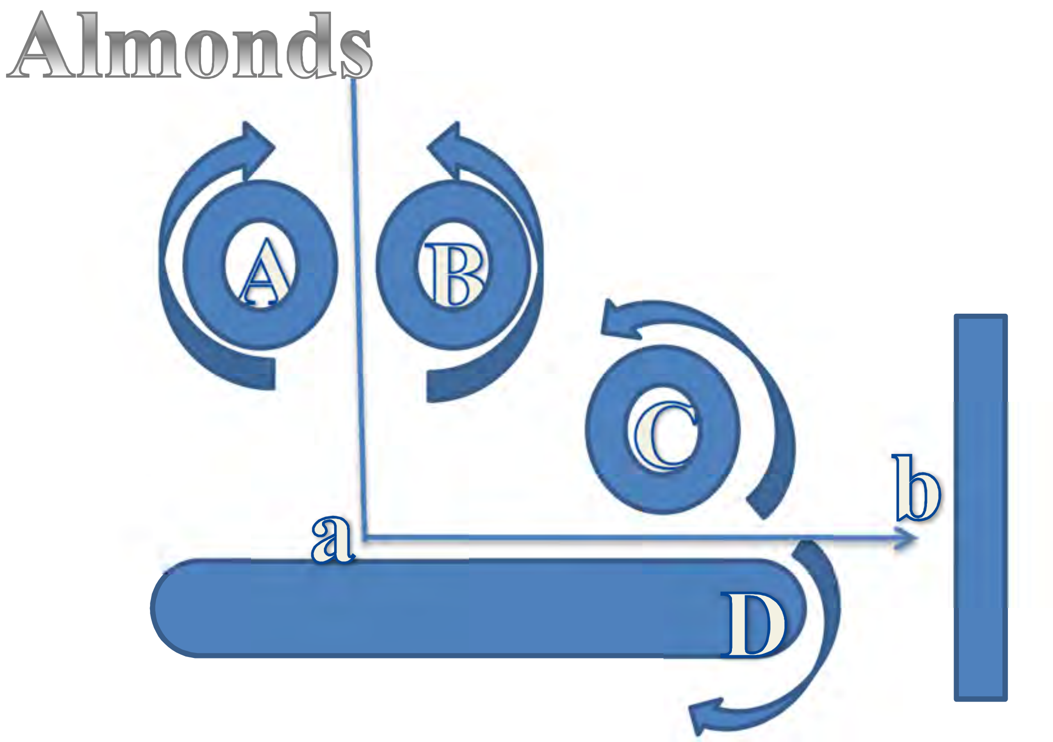


Figure 5.14 Diagrammatical representation of a stage of the hulling and shelling process.

The calculations for the kinetic energy of the almond kernels that are flung out from the rollers and belt with the mentioned assumptions are presented in Table 5.5.

Table 5.5 Tangential velocity of the various stages and the kinetic energy calculated for each stage of Costa Almonds' hulling and shelling process.

Calculations based on mean almond mass = 1.21 grams				
Cracker stage	Roller 'A' speed (RPM)	Diameter of hard shell roller 'A' (m)	Roller 'A' Tangential velocity (m/s)	Almond Average exit kinetic energy from 'A' (mJ)
1	288	0.21589	3.26	6.40
2	287	0.21589	3.24	6.36
3	287	0.21589	3.24	6.36
4	287	0.21589	3.24	6.36
5a	235	0.21589	2.66	4.26
5b	N/A	N/A	N/A	N/A
6	288	0.21589	3.26	6.40
Cracker stage	Roller 'B' speed (RPM)	Diameter of hard shell roller 'B' (m)	Roller 'B' Tangential velocity (m/s)	Almond Average exit kinetic energy from 'B' (mJ)
1	288	0.21589	3.26	6.40
2	287	0.21589	3.24	6.36
3	287	0.21589	3.24	6.36
4	287	0.21589	3.24	6.36
5a	235	0.21589	2.66	4.26
5b	N/A	N/A	N/A	N/A
6	288	0.21589	3.26	6.40
Cracker stage	Roller 'C' speed (RPM)	Diameter of rubber roller 'C' (m)	Roller 'C' Tangential velocity (m/s)	Almond Average exit kinetic energy from 'C' (mJ)
1	300	0.2667	4.19	10.6
2	310	0.21589	3.50	7.42
3	327	0.19685	3.37	6.86
4	300	0.21589	3.39	6.95
5a	306	0.24129	3.87	9.03
5b	306	0.22225	3.56	7.66
6	291	0.2667	4.06	9.98
Cracker stage	Roller and belt 'D' speed (RPM)	Diameter of roller and belt 'D' (m)	Roller and belt 'D' Tangential velocity (m/s)	Almond Average exit kinetic energy from 'D' (mJ)
1	150	0.22	1.73	1.80
2	150	0.22	1.73	1.80
3	150	0.22	1.73	1.80
4	150	0.22	1.73	1.80
5a	150	0.17	1.34	1.08
5b	150	0.17	1.34	1.08
6	72	0.22	0.83	0.42

Based on the results of Table 5.5, the possible exit velocities of the almonds ranges from a low of 0.83 m/s to a maximum of 4.19 m/s. The possible impact energy of the almonds ranges from a low of 0.42 mJ to 10.6 mJ of energy.

When the results are compared to the higher range of machine settings provided by Costa Almonds, rollers ‘C’ are running at approximately 300 RPM as shown in Table 5.5. This would result in a possible mean almond exit velocity of between 3.5 m/s to 4.19 m/s and energy levels of between 6.86 to 10.6 mJ of energy.

The impact test using an almond point directed at an offset almond kernel chipped 40% of the almond kernels tested at 7.1 mJ of energy. This falls within the range of the energy levels produced by rollers ‘C’.

The velocity test showed that 1 out of 10 almonds will be chipped at 5.5 m/s and 11 out of 30 almonds will be chipped at 8.2 m/s. Both of these values are beyond the higher velocity range of the machine settings used by Costa Almonds.

When the results are compared to the lower range of machine settings provided by Costa Almonds, roller and belt ‘D’ is running from 72 RPM to 150 RPM as shown in Table 5.5. This would result in a possible mean almond exit velocity of between 0.83 m/s to 1.73 m/s and energy levels of between 0.42 mJ to 1.8 mJ of energy. This is much lower than the velocities and energy levels required to damage almonds in the test results.

The energy levels of the almonds being processed by the machine can be related to fall height using Equation 5.3.

$$\textbf{Potential Energy, } PE = mgh \qquad (5.3)$$

Where:

m = the mass of the almond
g = gravitational acceleration
h = fall height

The results of converting the relevant energy levels to a corresponding fall height are shown in Table 5.6.

Table 5.6 Corresponding fall heights of the possible almonds exit energy from the rollers and belts.

Gravitational acceleration (m/s)	9.81	Almond mass (grams)	1.21
Almond Average exit kinetic energy from roller 'C' (mJ)	Fall height (m)	Almond Average exit kinetic energy from roller and belt 'D' (mJ)	Fall height (m)
10.6	0.893	1.8	0.152
7.42	0.625	1.8	0.152
6.86	0.578	1.8	0.152
6.95	0.586	1.8	0.152
9.03	0.761	1.08	0.091
7.66	0.645	1.08	0.091
9.98	0.841	0.42	0.035
Almond Average exit kinetic energy from roller 'A' (mJ)	Fall height (m)	Almond Average exit kinetic energy from 'B' (mJ)	Fall height (m)
6.4	0.539	6.4	0.539
6.36	0.536	6.36	0.536
6.36	0.536	6.36	0.536
6.36	0.536	6.36	0.536
4.26	0.359	4.26	0.359
N/A	N/A	N/A	N/A
6.4	0.539	6.4	0.539

The range of possible almond exit energy from the rollers corresponds to a fall height ranging from 0.035 m to 0.893 m. This is a fall height of less than 1 meter.

The corresponding fall heights for some of the values in the pendulum impact tester's anvil against almond kernel tests were calculated and are shown in Table 5.7. The results show that the almond kernels have to be dropped from a height of at least 3.9 m before 3% of the kernels are chipped.

Table 5.7 Corresponding fall height from anvil against almond impact test.

Impact Energy (mJ)	Chipped kernel	Cracked kernel	Fall Height (m)
46.7	3%	0%	3.934
73	0%	10%	6.150
105	0%	10%	8.846
142.6	3%	13%	12.013
150.9	0%	73%	12.713

The results from the tests have proved to be inconclusive as to the source of damage. The changes in the directional flow of the almonds at point ‘a’ and ‘b’ are potential areas for impact damage from an almond point projected against another almond to occur. However, due to the fact that the actual almond exit velocity from the rollers and belt is unknown, this study is unable to state conclusively if the velocity or impact at these points is a direct cause of mechanical damage in almond kernels.

5.4 Finding the effects of shear rolls in hulling and shelling almonds

This part of the study aims to find out the effects of using shear rolls to hull and shell almonds. The study was carried out using a shear rolls machine as shown in Figure 5.15. The machine has a pair of shear rolls that are controlled by separate motors. The motor speeds can be adjusted to provide the desired differential roller speed. The clearance between the shear rolls can also be adjusted. The almonds were dropped into the hopper on top of the machine; they would then fall through the pair of shear rolls and down the bottom into the bin.

Figure 5.15 Shear roll tester (left). Adjusting the clearance between the shear rolls (right).

5.4.1 Testing the effects of shear rolls on individual almonds

For this experiment, the speed of the first roller was set at 200 RPM and the second roller at 300 RPM to get a speed ratio of 1.5 (similar to the settings at Costa Almonds). The almonds were introduced into the shear roll tester individually in order to see the effect the shear rolls had on the almond. The process was then carried out for a total of 45 almonds. The shear rolls clearance was then reduced before the whole process was carried out again. The shear rollers clearance was initially set at 18.7 mm, and then reduced to 15.1 mm, 12.4 mm, 11 mm, 9.85 mm and 9.05 mm. This process resulted in all of the kernels being removed from their husks and shells. The result of the study is shown in Table 5.8.

For the purposes of this study, a hulled almond is an almond that has had its husk fully removed; a cracked shell almond is an almond that has its shell cracked and the kernel is still inside the shell. The results show that not all of the almonds are hulled or have their shells cracked before the kernels are removed. Only 19 out of 45 almonds had their husks removed and 24 out of 45 almonds had their shells cracked; the rest of the almonds had their husks and shells removed in one operation as shown in Figure 5.16.

Table 5.8 Results from the shear rolls test.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	
Shear rolls Clearance (mm)	18.7	15.1	12.4	11	9.85	9.05	Total
No. of Almonds Hulled	9	9	1	0	0	0	19
No. of Almonds with Cracked Shell	1	2	12	7	2	0	24
No. of Undamaged Kernels	0	1	5	10	10	3	29
No. of Chipped Kernels	0	0	2	0	2	1	5
No. of Broken Kernels	0	0	2	4	5	0	11
Percentage of almonds hulled and shelled at each clearance setting							
Shear rolls Clearance (mm)	18.7	15.1	12.4	11	9.85	9.05	Total
Hulled	20%	20%	2%	0%	0%	0%	42%
Cracked Shell	2%	4%	27%	16%	4%	0%	53%
Loose Kernels	0%	2%	20%	31%	38%	9%	100%

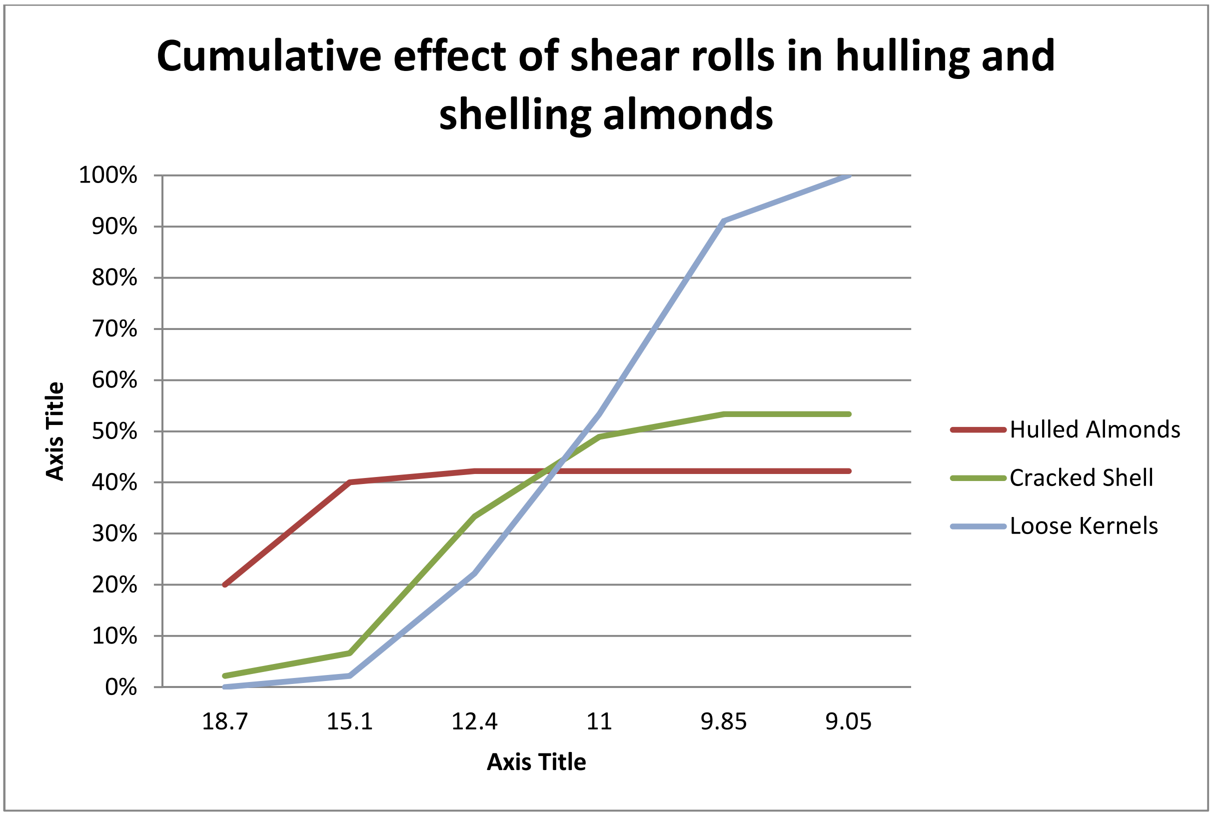


Figure 5.16 Cumulative effect of shear rolls on the almonds.

The mechanical damage caused to the kernels by hulling and shelling the almonds using shear rolls is shown in Table 5.9. There was 64% undamaged kernels, 11% chipped kernels and 24% broken kernels at the end of the whole experiment. The highest percentage of loose kernels was obtained at 11 mm and 9.85 mm shear rolls clearance as shown in Figure 5.17. The highest percentage of broken kernels was also obtained at the 11 mm and 9.85 mm shear rolls clearance setting.

Table 5.9 Mechanical damage caused by shear rolls.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	
Clearance (mm)	18.7	15.1	12.4	11	9.85	9.05	Total
Kernel Undamaged	0%	2%	11%	22%	22%	7%	64%
Kernel Chipped	0%	0%	4%	0%	4%	2%	11%
Kernel Broken	0%	0%	4%	9%	11%	0%	24%
Loose Kernels	0%	2%	20%	31%	38%	9%	100%

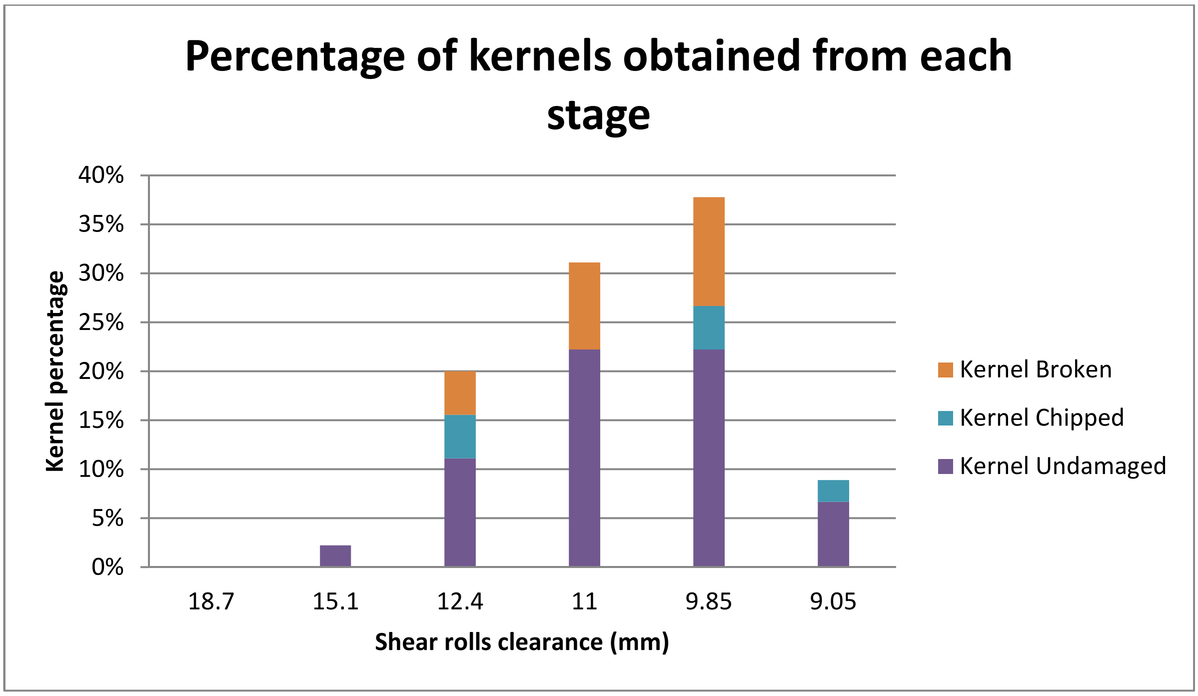


Figure 5.17 Percentage of kernels obtained at each shear rolls clearance setting.

The high percentage of broken kernels at the 11 mm and 9.85 mm shear rolls clearance setting could possibly be because the reduction in clearance by 1.15 mm was too drastic. Further tests could be carried out with the clearance being reduced more gradually in order to find possible ideal machine settings.

5.4.2 Finding a correlation between almond dimension and shear rolls clearance for almonds that have been worked on

The almond widths, shear rolls clearance and amount of almonds that had been worked on were compared to find a correlation between the amount of almond and roller interference and the hulling and shelling process. All of the almonds were wider than the shear rolls clearance as shown in Table 5.8 and Figure 5.18. No clear correlation was seen from the results.

Table 5.10 Almond width and roller interference effect on almonds.

Shear rolls clearance (mm)	18.7	15.1	12.4	11	9.85	9.05
Almond width > clearance + 5 mm	60%	78%	93%	86%	100%	80%
Almond width> clearance + 4 mm	71%	91%	100%	97%	100%	80%
Almond width > clearance + 3 mm	91%	96%	100%	100%	100%	80%
Almond width > clearance + 2 mm	96%	96%	100%	100%	100%	80%
Almond width > clearance< clearance+2 mm	4%	4%	0%	0%	0%	0%
Almond width < clearance	0%	0%	0%	0%	0%	0%
Hulled	20%	20%	2%	0%	0%	0%
Cracked Shell	2%	4%	27%	20%	10%	0%
Kernel Undamaged	0%	2%	11%	29%	48%	60%
Kernel Chipped	0%	0%	5%	0%	10%	20%
Kernel Broken	0%	0%	5%	11%	24%	0%
Affected almonds	22%	27%	50%	60%	90%	80%

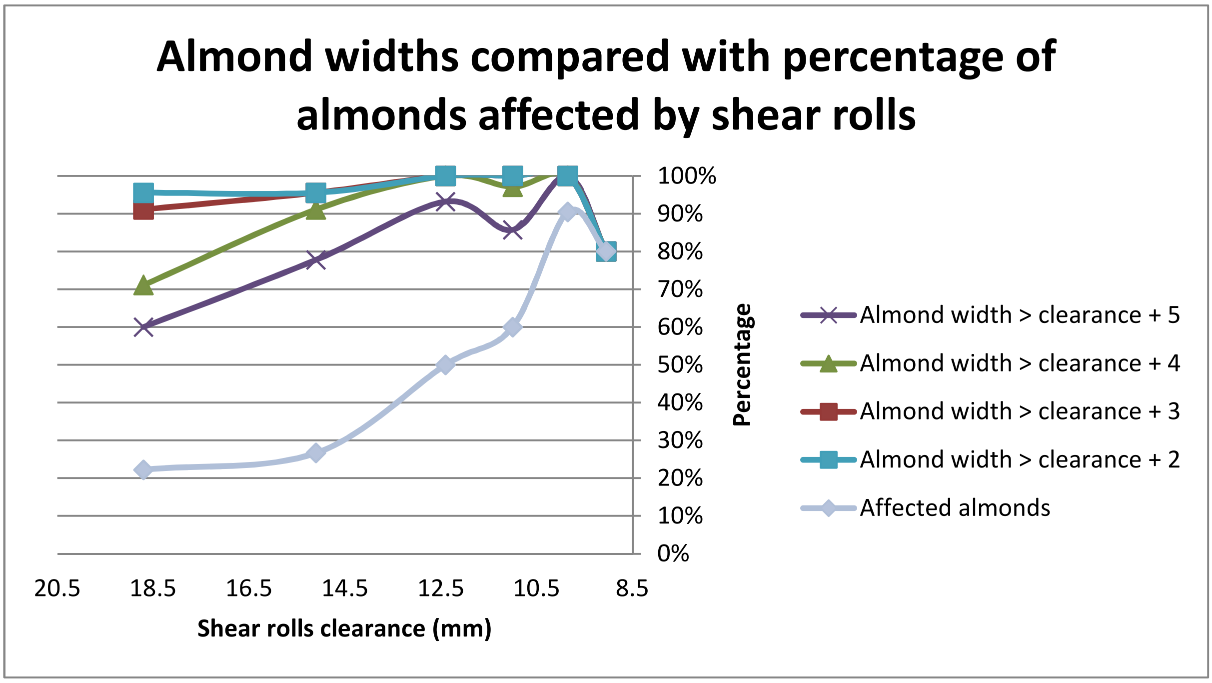


Figure 5.18 Almond widths at each shear rolls setting compared with the percentage of almonds affected by the shear rolls.

The almond thicknesses, shear rolls clearance and amount of almonds that had been worked on were then compared to find a correlation between the almond thickness and roller interference and the hulling and shelling process. There appeared to be a correlation between the affected almonds and their thickness as shown in Table 5.9. At 18.7 mm shear roll clearance, the percentage of almonds that had been worked on fell between the clearance +4 mm and +5 mm region. As the shear rolls clearance was reduced to 15.1 mm and 12.4 mm, the percentage of almonds that had been worked on seemed to trend towards the clearance +4 mm and +3 mm region. At the shear rolls settings of 11 mm, 9.85 mm and 9.05 mm, the percentage of almonds that had been worked on followed the Almond Thickness > clearance +3 mm curve closely as shown in Figure 5.19.

Table 5.11 Almond thickness and roller interference effect on almonds.

Shear rolls Clearance (mm)	18.7	15.1	12.4	11	9.85	9.05
Almond Thickness > clearance + 5 mm	16%	33%	39%	29%	29%	0%
Almond Thickness > clearance + 4 mm	31%	44%	52%	31%	76%	40%
Almond Thickness > clearance + 3 mm	49%	56%	59%	57%	95%	80%
Almond Thickness > clearance + 2 mm	56%	69%	75%	91%	100%	80%
Almond Thickness > clearance< clearance+2 mm	22%	9%	25%	9%	0%	0%
Almond Thickness < clearance	22%	22%	0%	0%	0%	0%
Hulled	20%	20%	2%	0%	0%	0%
Cracked Shell	2%	4%	27%	20%	10%	0%
Kernel Undamaged	0%	2%	11%	29%	48%	60%
Kernel Chipped	0%	0%	5%	0%	10%	20%
Kernel Broken	0%	0%	5%	11%	24%	0%
Affected almonds	22%	27%	50%	60%	90%	80%

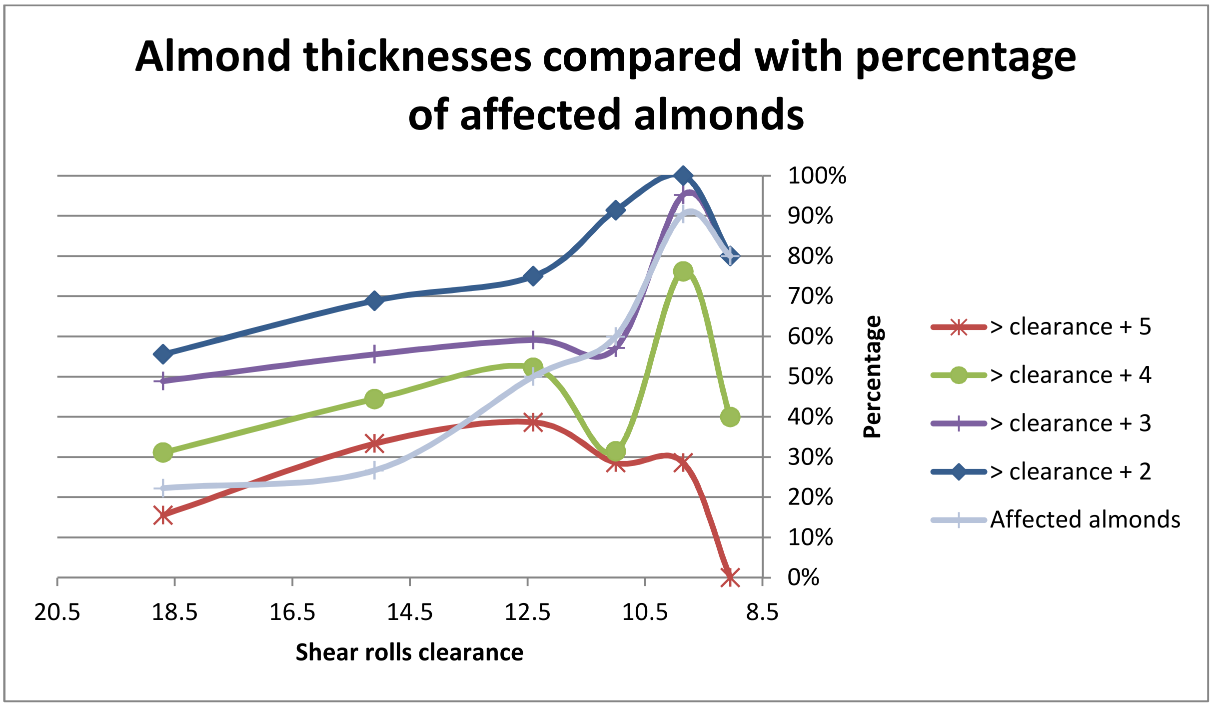


Figure 5.19 Almond thicknesses at each shear rolls setting compared with the percentage of almonds affected by the shear rolls.

The data was analyzed again to check the thicknesses of almonds that were worked on by the shear rolls. The difference between the almond widths and shear rolls clearance ranged from 0 mm to 12.4 mm thicker than the shear roll clearance with only 2 almonds falling below the 2 mm threshold as shown in Figure 5.20. Therefore, the almonds would have to be at least as thick as the shear rolls clearance before they can be worked on as shown in Figure 5.20.

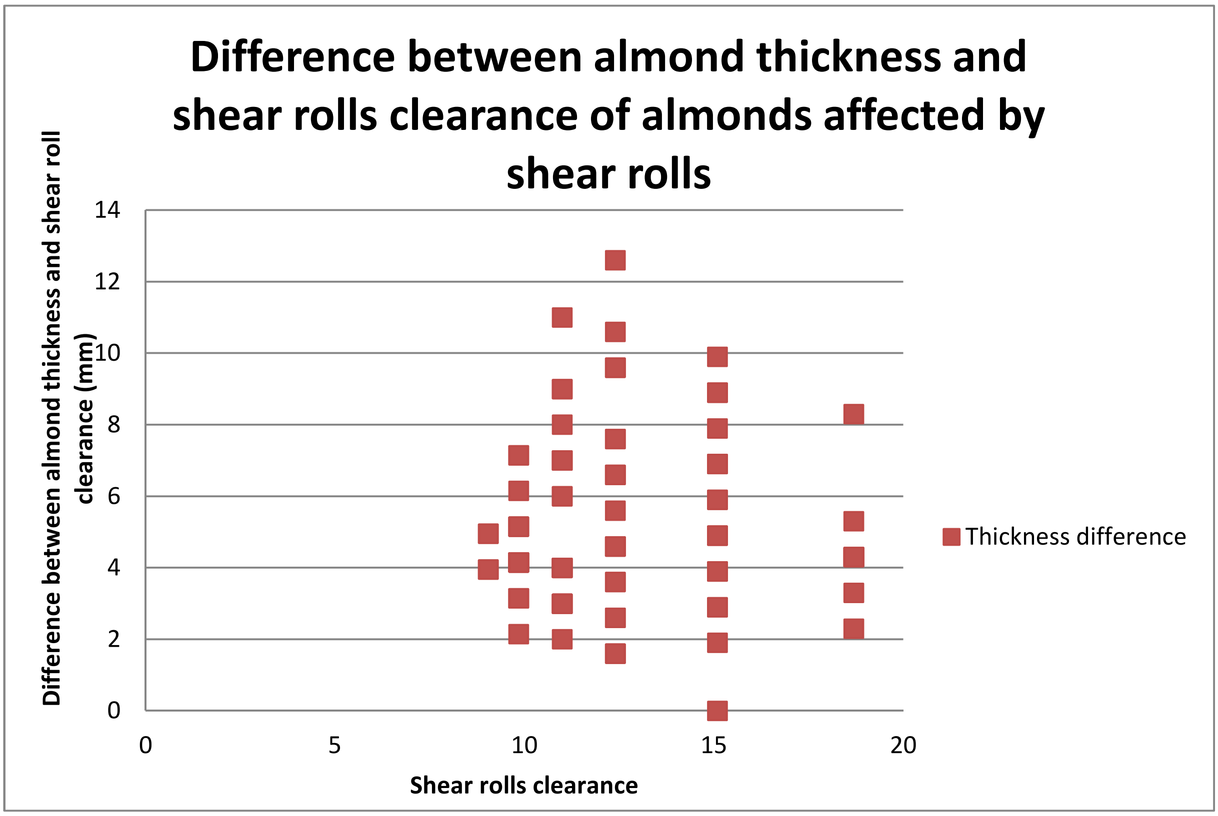


Figure 5.20 Difference between almond thickness and shear rolls clearance of almonds that have been worked on by shear rolls.

When the data on the widths of the almonds that had been worked on by the shear rolls was analyzed, it was found that all of the worked on almonds had widths greater than the shear rolls clearance. The difference between the almond widths and shear rolls clearance ranged from 3.9 mm to 13.6 mm with only one almond falling below the 4 mm threshold as shown in Figure 5.21. Therefore, the almonds would have to be at least 4 mm wider than the shear rolls clearance before they can be worked on.

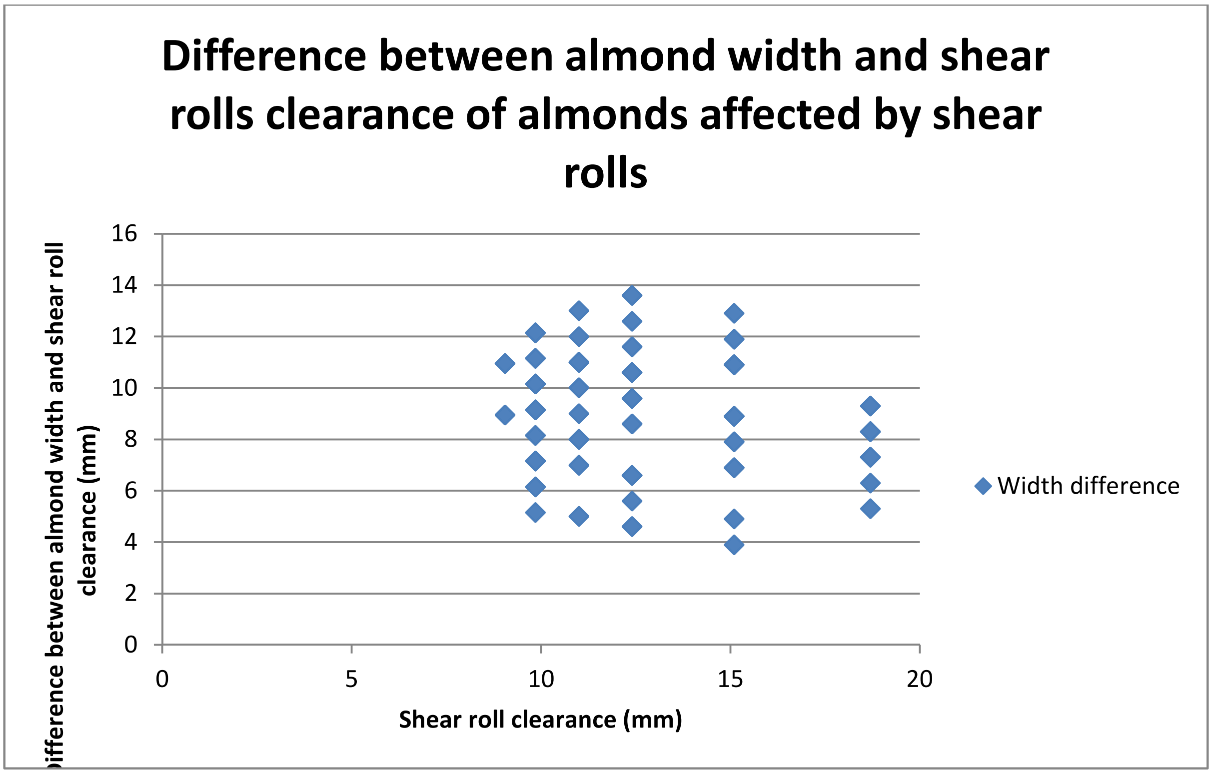


Figure 5.21 Difference between almond widths and shear rolls clearance of almonds that have been worked on by shear rolls.

5.4.3 Testing the effects of shear rolls on multiple almonds

The shear rolls test was then carried out on multiple almonds added at once. For this test, 30 in husk almonds were dropped into the hopper at once and the resulting damage to the almond kernels were recorded. The test was then carried out on 30 almond kernels. The test was carried out at shear rolls clearances of 12.15 mm, 10.8 mm and 9.08 mm; the results are shown in Table 5.12.

Table 5.12 Results of multiple almonds put through shear rolls at once.

In-husk Almonds			
Clearance (mm)	12.15	10.8	9.05
No. of almonds still in husk	11	12	0
Damaged kernel in husk	1	5	0
No. of almonds still in shell	9	0	0
Damaged kernel in shell	5	0	0
No. of loose kernels	10	18	30
Total number of damaged kernels	10	16	30
Kernels 8 mm to 9 mm thickness			
Clearance (mm)	12.15	10.8	9.05
Broken	0	0	3
Chipped	1	4	1
Undamaged	29	26	26

When the in-husk almonds are put through a shear roll clearance of 12.15 mm, a total of 10 kernels are damaged. Out of these 10 damaged kernels, 1 was still in its husk and 5 were still in their shells. When the shear rolls clearance was reduced to 10.8 mm, there were 5 damaged almond kernels still in their husks. When the shear rolls clearance was further reduced to 9.05 mm, all of the almond kernels were broken. Therefore, it is possible to damage kernels that are still in their husks and shells if the first stage of shear rollers has a clearance that is too narrow. Therefore, if the first stage of shear rollers starts off with a clearance that is 12.15 mm and the almonds are allowed to go through the shear rolls together rather than individually, 6 out of 30 almonds will be damaged before their husks and shells are removed. As the clearance of the shear rolls is decreased, the quantities of damaged kernels also increase.

When the almond kernels were put through the shear rolls with a 12.15 mm clearance, 1 out of 30 kernels was damaged. At 10.8 mm and 9.05 mm clearance, 4 out of 30 kernels were damaged. Therefore, if the kernels are allowed to go through the shear rolls together rather than individually, 1 out of 30 almonds will be damaged at 12.15 mm shear roll clearance despite all the kernels having a smaller thickness than the shear rolls clearance. When the clearance is reduced so that it is up to 0.5 mm more than the kernel thickness, there will be 4 out of 30 kernels damaged.

6. Conclusion

This study started out with the aims of identifying and ranking sources of mechanical damage, finding the dimensional characteristics of almonds and to rate the sorting capability of the machines used by the secondary processors.

6.1 Sources of mechanical damage

The study found that the mechanical damage to the kernels were occurring after the kernels were removed from their shells by the hulling and shelling machines. This implies that the kernels should be kept in their shells until ready for the hulling and shelling process.

The hulling and shelling machines at the secondary processers has been identified as a significant contributor to mechanical damage in the almond kernels. The source of the mechanical damage has been narrowed down to the shear rolls and belts. However, the exact cause of the damage has not been identified. Further studies can be carried out to find the effects of the machine settings on the kernels.

6.2 Dimensional characteristics of almonds

The width and thickness distribution of almonds was found in this study. The study found that the almond kernel thickness and width does not increase proportionally with in-shell or in-husk thickness and width. The study also found that there is a clearance between the kernel and its shell and this clearance increases as the in-shell size of the almond increases. All of this information could be used in future studies.

6.3 Current sorting capability

The current sorting capability is still leaving some insect and rodent damaged kernels in the sample. In order to remove all of the insect and rodent damaged kernels, at least an additional pass will be required. This could be accomplished by having another group of machines to do the next pass after the kernels have gone through the first group of machines.

Bibliography

Abbasgolipour, M., M. Omid, et al. (2010). "Sorting Raisins by Machine Vision System." Modern Applied Science **4**(2): 49.

Abbey, M., M. Noakes, et al. (1994). "Partial replacement of saturated fatty acids with almonds or walnuts lowers total plasma cholesterol and low-density-lipoprotein cholesterol." American Journal of Clinical Nutrition **59**(5): 995-999.

Aktas, T., R. Polat, et al. (2007). "COMPARISON OF MECHANICAL PROPERTIES OF SOME SELECTED ALMOND CULTIVARS WITH HARD AND SOFT SHELL UNDER COMPRESSION LOADING." Journal of Food Process Engineering **30**(6): 773-789.

Almond Board of Australia (2009). All About Australian Almonds. Almond Board of Australia. Berri, Almond Board of Australia**:** 16.

Almond Board of Australia (2009). Guide to Australian Almonds Naturally the best! Almond Board of Australia,. Berri, South Australia, Almond Board of Australia.

Almond Board of Australia (2010). The Australian Almond Industry. Almond Board of Australia. Berri, SA**:** 8.

Almond Board of Australia (2010). Australian Almond Statistics 2010. Berri, Almond Board of Australia**:** 12.

Almond Board of Australia (2011). Strategic R&D Plan 2011-2016. Berri, Almond Board of Australia**:** 34.

Antosh, N. (1985). Culling out bad seed/Houston firm makes light-sorting machine. Houston Chronicle. Houston, Tex, Houston Chronicle Publishing Company Division.

Austin, N. (2008). Farmers go nuts about almonds. The Advertiser. Adelaide, S Australia, News Digital Media.

Axelrod, N. (2011). "Smart Machine Vision Systems." Quality **50**(2).

Aydin, C. (2003). "Physical properties of almond nut and kernel." Journal of Food Engineering **60**(3): 315-320.

Brosnan, T. and D.-W. Sun (2004). "Improving quality inspection of food products by computer vision--a review." Journal of Food Engineering **61**(1): 3-16.

Brown, B. (2011). Almond Industry Site visit to Jubilee Almonds and Almondco. J. Fielke, S. Tok and F. Tang. Adelaide.18 Mar

Churchill, D. B., D. M. Bilsland, et al. (1992). "COMPARISON OF MACHINE VISION WITH HUMAN MEASUREMENT OF SEED DIMENSIONS." Transactions of the Asae **35**(1): 61-64.

Cline, H. (2006) Almond harvest brings optimism. Western Farm Press **28**, 1

Cline, H. (2010). "2010 almond crop measures up." Western Farm Press.

Connolly, C. (2005). "The challange of food inspection." Sensor Review **25**(3): 1.

Elexso (2005). "Elexso machines from Hamburg." Online. Retrieved 6 Nov, 2011, from http://www.sanmak.com.br/elexso/en/images/upload/26TRvierenglishhp.pdf.

Elexso (2005). "Optic principle." Online. Retrieved 6 Nov, 2011, from http://www.sanmak.com.br/elexso/en/images/upload/28Opticprinciple.pdf.

Esfahlan, A. J., R. Jamei, et al. (2010). "The importance of almond (Prunus amygdalus L.) and its by-products." Food Chemistry **120**(2): 349-360.

Fell, J., T. Thompson, et al. (2011). Commodity outlook and financial performance of key agricultural industries in the South Australian Greater South East region. Regional Outlook Conference. Hahndorf, SA, Australian Bureau of Agricultural and Resource Economics and Sciences**:** 26.

FSANZ (2011, 21 April). "Almonds – Microbial (Salmonella) – 21 April 2011." Current consumer level recalls. Retrieved 4 June, 2011, from http://www.foodstandards.gov.au/consumerinformation/foodrecalls/currentconsumerlevelrecalls/almondsmicrobialsalm5142.cfm.

Galedar, M. N., S. S. Mohtasebi, et al. (2009). "Mechanical behavior of pistachio nut and its kernel under compression loading." Journal of Food Engineering **95**(3): 499-504.

Gary Gentile, A. P. w. (2004). Salmonella jolts almond growers ; Contamination that led to broad recall is unusual. Columbian**:** A.5.

Goddard, J. (2007). US bees buzz off without trace The Australian. Canberra, A.C.T.

Gunasekaran, S. (1996). "Computer vision technology for food quality assurance." Trends in Food Science & Technology **7**(8): 245-256.

Hocking, A. D. and J. I. Pitt (2006). "Mycotoxins in Australia: biocontrol of aflatoxin in peanuts." Mycopathologia **162**(3): 233-243.

Koyuncu, M. A., K. Ekinci, et al. (2004). "Cracking Characteristics of Walnut." Biosystems Engineering **87**(3): 305-311.

Kris-Etherton, P. M., W. Karmally, et al. (2009). "Almonds Lower LDL Cholesterol." Journal of the American Dietetic Association **109**(9): 1521-1522.

Ledbetter, C. and M. Sisterson (2008). "Advanced generation peach-almond hybrids as seedling rootstocks for almond: first year growth and potential pollenizers for hybrid seed production." Euphytica **160**(2): 259-266.

Ledbetter, C. A. (2008). "Shell cracking strength in almond (Prunus dulcis [Mill.] D.A. Webb.) and its implication in uses as a value-added product." Bioresource Technology **99**(13): 5567-5573.

Narendra, V. G. and K. S. Hareesh (2010). "Quality Inspection and Grading of Agricultural and Food Products by Computer Vision - A Review." International Journal of Computer Applications **2**(1): 23.

National Heart Foundation of Australia (2011). Heart Foundation Tick Shopping Guide. N. H. F. o. Australia. Australia, National Heart Foundation of Australia**:** 9.

NewsRx (2003). Weight Loss; Almonds help dieters lose weight, according to study. Obesity & Diabetes Week. Atlanta, NewsRx**:** 40.

Nutraceutical Business & Technology (2009). "Prebiotic Potential for Almonds." Nutraceutical Business & Technology **5**(1): 8.

Olam (2009). Investors and Analysts Briefing: Acquisition Of Almond Orchards In Australia - Webcast - Final, Fair Disclosure Wire.

Page, R. (2011). Almondco site visit. University of South Australia. Adelaide.18 Mar

Pearson, T. and R. Young (2002). "Automated sorting of almonds with embedded shell by laser transmittance imaging." Applied Engineering in Agriculture **18**(5): 637-641.

Raine, G. (2007). Organic almond supporters roast pasteurization plan. San Francisco Chronicle**:** C.1.

Scussel, V. M. and F. R. d. Mello (2009). "Development of Physical and Optical Methods for In-shell Brazil Nuts Sorting and Aflatoxin Reduction." Journal of Agricultural Science **1**(2): 3.

Stoeckel, M. (2011). Site visit to orchird owned by Mark Stoeckel. J. Fielke, S.-H. Lee, S. Tok and F. Tang.13 Apr 2011

Sun, D.-W. (2000). "Inspecting pizza topping percentage and distribution by a computer vision method." Journal of Food Engineering **44**(4): 245-249.

The Cornucopia Institute (2007). "Controversial Almond Treatment Faces Delay; Public Opposition Growing." PR Newswire.

The Fresno Bee (1995). ALMONDS. The Fresno Bee. Fresno, Califonia, McClatchy Newspapers, Inc.

USDA (1997). United States Standards for Grades of Shelled Almonds. U. S. D. o. Agriculture, United States Department of Agriculture.

Vaughan, L. K. (1925). Almond Hulling and Separating Machine. United States Patent Office. United States of America,US1,564,914.

Vaughn, L. K. (1917). Nut Hulling and Cracking Machine. Google Patents. United States Patent Office. United States of America,US1,294,852.

Verma, B. (2010). Image Processing Techniques for Grading & Classification of Rice. International Conferance on Computer & Communication Technology. Allahabad, Uttar Pradesh 220-223.

Volk, J. S. (1981). Method of hulling pistachio nuts. United States Patent Office. United States of America.

Vursavus, K. and F. Özgüven (2005). "Fracture Resistance of Pine Nut to Compressive Loading." Biosystems Engineering **90**(2): 185-191.

Western Farm Press (2009). "Big price gap may alter almond variety choices." Western Farm Press.

Western Farm Press (2010). "California almonds turn in another good year " Western Farm Press.

Western Farm Press (2010) Self-compatible almond varieties to eliminate bees? Western Farm Press

Western Farm Press (2011). "Rootstock decisions vital to replanted almond orchards." Western Farm Press.

Whitaker, T. B., A. Slate, et al. (2010). "Correlation Between Aflatoxin Contamination and Various USDA Grade Categories of Shelled Almonds." Journal of AOAC International **93**(3): 943-947.

APPENDICES

Appendix A - Data for almond size distribution

Table A1 Almond width distribution

Sampled Almonds Measured Using Round Holed Template (Width)				
Width	Quantity	Total Mass (g)	Average Mass per Almond	%
15	1	1.1	1.1	0%
16	1	1	1.0	0%
17	4	4.8	1.2	1%
18	5	9.31	1.9	1%
19	22	15.5	0.7	6%
20	41	117.6	2.9	11%
21	105	347.3	3.3	28%
22	64	232	3.6	17%
23	60	237	4.0	16%
24	34	138.7	4.1	9%
25	22	99	4.5	6%
26	11	53.8	4.9	3%
27	4	18	4.5	1%
28	3	12.8	4.3	1%
Total:	377	1287.91		100%

Table A2 Almond thickness distribution data

Thickness	Inhusk Quantity	Inshell Quantity	Kernel Quantity	Inhusk %	Inshell %	Kernel %
7	0	0	6	0%	0%	2%
8	0	0	20	0%	0%	6%
9	0	0	197	0%	0%	54%
10	0	0	134	0%	0%	37%
11	0	4	5	0%	1%	1%
12	1	17	0	0%	5%	0%
13	2	90	0	1%	24%	0%
14	8	178	0	2%	48%	0%
15	12	66	0	3%	18%	0%
16	29	13	0	8%	3%	0%
17	91	1	0	24%	0%	0%
18	107	2	0	28%	1%	0%
19	66	1	0	18%	0%	0%
20	40	0	0	11%	0%	0%
21	16	0	0	4%	0%	0%
22	4	0	0	1%	0%	0%
23	1	0	0	0%	0%	0%
Total	377	372	362	100%	100%	100%

Table A3 Almond size distribution breakdown data

In-husk Width	In-husk Thickness	In-shell Width	In-shell Thickness	Kernel Width	Kernel Thickness
28	19	20	14	13	9
28	21	17	15	12	9
28	17	20	14	13	10
27	21	20	14	14	9
27	19	19	15	14	9
27	18	19	14	15	9
27	21	23	14	16	9
26	20	21	18	12	7
26	19	20	14	15	9
26	23	21	15	14	9
26	20	20	14	13	9
26	22	21	15	14	9
25	19	21	14	14	10
25	20	20	16	13	9
25	20	20	14	13	10
25	18	18	14	13	10
25	20	19	15	13	9
24	19	20	14	14	9
24	18	19	14	15	10
24	21	20	14	14	9
24	19	21	16	15	11
24	19	20	14	14	9
23	19	18	15	13	10
23	17	18	13	12	9
23	19	19	14	14	10
23	19	19	14	14	10
23	20	19	14	14	9
22	18	19	14	13	10
22	18	18	15	13	9
22	18	18	12	12	8
22	17	18	15	12	8
22	19	19	16	14	10

In-husk Width	In-husk Thickness	In-shell Width	In-shell Thickness	Kernel Width	Kernel Thickness
21	18	17	14	12	9
21	18	18	15	13	10
21	17	20	14	14	9
21	18	18	14	12	10
21	18	19	15	12	10
20	17	17	14	12	9
20	16	17	13	12	8
20	18	19	13	13	9
20	17	18	14	13	10
20	18	18	14	13	9
19	17	18	15	12	10
19	16	17	14	12	10
19	17	16	13	11	9
19	16	17	12		
19	18	17	15	12	9
18	16	16	13	12	9
18	14	15	13		
18	16	17	13	11	9
18	15	17	13	12	9
18	15	17	12		
17	13				
17	13				
17	14	14	11	9	8
17	15				
16	14	15	11		
15	12			9	4

Table A4 Shell thickness distribution data

In-shell Thickness	Kernel Thickness	Shell Thickness	Clearance between kernel and shell
12	10	0.36	0.64
12	8	0.73	1.27
12	9	0.37	1.13
12	8	0.38	1.62
13	9	0.39	1.61
13	9	0.49	1.51
13	9	0.43	1.57
13	9	0.45	1.55
13	10	0.45	1.05
13	10	0.5	1
13	9	0.6	1.4
13	9	0.6	1.4
13	9	0.48	1.52
13	9	0.46	1.54
14	9	0.69	1.81
14	8	0.9	2.1
14	9	0.73	1.77
14	10	0.67	1.33
14	9	0.6	1.9
14	9	0.43	2.07
14	9	0.48	2.02
14	10	0.53	1.47
14	9	0.54	1.96
14	9	0.74	1.76
15	10	1.14	1.36
15	10	0.81	1.69
15	10	0.72	1.78
15	10	0.85	1.65
15	9	1.22	1.78
15	9	1.79	1.21
15	10	0.92	1.58
15	10	0.82	1.68
15	10	0.82	1.68
15	10	1.3	1.2

In-shell Thickness	Kernel Thickness	Shell Thickness	Clearance between kernel and shell
16	9	1.71	1.79
16	9	1.08	2.42
16	10	1.4	1.6
16	9	1.54	1.96
17	9	1.66	2.34
17	10	1.7	1.8

Appendix B - Data for almond damage analysis at Costa Almonds

Table B1 Damage breakdown for sampling checks at each stage of Costa Almonds hulling and shelling process

	Before processing			**End of pre-cleaning (A)**			% of all almonds
	In-husk	In-shell		In-husk	In-shell	Kernel	
Good	208	57		147	30	82	
Broken				1		4	2%
Chipped							0%
Scratched						5	2%
Rodent damage	1					2	
Insect damage		2					
Mouldy	3						
Sticktights				1			
Total	**212**	**59**	**271**	**149**	**30**	**93**	**272**
Total %	**78%**	**22%**		**55%**	**11%**	**34%**	
C/B/S Total (% of Kernel)						**10%**	**4%**
Broken (% of Kernel)						**4%**	
Chipped (% of Kernel)						**0%**	
Scratched (% of Kernel)						**5%**	

	End of 1st Huller (B1)			% of all almonds
	In-husk	In-shell	Kernel	
Good	56	251	25	
Broken			2	0.6%
Chipped				0%
Scratched			6	1.7%
Rodent damage			1	
Insect damage				
Mouldy			1	
Sticktights	2			
Total	**58**	**251**	**35**	**344**
Total %	**17%**	**73%**	**10%**	
C/B/S Total (% of Kernel)			**23%**	**2.3%**
Broken (% of Kernel)			**6%**	
Chipped (% of Kernel)			**0%**	
Scratched (% of Kernel)			**17%**	
	End of 1st Screen(C1)			% of all almonds
	In-husk	In-shell	Kernel	
Good		2	114	
Broken			8	6%
Chipped			5	4%
Scratched			7	5%
Rodent damage				
Insect damage				
Mouldy				
Sticktights				
Total	**0**	**2**	**134**	**136**
Total %	**0%**	**1%**	**99%**	
C/B/S Total (% of Kernel)			**15%**	**15%**
Broken (% of Kernel)			**6%**	
Chipped (% of Kernel)			**4%**	
Scratched (% of Kernel)			**5%**	

	End of 2nd Huller (B2)			% of all almonds
	In-husk	In-shell	Kernel	
Good	72	447	23	
Broken				0.0%
Chipped			1	0.2%
Scratched			2	0.4%
Rodent damage				
Insect damage		1		
Mouldy				
Sticktights	5			
Total	**77**	**448**	**26**	**551**
Total %	**14%**	**81%**	**5%**	
C/B/S Total (% of Kernel)			**12%**	**0.5%**
Broken (% of Kernel)			**0%**	
Chipped (% of Kernel)			**4%**	
Scratched (% of Kernel)			**8%**	
	End of 2nd Screen (C2)			% of all almonds
	In-husk	In-shell	Kernel	
Good		1	96	
Broken			3	3%
Chipped			2	2%
Scratched			3	3%
Rodent damage			2	
Insect damage				
Mouldy				
Sticktights				
Total	**0**	**1**	**106**	**107**
Total %	**0%**	**1%**	**99%**	
C/B/S Total (% of Kernel)			**8%**	**7%**
Broken (% of Kernel)			**3%**	
Chipped (% of Kernel)			**2%**	
Scratched (% of Kernel)			**3%**	

	End of 3rd Huller (B3)			% of all almonds
	In-husk	In-shell	Kernel	
Good	20	531	201	
Broken			1	0%
Chipped			7	1%
Scratched			15	2%
Rodent damage				
Insect damage				
Mouldy			1	
Sticktights	4			
Total	**24**	**531**	**225**	**780**
Total %	**3%**	**68%**	**29%**	
C/B/S Total (% of Kernel)			**10%**	**3%**
Broken (% of Kernel)			**0%**	
Chipped (% of Kernel)			**3%**	
Scratched (% of Kernel)			**7%**	
	End of 3rd Screen (C3)			% of all almonds
	In-husk	In-shell	Kernel	
Good		3	433	
Broken			5	1.0%
Chipped			18	3.6%
Scratched			37	7.4%
Rodent damage			2	
Insect damage				
Mouldy				
Sticktights				
Total	**0**	**3**	**495**	**498**
Total %	**0%**	**1%**	**99%**	
C/B/S Total (% of Kernel)			**12%**	**12.0%**
Broken (% of Kernel)			**1%**	
Chipped (% of Kernel)			**4%**	
Scratched (% of Kernel)			**7%**	

	End of 4th Huller (B4)			% of all almonds
	In-husk	In-shell	Kernel	
Good	24	620	176	
Broken			2	0%
Chipped			12	1%
Scratched			28	3%
Rodent damage			1	
Insect damage				
Mouldy				
Sticktights				
Total	**24**	**620**	**219**	**863**
Total %	**3%**	**72%**	**25%**	
C/B/S Total (% of Kernel)			**19%**	**5%**
Broken (% of Kernel)			**1%**	
Chipped (% of Kernel)			**5%**	
Scratched (% of Kernel)			**13%**	
	End of 4th Screen (C4)			% of all almonds
	In-husk	In-shell	Kernel	
Good		5	356	
Broken			7	2%
Chipped			17	4%
Scratched			46	11%
Rodent damage				
Insect damage				
Mouldy				
Sticktights				
Total	**0**	**5**	**426**	**431**
Total %	**0%**	**1%**	**99%**	
C/B/S Total (% of Kernel)			**16%**	**16%**
Broken (% of Kernel)			**2%**	
Chipped (% of Kernel)			**4%**	
Scratched (% of Kernel)			**11%**	

	End of 5th Huller (B5)			% of all almonds
	In-husk	In-shell	Kernel	
Good	4	101	224	
Broken			3	1%
Chipped			53	13%
Scratched			17	4%
Rodent damage				
Insect damage		4		
Mouldy			1	
Sticktights	88			
Total	**4**	**105**	**298**	**407**
Total %	**1%**	**26%**	**73%**	
C/B/S Total (% of Kernel)			**24%**	**18%**
Broken (% of Kernel)			**1%**	
Chipped (% of Kernel)			**18%**	
Scratched (% of Kernel)			**6%**	
	End of 5th Screen (C5)			% of all almonds
	In-husk	In-shell	Kernel	
Good		76	295	
Broken			11	2.5%
Chipped			9	2.0%
Scratched			49	11.1%
Rodent damage				
Insect damage				
Mouldy				
Sticktights				
Total	**0**	**76**	**364**	**440**
Total %	**0%**	**17%**	**83%**	
C/B/S Total (% of Kernel)			**19%**	**15.7%**
Broken (% of Kernel)			**3%**	
Chipped (% of Kernel)			**2%**	
Scratched (% of Kernel)			**13%**	

	End of processing (D)			% of all almonds
	In-husk	In-shell	Kernel	
Good		66	4732	
Broken			111	1.9%
Chipped			410	7.0%
Scratched			519	8.9%
Rodent damage				
Insect damage			2	
Mouldy			9	
Sticktights	2			
Total	**2**	**66**	**5783**	**5851**
Total %	**0.03%**	**1.13%**	**98.84%**	
C/B/S Total (% of Kernel)			**18%**	**17.8%**
Broken (% of Kernel)			**2%**	
Chipped (% of Kernel)			**7%**	
Scratched (% of Kernel)			**9%**	

Appendix C – Final seminar PowerPoint charts

IDENTIFYING SOURCES OF MECHANICAL DAMAGE IN ALMOND PROCESSING

Final year project thesis for BEng Mechanical

Samuel Kwang Ming Tok
Supervised by
Associate Prof John Fielke

UNDERSTANDING THE INDUSTRY

- A number of site visits were carried out to gather background information on the almond industry in Australia
- Visits were to the almond orchards, primary processing and secondary processing facilities.
- Primary processing is the removal of the husk and shell of the almonds, known as hulling and shelling.
- Secondary processing is the removal of poor quality almonds and foreign material before packing it for the customer.

PRIMARY PROCESSING – HULLERS AND SHELLERS

- The almond's husk and shell is removed by shearing the almonds between a pair of rollers and then between a roller and belt that rotate with a speed differential.
- The shearing effect removes the hulls cracks the shells from the kernel.
- The almonds are then passed over a screen to remove the loose kernels before repeating the process on the next stage.
- The space between each subsequent stage of rollers and belt is reduced to hull and shell increasingly smaller almonds.

SECONDARY PROCESSING - PACKERS

- Almonds go through a colour sorter that picks out 'out of spec' almonds based on colour.
- The product is then packed into bulk bags or cartons for the customer.

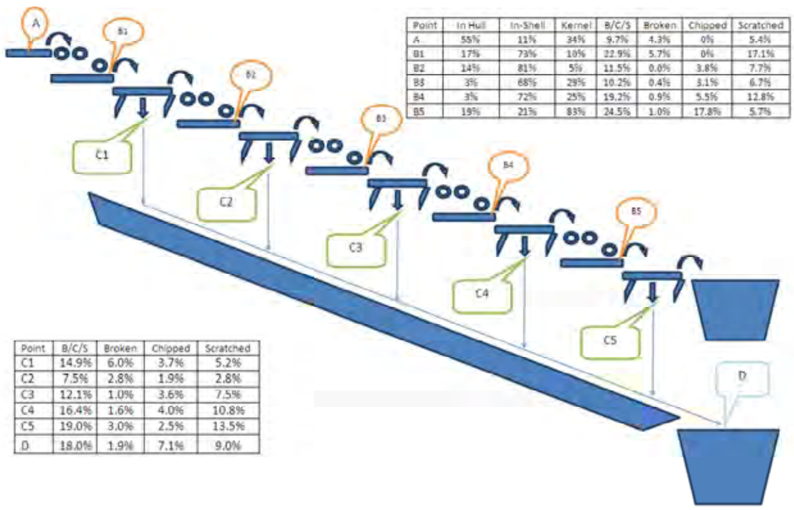
SAMPLING AT SECONDARY PROCESSOR FOR MECHANICAL DAMAGE

- Sample taken at the start and end of the colour sorting process.
- Results show that about 40% of the almond kernels arrive at the packers with some form of mechanical damage.

Table 1 Results of Riverland Almond's sampling

	Before		After	
	Quantity	%	Quantity	%
Good	455	58.5	588	70.33
Chipped	253	33	193	23.9
Scratched	34	7.5	52	8.84
Insect/Rodent Damaged	36	4.6	3	0.36
Doubles	5		0	

SAMPLING FOR MECHANICAL DAMAGE AT PRIMARY PROCESSOR



Point	In Hull	In-Shell	Kernel	B/C/S	Broken	Chipped	Scratched
A	55%	11%	34%	9.7%	4.3%	0%	5.4%
B1	17%	73%	10%	22.9%	5.7%	0%	17.1%
B2	14%	81%	5%	11.5%	0.0%	3.8%	7.7%
B3	3%	68%	29%	10.2%	0.4%	3.1%	6.7%
B4	3%	72%	25%	19.2%	0.9%	5.5%	12.8%
B5	19%	21%	83%	24.5%	1.0%	17.8%	5.7%

Point	B/C/S	Broken	Chipped	Scratched
C1	14.9%	6.0%	3.7%	5.2%
C2	7.5%	2.8%	1.9%	2.8%
C3	12.1%	1.0%	3.6%	7.5%
C4	16.4%	1.6%	4.0%	10.8%
C5	19.0%	3.0%	2.5%	13.5%
D	18.0%	1.9%	7.1%	9.0%

SAMPLING FOR MECHANICAL DAMAGE AT PRIMARY PROCESSOR

Table 2 Results from sampling for mechanical damage at secondary processor

Point	In husk	In shell	kernel	B/C/S	Broken	Chipped	Scratched
A	54.8%	11%	34%	9.7%	4.3%	0.0%	5.4%
B1	16.9%	73.0%	10.2%	22.9%	5.7%	0%	17.1%
B2	16.9%	81.3%	4.7%	11.5%	0.0%	3.8%	7.7%
B3	3.1%	68.1%	28.8%	10.2%	0.4%	3.1%	6.7%
B4	2.8%	71.8%	25.4%	19.2%	0.9%	5.5%	12.8%
B5	1.0%	25.8%	73.2%	24.5%	1.0%	17.8%	5.7%
	Remaining Kernels	Kernels Removed	No. of kernels in sample	B/C/S	Broken	Chipped	Scratched
		10.2%	134				

RESEARCH WITH PENDULUM IMPACT TESTER

- Attempt to find the impact energy necessary to create damage to the almond kernel.

RESEARCH WITH PENDULUM IMPACT TESTER

Table 3 Results of test with pendulum tester – anvil against almond.

Impact Energy (mJ)	Angle	Dent	Broken Skin	Chipped Almond	Cracked	Broken	Sample size
2.38	5	0%	0%	0%	0%	0%	30
11.5	10	0%	0%	0%	0%	0%	30
26.2	15	0%	0%	0%	0%	0%	30
46.7	20	0%	3%	3%	0%	0%	30
73	25	0%	0%	0%	10%	0%	30
105	30	0%	0%	0%	10%	0%	30
142.6	35	7%	7%	3%	13%	0%	30
150.9	36	0%	0%	0%	73%	0%	15
159.4	37	0%	0%	0%	80%	0%	15
168.1	38	0%	0%	0%	73%	0%	15
186.1	40	0%	5%	0%	60%	25%	20
235.3	45	0%	0%	0%	33%	67%	15
290.1	50	0%	0%	0%	27%	73%	15
350.7	55	0%	0%	0%	13%	87%	15
417.1	60	0%	0%	0%	0%	100%	15

RESEARCH WITH PENDULUM IMPACT TESTER

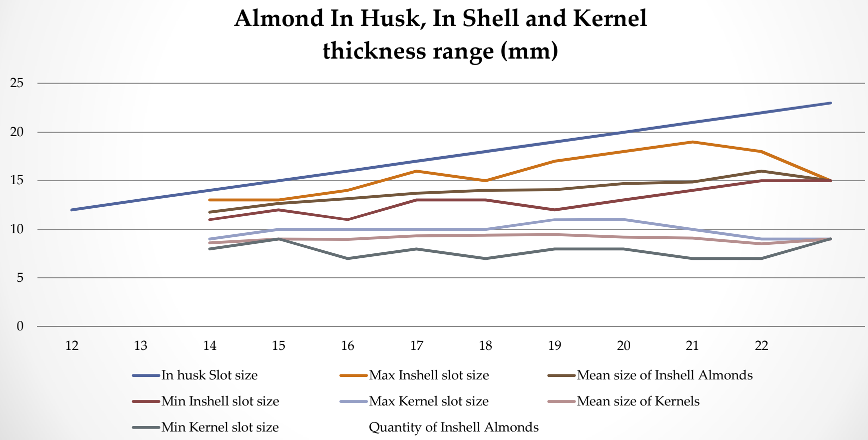
Table 4 Results of test with pendulum tester – almond point against almond

Angle	Impact Energy (mJ)	Signs of impact	Broken Skin	Chipped Almond	Sample size
5	2.3	0%	0%	0%	50
8	7.1	52%	0%	0%	50
10	11.5		48%	12%	50
15	26.2		78%	34%	50
20	46.8		92%	72%	50

Table 4 Results of test with pendulum tester – almond point against offset almond

Impact Energy (mJ)	% Broke Skin	% Chipped	Sample Size
5.3	0%	0%	10
7.1	50%	40%	10
9.2	50%	30%	10
11.5	70%	50%	10

Measuring almonds to find range of dimensions



CONCLUSION

- Various other test have been carried out their results are not presented here.
- Anticipated results would be information on energy level, velocity and roller clearances required to damage almond kernels.
- These results can be used in further studies or research to improve the machines and process so that mechanical damage is minimised.

Appendix D – Project diary

Project Number	Project Title: **Identifying sources of mechanical damage in almond processing**			
	Student Name:Samuel Tok Student ID Number: 110063633		University Supervisor **John Fielke**	
Program **LBMR**	Units **18**	Study Period **2 and 5**	Honours **No**	Confidentiality **N/A**

Date	**Description of activities**	**Duration (hours)**	**Progress (Result of effort)**
11/03/11	Project meeting, library consultation on research. Research.	10	Obtained some background on harvesting and processing. Understanding of Almond industry's OHS issues.
18/03/11	Trip up to Berri to visit Almond Co, Simarloo and Jubilee Almonds	13	Observed firsthand Almond processing from harvesting through to packing.
22/03/11	Project meeting	1.5	Agreement on outline of project
24/03/11	Research on optical sorting technologies and companies	8	Found some commercial optical sorters
25/03/11	Project meeting. Research.	10	Finalization of project proposal. Found related citation sources for background and optical sorting.
11-13/4/11	Trip to Almond Co, Riverland Almonds, Laragon, Omega Orchard,	57	Observe firsthand processing at other companies.

	Pistachio Farm, Select Harvest Orchards.		Gain understanding regarding the processing flow and methods used in hulling and shelling and sorting process.
5/4/11	Project Meeting with John Fielke and Lee Sang Heon	2.5	Guidance on project and background.
12/4/11	Thesis Writing	8	Wrote part of Thesis background.
14/4/11	Thesis Writing	10	Wrote part of Thesis background.
17/4/11	Thesis Writing	8	Wrote part of Thesis background.
19/4/11	Research for literature review	10	Found literature on optical sorting methods and studies.
26/04/11	Research and Thesis Writing	8	Literature review on optical sorting methods and studies.
27/04/11	Research and Thesis Writing	8	Literature review on optical sorting methods and studies.
29/04/11	Research	8	Found literature on optical sorting methods and studies.
5/5/11	Project meeting	1	Guidance on thesis
24/5/11	Project meeting, Thesis writing	6	Guidance on thesis
28/5/11	Thesis writing, formatting citations	10	Wrote part of thesis

29/5/11	Thesis writing	12	Formatted thesis document
4/6/11	Research and Thesis Writing	6	Found related citation sources. Wrote part of the-sis on secondary pro-cessing.
5/6/11	Almond sorting field work	8	Sort and tabulate results
6/6/11	Thesis writing	10	Wrote part of thesis on secondary processing
7/6/11	Thesis writing, project meeting	8	Wrote part of thesis on secondary processing, guidance on how to pro-ceed with project.
9/6/11	Almond measuring field work	10	Gathered data on almond size distribution
10/6/11	Almond measuring field work	12	Gathered data on almond size distribution
14/6/11	Sort and analyze data gathered	8	Obtain information on anatomy of almonds
16/6/11	Site visit to Costa Almonds	2	Understand process used at Costa Almonds.
21/6/11	Almond measuring field work	12	Gathered data on almond size distribution
23/6/11	Almond sampling field work at Cos-ta Almonds	10	Gathered data on mechani-cal damage
24/6/11	Almond sampling field work (Costa Almonds)	10	Gathered data on mechani-cal damage
25/6/11	Almond sampling field work	8	Gathered data on mechani-

	(Costa Almonds)		cal damage
4/7/11	Almond sampling field work (Costa Almonds)	9	Gathered data on mechanical damage
5/7/11	Sort and analyze data gathered Thesis writing	7	Sort data into information on anatomy of almonds. Wrote part of thesis on almond anatomy.
6/7/11	Sort and analyze data gathered Thesis writing	8	Sort data into information on almond damage. Wrote part of thesis on almond damage.
7/7/11	Almond sampling field work (Costa Almonds)	9	Gathered data on mechanical damage
8/7/11	Almond sampling field work (Costa Almonds)	8	Gathered data on mechanical damage
16/7/11	Sort and analyze data gathered Thesis writing	10	Plotted some relevant graphs from the data. Wrote part of thesis on almond damage.
18/7/11	Project Meeting	1	Presented data and got advice on how to proceed.
19/7/11	Sort and analyze data gathered Thesis writing	8	Convert data and graphs to percentage.
20/7/11	Sort and analyze data gathered	6	Flow chart for almond hulling and shelling process
22/7/11	Project Meeting, Thesis writing	8	Flow chart for almond

			hulling and shelling process
23/7/11	Sort and analyze data gathered	6	Plotted almond comparison graphs
26/7/11	Thesis writing, literature review for studies on nut damage.	10	Wrote part of thesis for almond damage.
27/7/11	Thesis writing, literature review for studies on nut damage.	7	Wrote part of thesis for almond damage
1/8/11	Project Meeting, literature review for studies on nut damage.	5	Got advice on how to proceed
5/8/11	Thesis writing, literature review for related nut damage.	8	Wrote part of thesis on almond damage
7/8/11	Thesis writing, literature review for related nut damage.	8	Wrote part of thesis on almond damage
10/8/11	Thesis writing, literature review for related nut cracking patents.	8	Wrote part of thesis on almond damage
11/8/11	Thesis writing, literature review for related nut cracking patents.	6	Wrote part of thesis on almond damage
13/8/11	Thesis writing.	12	Wrote part of thesis
15/8/11	Thesis writing. Contact Costa Almonds for information.	8	Wrote part of thesis
31/8/11	Project Meeting	3	Got advice on how to proceed
1/9/11	Analyze data provided by Costa Almonds	5	Acquired data on machine settings
7/9/11	Thesis writing.	8	Wrote part of thesis on almond damage.

10/9/11	Sort and analyze data gathered	8	Plotted almond size comparison graphs
11/9/11	Sort and analyze data gathered	12	Plotted almond size comparison graphs
12/9/11	Almond Impact Testing	5	Acquired data on impact energy effects on kernel.
13/9/11	Almond Impact Testing	2	Acquired data on impact energy effects on kernel.
14/9/11	Sort and analyze data gathered	6	Plotted almond size comparison graphs
15/9/11	Contact Costa Almonds for further information. Thesis Writing. Sent graphs for supervisor's comments	4	Wrote part of thesis on almond anatomy.
19/9/11	Thesis writing	7	Wrote part of thesis on primary processing
20/9/11	Thesis writing	8	Wrote part of thesis on primary processing
21/9/11	Project Meeting, Almond Impact Testing	6	Acquired data on kernel impact characteristics
5/10/11	Thesis writing find references online	8	Wrote part of thesis on primary processing
6/10/11	Thesis writing	8	Wrote part of thesis on primary processing
7/10/11	Thesis writing	8	Wrote part of thesis on primary processing
13/10/11	Project Meeting, Thesis writing	8	Got pointers and comments on thesis, wrote part of the-

			sis on impact tests
14/10/11	Thesis writing	4	Wrote part of thesis
15/10/11	Thesis writing	8	Wrote part of thesis
16/10/11	Thesis writing	10	Wrote part of thesis
17/10/11	Project Meeting, Almond velocity Testing, data analysis	10	Acquired data on velocity effects on kernel.
25/10/11	Project Meeting, Almond shear roll testing	8	Acquired data on shear roll effect on kernel.
26/10/11	Almond shear roll testing, velocity testing.	8	Acquired data on shear roll and velocity effect on kernel.
28/10/11	Thesis writing	12	Wrote part of thesis on impact tests.
29/10/11	Thesis writing, Prepare presentation	10	Wrote part of thesis, PowerPoint slides for presentation.
30/10/11	Thesis writing	10	Wrote part of thesis on impact tests.
2/11/11	Project Meeting, Thesis writing	8	Got pointers and comments on thesis, wrote part of thesis on impact tests.
3/11/11	Thesis writing	8	Wrote part of thesis on velocity tests.
4/11/11	**Project presentation**	6	Present project and watch the presentation of peers on their projects.
5/11/11	Thesis writing.	12	Abstract, impact tests.

6/11/11	Thesis writing	10	Wrote part of thesis on velocity tests.
7/11/11	Thesis writing	6	Wrote part of thesis on velocity tests.
9/11/11	Thesis writing	6	Update and finalise project plan.
10/11/11	Thesis writing on shear rolls test.	10	Wrote part of thesis on shear rolls tests.
14/11/11	Project meeting, thesis writing.	8	Improve on various parts of thesis.
15/11/11	Analyse data on shear rolls test.	10	Wrote part of thesis on shear rolls tests.
16/11/11	Project meeting. Thesis writing on shear rolls test.	8	Wrote part of thesis on shear rolls tests.
17/11/11	Thesis writing on shear rolls test.	8	Wrote part of thesis on shear rolls tests.
18/11/11	Project meeting. Thesis writing.	6	Improve on various parts of thesis.
19/11/11	Thesis writing.	10	Improve on various parts of thesis and formatting
20/11/11	Thesis writing.	10	Improve on various parts of thesis and formatting
21/11/11	Project meeting.	1	Hand in thesis, discussion on shear rolls results.
	Total Hours:	760	

Appendix 6 – Adrien Garderes, Performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell

Performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell

John Fielke and Adrien Garderes

Barbara Hardy Institute, School of Advanced Manufacturing and Mechanical Engineering, University of South Australia, Mawson Lakes

Nonpareil in-shell almonds from South Australia (harvested in 2011) were shelled using a set of polyurethane coated shear rollers with a range of settings. The results showed that the compression of the almond (almond thickness minus the roller clearance) was a critical factor. A high compression setting was required to achieve 100% shelling in one pass but this resulted in 90% of the kernels being broken and the remaining 10% were chipped. Using multiple passes with a smaller compression was able to achieve at best 10% broken kernels and 20% chipped kernels but required from 6 to 40 passes to achieve 100% shelling. The speed ratio of the rollers rotating in opposite directions did not affect shelling performance between 50 and 80% speed ratio but as the speed ratio reduced below 50% the amount of damage increased. When holding the speed ratio constant, decreasing the overall speeds reduced both chipped and broken kernels but increased the number of passes to achieve shelling of all almonds.

1. Introduction

Hulling and shelling is one of the main post-harvest processes for almonds. Hulling is the process of removing the hull from the almond which leaves it as an in-shell almond. Shelling consists of breaking the almond shell and releasing the kernel. Industry uses two rollers spinning in opposite directions at different speeds (typical values are: 200 rpm and 300 rpm) with a set clearance between them as part of their hulling and shelling process.

Tok (2011) reported varying levels of damage to almond kernels during the hulling and shelling process with the findings shown in Table 1.

Table 1. Breakdown of damage to kernels from shelling process

	Good kernel	Broken kernel	Chipped kernel	Scratched kernel
Sample A	72%	2%	7%	9%
Sample B	59%	0%	33%	8%

Tok (2011) also evaluated the performance of a shear roller at UniSA using in-husk almonds. He recorded the final kernel state (undamaged, chipped, broken…etc.) after putting almonds in-husk (husk + shell + kernel) with random sizes through a shear roller operating with speed of 200 and 300 rpm, respectively and a range of clearances. He found that after 6 passes of decreasing roller clearances of 18.7, 15.1, 12.4, 11.0, 9.9 and 9.1 mm, respectively he could achieve a kernel recovery of 65% undamaged kernel, 11% chipped kernel and 24% broken kernel.

The work presented in this paper examines the factors influencing the performance of polyurethane coated shear rollers for shelling in-shell almonds.

2. Materials and methods

Nonpareil almonds were used for all the experiments in this study. The crop was collected from Mark Stoeckel's farm at Paringa, South Australia during 2011 season harvest and tested between January and February 2012. The hulls were manually removed before each test.

Testing was conducted using a set of shear rollers (Figure 1). The rollers of 235 mm outside diameter were coated with polyurethane. The machine is similar to the process used in the almond industry (two shear rollers spinning at different speeds and in different directions). Different configurations were tested. First, the roller's spinning speeds were set to 200 rpm and 300 rpm and different clearances between the two rollers were tested. Then the clearance was fixed and the shear roller's speed ratio was changed. And finally the shear roller's speeds were changed keeping a speed ratio of 50%. All the tests were performed putting batches of 20 to 50 in-shell almonds individually through the shear rollers.

Figure 1: Shear roller machine at UniSA used for the tests

3. Results

3.1. Roller clearance for one pass

Firstly, different roller clearances were tested. Batches of 20 in-shell almonds (7.5, 8, 8.5, 9.5, 10.5, 11.5 mm gaps) and 50 (8.9, 10.9, 12 and 14 mm gaps) with a thickness from 13 to 14 mm were passed once through the shear roller (gap ranging from 7.5 to 14 mm), which gave the almond's compression values (almond thickness minus roller clearance) from 0 up to 7.5 mm. Figure 2 shows the results of the tests.

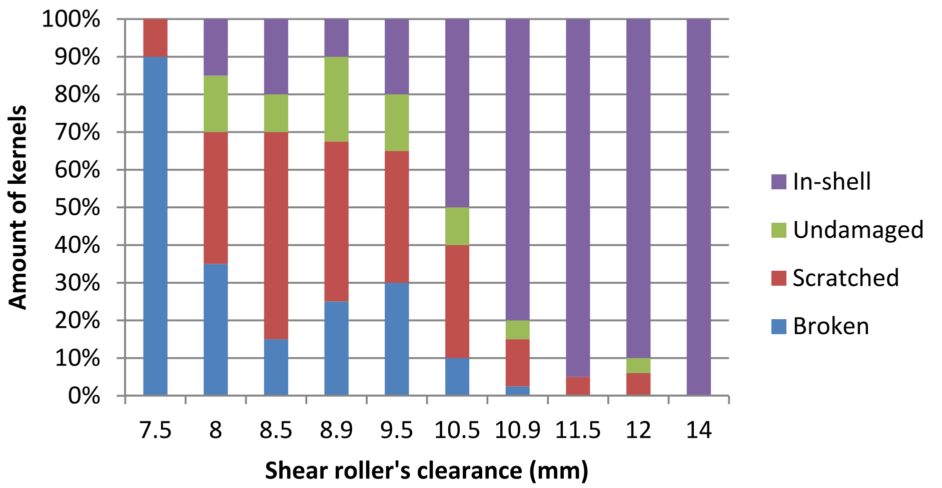


Figure 2: Results of one pass through the shear roller using various clearances. Almond thickness was 13 to 14 mm. Roller speeds were 200 and 300 rpm, respectively.

Figure 2 shows that a small compression (e.g. 14 mm clearance for almonds of 13-14 mm thickness) was not enough to remove kernels from their shell. As the clearance was reduced, the shell was broken and kernels released. The amount of kernels released and the damage to the kernels increased as the gap was reduced. For the sample of kernels extracted their thicknesses ranged from 6 to 9 mm with an average of 8.7 mm, hence for many kernels, the roller clearance of 7.5 mm was less than their thickness.

3.2. Roller clearance and multiple passes to achieve 100% kernel removal

Based on the very high amounts of damage occurring to kernels when they were extracted in one pass, testing was conducted that examined multiple passes through the shear rollers using a range of clearances. In this test the almonds remaining in-shell were repeatedly passed through the shear rollers until 100% of the kernels were released from the shell.

A typical result for the repeated passes is shown in Figure 3. Results for various clearances are shown in Figure 4.

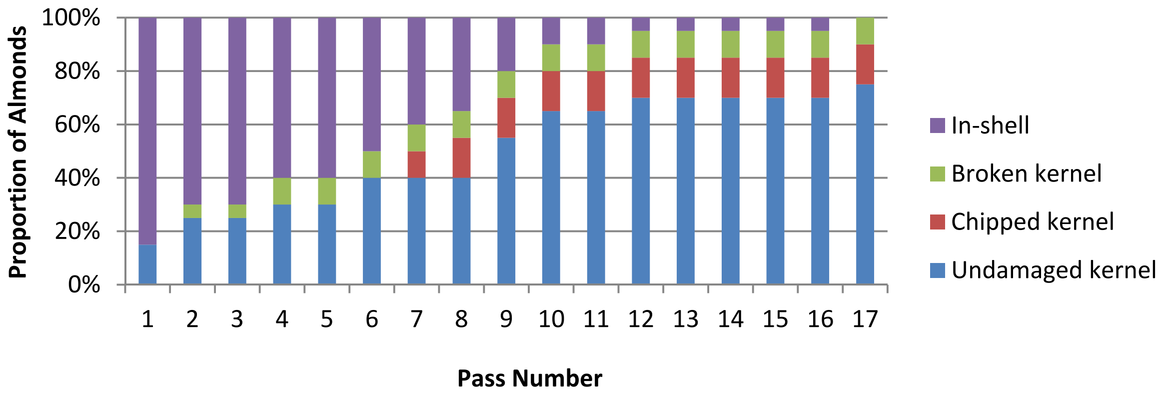


Figure 3. Typical result for repeated passes of almonds through shear rollers until all kernels were removed from their shell. Roller clearance was 11.9 mm with almonds of 12 to 13 mm thick.. Roller speeds were 200 and 300 rpm, respectively

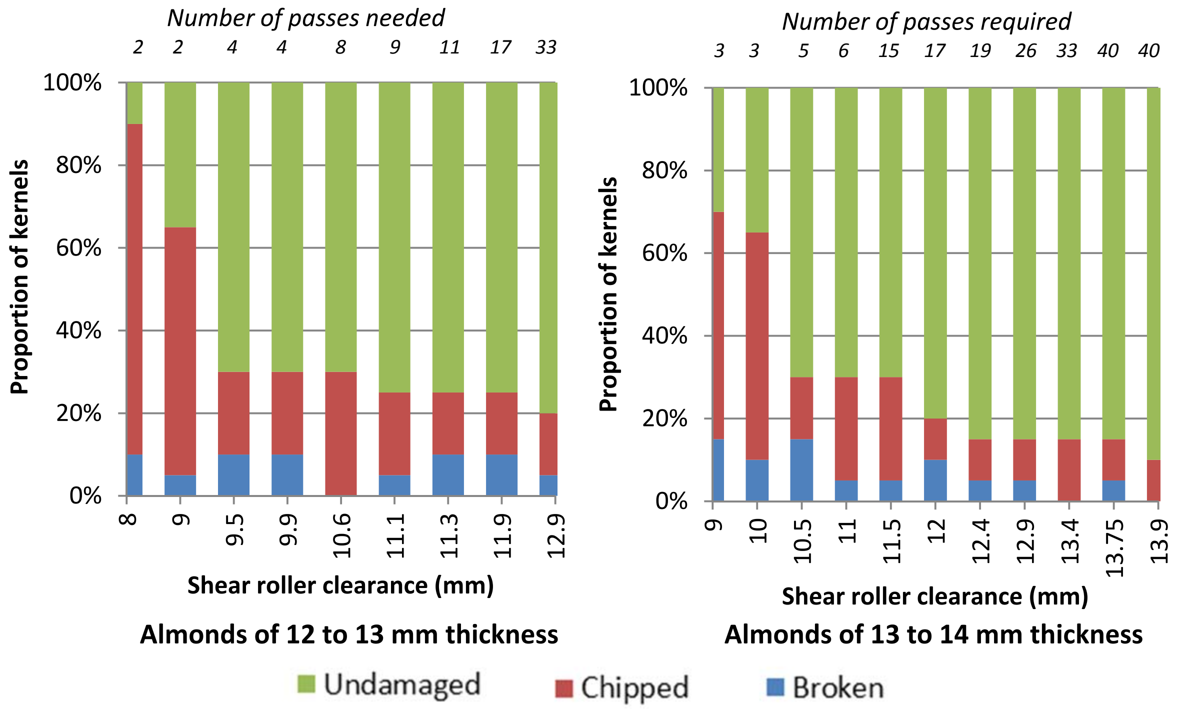


Figure 4. Results of repeated passes of almonds through shear rolls with various clearances until all kernels were removed from their shell.
Roller speeds were 200 and 300 rpm, respectively.

The results of Figure 4 show that with repeated passes through the shear roller that a high number of undamaged kernels (90%) could be obtained, but this required up to 40 passes using a small compression on the almond. This setting would not be practical as almonds would need to be divided into many size categories and many passes would be required.

As a compromise, the results showed that for a 3 to 4 mm compression of the almond only 3 to 6 passes were required for all kernels to be released, but there were 10% broken kernels and 20% chipped kernels.

The results of Figure 4 were normalized for compression on the almond and shown in Figure 5. Figure 5 shows that for compressions up to 3.5 mm on the almond the proportion of almonds damaged (increasing chipping) increased linearly at a rate of about 3% per mm of extra compression. After about 3.5 mm of shell compression the damage increased rapidly with further reduction in roller clearance.

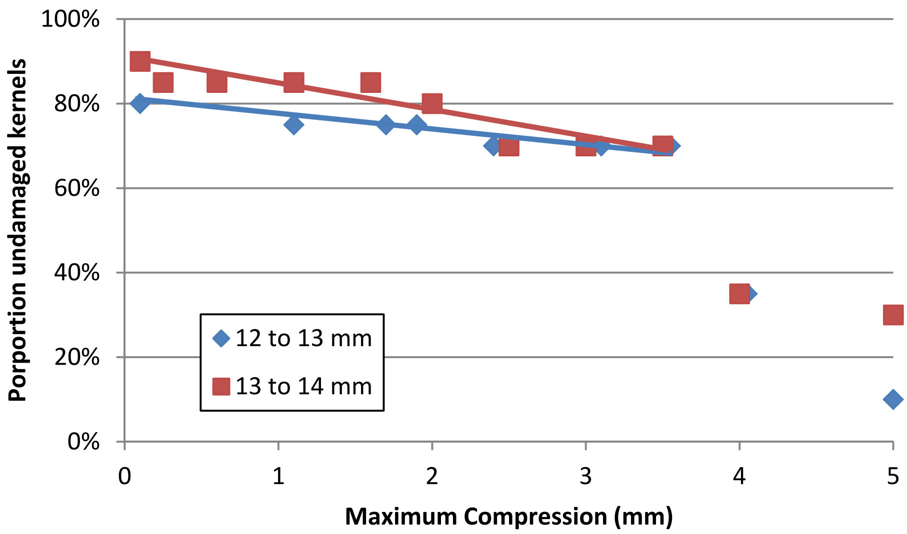


Figure 5. Results of repeated passes of almonds through shear rolls with various clearances until all kernels were removed from their shell.
Roller speeds were 200 and 300 rpm, respectively.

3.3. Roller speed ratio

Using a roller clearance of 12 mm with almonds of thickness between 13 and 14 mm, tests were undertaken for various speed ratios. The results are shown in Figure 6.

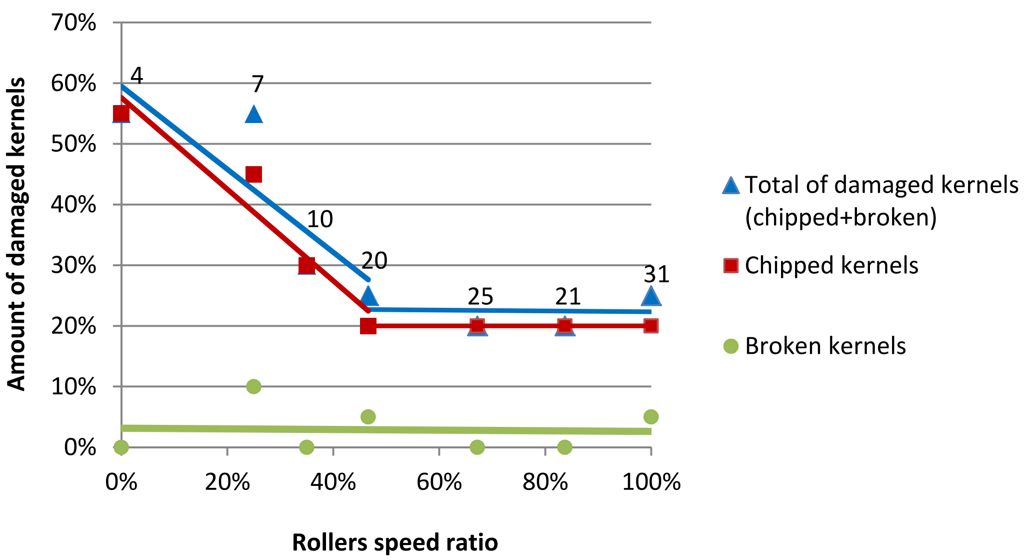


Figure 6. Results of various speed ratios on almond shelling with on roller fixed at 300 rpm and the other varied from 0 to 300 rpm. Roller clearance was 12 mm and almond thickness ranged from 13 to 14 mm. The numbers of passes needed to remove all the kernels are indicated on graph.

As shown in Figure 6, the level of broken kernels was around 5% (1 in 20) and stayed at that level for all speed ratios. The results showed that the amount of chipped kernel increased with reducing speed ratio below 50%. The best setting appeared to be in the range of 50 to 85% speed ratio.

3.4. Roller speed using a speed ratio of 50%

Using a speed ratio of 50% a range of roller speed combinations were evaluated with the results shown in Figure 7.

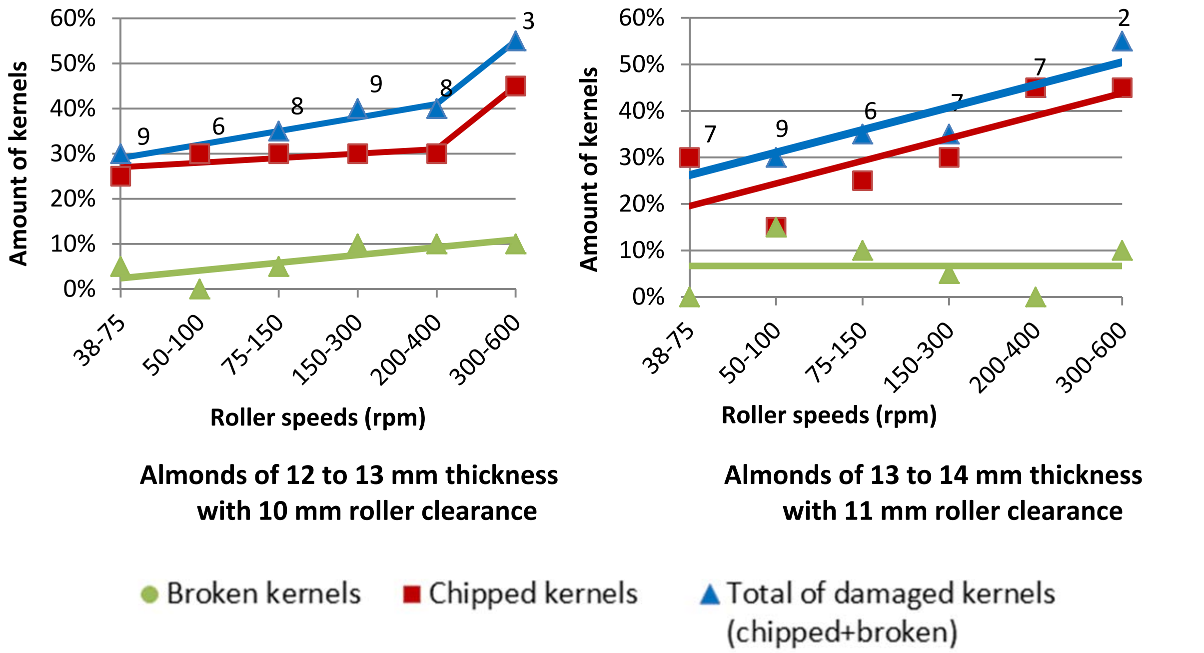


Figure 7. Comparison of damage to kernels for various roller speeds with a constant 50% speed ratio.

The results of Figure 7 show that reducing the roller's speeds reduced the amount of damage to the kernel.

In order to compare the size of the kernels that were chipped and broken with those undamaged, all kernels were measured for their thickness. As shown in Table 1 there was no statistical difference in mean kernel thickness of those that were damaged and those undamaged.

Table 1. Comparison of almond kernel thickness of those undamaged vs damaged

	Undamaged				Chipped and broken			
In shell thickness	Number	Mean (mm)	Standard Deviation (mm)	CV (%)	Number	Mean (mm)	Standard Deviation (mm)	CV (%)
12-13 mm	164	8.67	0.46	5.3	86	8.79	0.395	4.5
13-14 mm	91	8.86	0.38	4.2	54	8.81	0.43	4.9

4. Conclusions

The evaluation of the performance of polyurethane shear rolls for shelling individual nonpareil almonds showed that to achieve low levels of kernel damage from breaking or chipping during shelling that:-

- Almonds need to be pre-hulled and size graded on their thickness so as to apply not too much or too little compression on the almond.
- A compression on the almond (thickness minus roller clearance) should be set to no more than 3.5 mm.
- The almonds are passed multiple times through the shear rolls (up to 6 passes).
- The rollers be run with a speed ratio of 50 to 85%.
- The rollers have as low a speed as possible (150 and 300 rpm).
- That the expected best possible result is 10% broken and 20% chipped kernel.

The levels of kernel damage sustained using the shear rollers in a commercial manner are similar to those experienced in industry using a combination of shear rollers and shear belts.

Hence, further work is needed to:-

- Examine the role of moisture content on shelling performance as the tests.
- Examine using a high speed camera the mechanism of how the shear rolls are breaking and scratching the kernels.
- Examine the scenario of the shear rolls operating in the same direction.
- Replicate the tests using a shear belt whereby the almonds lie flat on the belt as they pass under the roller.

References

Aktas, T. Polat and Atay, (2007). Comparison of mechanical properties of some selected almond cultivars with hard and soft shell under compression loading. Journal of Food Process Engineering. Volume 30, Issue 6, pp 773 to 789.

Tok, S. (2011). Identifying sources of mechanical damages in almond process. Final year mechanical engineering project thesis, UniSA, School of Advanced Manufacturing and Mechanical Engineering.

Appendix 7 – Matthieu Stirn, Understanding the performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell.

Understanding the performance of polyurethane coated shear rollers to shell nonpareil almonds: In-shell

John Fielke and Matthieu Stirn

Barbara Hardy Institute, School of Advanced Manufacturing and Mechanical Engineering, University of South Australia, Mawson Lakes

Nonpareil in-shell almonds from South Australia (harvested in 2012) were shelled using a set of polyurethane coated shear rollers with a range of settings. High speed video was taken of the shelling process.

Results of the tests showed the importance of orientation on the shelling outcome when passing in-shell almonds through a set of shear rollers.

1. Introduction

Hulling and shelling is one of the main post-harvest processes for almonds. Hulling is the process of removing the hull from the almond which leaves it as an in-shell almond. Shelling consists of breaking the almond shell and releasing the kernel. Industry uses two rollers spinning in opposite directions at different speeds (typical values are: 300 rpm and 200 rpm) with a set clearance between them as part of their hulling and shelling process.

Tok (2011) reported varying levels of damage to almond kernels during the hulling and shelling process with the findings shown in Table 1.

Table 1: Breakdown of damage to kernels from shelling process

	Good kernel	Scratched kernel	Chipped kernel	Broken kernel
Sample A	72%	9%	7%	2%
Sample B	59%	8%	33%	0%

Tok (2011) also evaluated the performance of a shear roller at UniSA using in-husk almonds. He recorded the final kernel state (undamaged, chipped, broken, etc.) after putting almonds in-husk (husk + shell + kernel) with random sizes through a shear roller operating with speed of 200 and 300 rpm, respectively and a range of clearances. He found that after 6 passes of decreasing roller clearances of 18.7, 15.1, 12.4, 11.0, 9.9 and 9.1 mm, respectively he could achieve a kernel recovery of 65% undamaged kernel, 11% chipped kernel and 24% broken kernel.

Fielke and Garderes (2012) showed that passing in-shell almonds though a set of shear rollers that a high recovery of undamaged kernels (up to 90%) could be achieved using a small clearance on the almond and up to 40 passes through the equipment when using thickness graded in-shell almonds.

This paper examines some of the factors that lead to the damage of kernels when shelling with a set of polyurethane shear rollers.

2. Definitions of Kernel Damage

In order to describe damage to almonds during the shelling process the following terms are defined and shown in Figure 1.

Undamaged = a kernel with no visible damage to its skin (seed coat).

Scratched = a kernel which has a portion of its skin removed but no damage to the kernel.

Chipped = a kernel which has a portion of its skin removed and also a small chip from the kernel. The chip from the kernel is too small to recover.

Broken = a kernel which is in several pieces.

Undamaged

Chipped

Broken

Figure 1: Defining damage to shelled almond kernels

3. Materials and Methods

Nonpareil almonds were used for all the experiments in this study. The almonds were harvested in South Australia during the 2012 season. The hulls were manually removed before each test.

Testing was conducted using a set of shear rollers (Figure 2). The rollers of 235 mm outside diameter were coated with polyurethane. The machine is similar to the process used in the almond industry (two shear rollers spinning at different speeds and in different directions). Different configurations were tested.

Figure 2: Shear roller machine at UniSA used for the tests

4. Results

4.1. Almond orientation

Almond orientation as it entered the shear roller was evaluated. There were two main orientations, with the thickness presented to the shear rollers and the width presented to the shear rollers. The in-shell almonds were size graded for a thickness range of 13 to 14 mm. The roller clearance was set to 11.25 mm, and the roller speeds were in opposite directions at 300 and 200 rpm.

Almonds were tested in batch sizes of 40 for random, 20 for thickness presentation and 40 for width presentation.

The results showed that for a thickness presentation of the almonds to the shear rollers it took 30 passes through the rollers to remove all kernels from their shell. With the thickness presentation only 5% were chipped and none were broken. Conversely, when the almonds were presented with a width presentation only 33% of the kernels were removed without damage and 25% were broken.

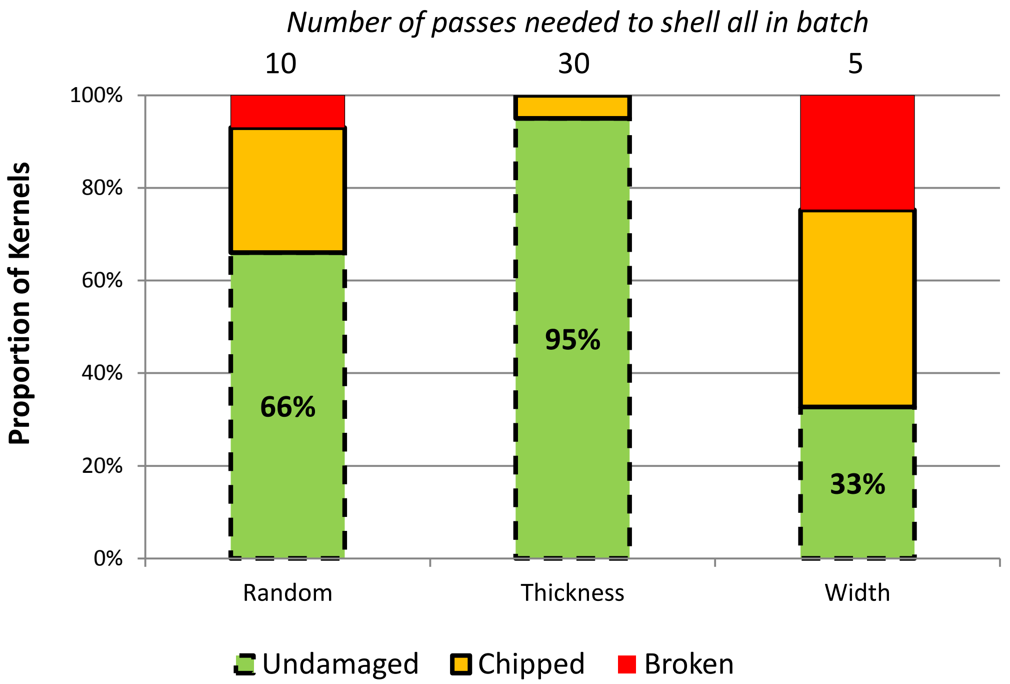


Figure 3: Results of multiple passes to achieve 100% kernel removal through the shear roller.
Various orientations were used with 13 to 14 mm thickness in-shell almonds passing through an 11.25 mm roller clearance. Roller speeds of 200 and 300 rpm

Measurements were made of the dimensions of the kernels extracted during the experiment. In comparison to the roller clearance of 11.25 mm, the average kernel thickness was 8.85 mm and the average kernel width was 13.05 mm. As the average kernel width was much larger than the roller clearance this shows that if the kernel is to pass through the roller clearance without damage it must rotate to a thinner (thickness) orientation. The width presentation explains why an almond kernel is sometimes broken as no kernels were broken with a thickness presentation.

4.2. Typical shell failure modes

When passing almonds though the shear rollers with a thickness presentation, there were two distinct stages. Firstly, the passage through the rollers resulted in detachment of a thin “tounge” off the shell as shown in Figure 4.

Figure 4: First action of passing through shear rollers – removal of tongue.
The green item highlight the tongue removed.

Secondly, the action of the shear rollers was to crack the shell as shown in Figure 5.

Figure 5: Second action of passing through shear rollers – cracking of shell

Finally the shell fails after successive passes through the shear rollers, in one of two manners as shown in Figure 6.

Figure 6: Final breaking of the shell in one of 2 ways. Either single sided or double sided cracking

The reason for this typical failure mode can be explained by local compression at the point of contact as it enters the rollers. It was observed that the shell breaks exactly at the first contact with the shear roller, see Figure 7. Hence, the location of the crack around the almond depends upon the gap between the shear roller and the almond size.

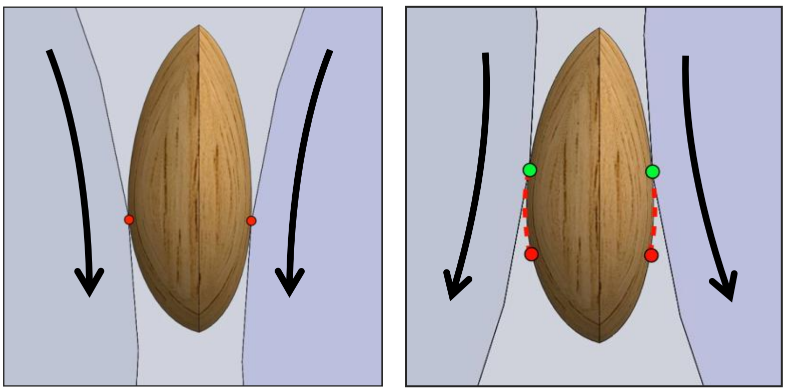


Figure 7: The first point of contact (left, shown in red) and last point of contact (right, shown in green) as the almond moves downward through a set on the shear rollers. The red dotted line shows the pathway of contact force

The experiment showed that for a 13 to 14 mm thickness range of in-shell almonds, the force of the shear roller is applied on average over 21.25 mm of the length when presented in the width orientation between the rollers and only over 13.00 mm of length when presented with its thickness dimension to the shear rollers.

Then, during the breaking test (11.25mm gap, +300 rpm, -200 rpm, thickness orientation), we discovered that, for 100% of the chosen shell sample, the typical shell failure mode is crossing the black line drawn at the location of initial contact with the shear rollers.

Figure 8: Results of a thickness orientation breaking test. Gap was 11.25 mm

Figure 8 shows that for every shell sample, the second step of the failure is situated on the path of one of the two black lines drawn before. That's what creates the typical shell failure mode, and determines its location.

<*next part must be the link between the location of the failure and the location of the chipping. And also check if there is any difference between tip first and base first. Add Solidworks findings when finished.*>

4.3. Cause of chipping of kernels

The mode of failure indicates a central failure plane across the shell and as it rotates apart appears to dig in and chip the kernel. Hence, the centrally located chips in the kernel as shown in Figure 9.

Figure 9: Chips on kernels aligning with failure plane across shell

There were also occurrences of chips on the pointy ends of the kernel, as shown in Figure 9. These are may be explainable by the shock on the reception device (as shown in Figure 2), just below the shear rollers. Made of steel, some kernels could have been chipped on their pointy ends. This is a sensitive and fragile point in the kernel, and moreover, the falling force that gains the kernel after the shear roller is quite important.

<put a sentence about adding a cution on it, do a test and see if it’s a problem or not.>

We know that it’s not the dimension which is in cause of the chipping: there is no difference between the width, neither the length, nor the thickness of the kernel. The dimensions of the kernel are approximately the same. Some experiments could be done about the dimensions of the shell. May be there are some differences between them.

<speak about the kernel breaking video tests, (not the shell breaking tests). Analyse the video files to go deeper in the link between classic shape and location of chipping.>

4.4. Multiple passes of kernels through the shear rollers

Multiple passes of kernels through the shear rollers showed that:

- The orientation of the almond is an important factor for the results ;
- The number of passes and the percentage of undamaged kernels is highly depending on the orientation ;
- The dimensions of the undamaged kernels and the chipped has nothing to do with the final state, it's all about the orientation and the gap ;
- There is a typical shell failure mode, whatever the orientation is: thickness or width.
- With a thickness presentation: there was no damage, no matter how many times they passed through the rollers, due to the force length application of the shear roller.
- With a width presentation: the kernels cracked into halves along their length. (need to check)

5. Conclusions

The investigation of shelling of almonds with shear rollers showed that:

Breaking of the kernels was a result of entering the shear rollers with a widthwise presentation.

Central chipping of the almonds was observed to be created by the cracking and rotation of the shell into the kernel as it breaks apart.

With multiple passes through the shear rollers with a thickness-wise presentation and a small compression, only 5% of kernels were chipped. Thus creating a good end product.

Hence, further work is needed to:-

References

Aktas, T. Polat and Atay, (2007). Comparison of mechanical properties of some selected almond cultivars with hard and soft shell under compression loading. Journal of Food Process Engineering. Volume 30, Issue 6, pp 773 to 789.

Tok, S. (2011). Identifying sources of mechanical damages in almond process. Final year mechanical engineering project thesis, UniSA, School of Advanced Manufacturing and Mechanical Engineering.

Appendix 8 – Feedback Form

Almond Board of Australia
ABN: 31 709 079 099
9 William Street
PO Box 2246 BERRI SA 5343 Australia

T +61 8 8582 2055
F +61 8 8582 3503
admin@australianalmonds.com.au
www.australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

Feedback Form

Course:..

Location:..

Date:..

Name (optional):...

Did the course provide you with what you expected to learn?	Less than expected … More than expected 1 2 3 4 5	
Was the level of detail enough? If not, what else could be included?	Less than expected … More than expected 1 2 3 4 5	
Do you intend to implement the knowledge from this training into your business?	☐ Yes ☐ No ☐ Unsure	
Overall, how satisfied are you with the quality of the course content?	Dissatisfied … Satisfied 1 2 3 4 5	
Overall, how satisfied are you with the quality of the course material/s?	Dissatisfied … Satisfied 1 2 3 4 5	
Overall, how satisfied are you with the way the course was presented by the presenter?	Dissatisfied … Satisfied 1 2 3 4 5	
What was the main reason for choosing this training?	☐ Meet a particular need ☐ Course content ☐ Location ☐ Other?............................	☐ Timing ☐ Training Provider ☐ Training Delivery Style

Please turnover.

Almond Board of Australia
ABN: 31 709 079 099
9 William Street
PO Box 2246 BERRI SA 5343 Australia

T +61 8 8582 2055
F +61 8 8582 3503
admin@australianalmonds.com.au
www.australianalmonds.com.au

ALMOND BOARD OF AUSTRALIA

How did you find out about the course?	☐ Email ☐ Internet ☐ Fax ☐ Post ☐ Other? ....
Any other comments or suggested improvements?	....

Thank you for taking the time to complete this form. Please return to training provider or forward to Almond Board of Australia, PO BOX 2246, Berry SA, 5343 or fax (08) 8582 3503