Final Report

Advanced Processing of Almonds

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Delivery partner:

University of South Australia

Project code:

AL12003

Project:

Advanced Processing of Almonds – AL12003

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Content

Summary

Hort Innovation and the Australian almond industry has supported a six year project at the University of South Australia to develop engineering improvements to provide advancements in the harvest and processing of almonds. The project has engaged with food scientists, microbiologists and agronomists from Australia and the United States of America.

The project has resulted in evidence that almonds can be harvested prior to them being fully dried and taken out of the orchard and then placed into aerated sheds, containers and/or stockpiles for finish drying without a loss of quantity or quality. This avoids potential damage from rains and pests.

The project defined the boundaries for good dehydration of almonds which mimics the best aspects of natural drying in the orchard without the damaging extremes of high temperatures and humidity. When almonds dry too fast they will have split cotyledons. When almonds get too hot during drying they can have skin flaking and when they are held at hot and humid conditions during drying rancidity and brown centres can result.

The project has developed equipment that can remove the hulls from soft-shelled almonds during the harvest operation without creating much loose kernel. The work showed that the hulls are easiest to detach and remove from the newly created inshell almonds soon after the hulls have fully butterflied open and before they dry to a grey color.

The project also developed equipment that can separate the detached hulls using air separation before they are finish dried. This hull removal can halve the volume of almonds that needs to be subsequently dried, stored and transported. Work has also shown that there is commercial equipment entering the market that is able to mill the hulls and sticks fine enough be allow the milled hulls to be returned to the orchard.

The next opportunity is to integrate this patent pending equipment into almond harvesters so that the harvester gathers, hulls and cleans the almonds in the orchard, leaving the milled hulls and sticks in the orchard and only collecting and taking inshell almonds out of the orchard. This could be used with the current harvest practices that collects the almonds from the ground or with the new shake and catch techniques, whereby the almonds are never dropped onto the soil.

Finally, the project has shown how sensors and controllers can be placed into stored almonds and used to modify the air being blown through almonds to aerate them to achieve a range of desired kernel moisture contents that can enhance storage life and meet processability and customer requirements, respectively.

In conclusion, this project has achieved its aims of developing a path forward for the almond industry in Australia (and California) to move toward adopting on-farm hulling, improved shelling with less kernel damage and aeration of almonds for moisture control.

Public summary

Global production of almonds is increasing and in the next 5 years almond production is expected to increase by as much as 50% in both the USA and Australia as new plantings come into full production. To handle this increase and expand markets, advances in the processing and quality management of almonds is required.

There are many factors that can lead to quality downgrades of almonds such as weather damage (rain = staining; hot and humid = concealed damage; hot and dry = skin flaking and split cotyledons; humid = mould) and pests (birds, rodents and insects). Hence, one method being recommended by this project is to harvest the fruit after hull split but before it is fully dry so it can come out of the weather, thus avoiding damaging rains and extremes in temperature and humidity. Related research has shown that early harvest and dehydration preserves the micro-nutrients in the almond kernels at their maximum status. It was also found that the hulls are easier to remove from the shells before they are fully dried. This project shows that the direction to move toward shake and catch harvest systems for almonds does not decrease yields nor quality but has many advantages when combined with in-field hulling and hull separation. Equipment has been developed and patent pending that can undertake the hulling and separation of the detached hulls in the field on mobile equipment and at storage facilities and factories. Hence, if only in-shell almonds are brought in from the orchards, the volume of almonds can be halved thus reducing transport, storage and processing costs. Also, the nutrients that are in the hulls can remain in the orchard.

The project has started working toward a retro-fittable yield mapping system for almond harvesters to provide growers with a map of their almond harvest yields. The data collected could then be used for future orchard management.

The project has shown that temperature and humidity sensors placed into an almond stockpile can provide an in-situ measure of kernel moisture content even when the almonds are as in-hull, in-shell or kernel forms. It relies on the almonds being at their equilibrium condition and a calibration being formed between moisture content and relative humidity/temperature readings. The system was used effectively with on-farm stockpiles before dispatch to a processor, whilst in transit to give an automated moisture reading upon arrival at the receival weighbridge, in silos as the almonds move past them to go into the processing line and in finished product whilst it is stored in a warehouse.

Keywords

Aeration; Almonds; Concealed damage; Contamination; Cotyledon splitting; Damage; Dehydration; Hulling; Moisture; Quality; Rancidity; Separation; Shelling; Silo storage; Skin Flaking; Yield Mapping

1. Introduction

Almonds are a major horticultural crop in Australia. Traditionally, Australian growers have adopted varieties, growing practices and equipment from California. Due to a higher cost of farm labour, less fertile soils and a higher likelihood of rain during harvest, Australian almond growers have been evolving away from Californian almond growing methods. This project was initiated by the Almond Board of Australia to help develop new methods for the advanced processing of Australian almonds. The project had three main objectives.

1. Develop on-farm hulling of almonds so that only half of the volume of almonds needed to be stored and transported for processing.
2. Develop new methods for the shelling of almonds to reduce chips and scratches.
3. Develop methods for effective aeration and dehydration of bulk almonds in silos/bunkers/sheds.

This project is important to the Australian almond industry as:

1. Harvested almonds are currently stored in stockpiles on the ground and are covered in plastic to protect them from rain and pests. Whilst outdoor stockpiles are cost effective to construct, moving to silo storage of almonds will eliminate the issues of:-
    a. sweating of the almonds under the plastic which can lead to mould forming on the outer almonds, which can contaminate the almonds with toxins,
    b. rain seeping under the plastic at the edges and through holes, wetting up and damaging the almonds,
    c. the need to remove the plastic cover during hot weather to stop sweating under the plastic but this exposes the almonds to birds and insects, which lead to contamination and damage,
    d. less than perfect fumigation for insect control and inability to use controlled atmosphere storage,
    e. potential for rodent damage and contamination.
2. Consumers are demanding increasingly higher quality almonds with less chips and scratches which degrade the mass of the final product and its appearance. Also, the current processing equipment has a large footprint and limited throughput capacity. Hence, gaining more production capacity from the current equipment will reduce the time almonds are stored awaiting processing. New equipment that can reduce kernel damage and increase throughput will be of benefit to the industry.
3. Almonds are brought in from the orchard at a range of moisture contents and placed into storage. By introducing aerated storage the moisture content of the almonds can be regulated at various stages to achieve the different optimums for:-
    a. Long term storage to preserve nutritional quality (approx. 4% kernel mc)
    b. Processability to reduce chips and scratches (approx. 5.5 to 6.5% mc)
    c. Consumer satisfaction to be crunchy and not chewy (approx. 5 to 5.5% mc)

Through adopting these developments the Australian almond industry will be able to take control of the almond's final quality, reduce the risks of harvest and post harvest losses and be able to expand the regions in Australia where almonds are grown.

2. Methodology

The project was undertaken as several simultaneous topics by multiple researchers with research undertaken during both Australian and Californian almond harvests.

2.1 Almond moisture control - Laboratory testing

In order to study the drying and wetting up of almonds a PhD degree was undertaken by Michael Coates. The title of his thesis was “Defining and modelling the boundaries for mechanised dehydration to produce high quality almonds”. Some of the various items of equipment that were developed and used by Michael Coates for his work are shown in Figures 1 to 3.

Figure 1. Michael Coates with his instrumented 3m and 2 m drying tower

Figure 2. Laboratory scale dryers used in Australia and California

Figure 3. Controlled dehydration using data logged scales being undertaken with temperature and humidity control

The method used was to collect almond samples from the orchard at various stages of maturity that were classified as per the UC Davis IPM Categories A to F, as shown in Figure 4. The fruit was used for both processing and drying trials.

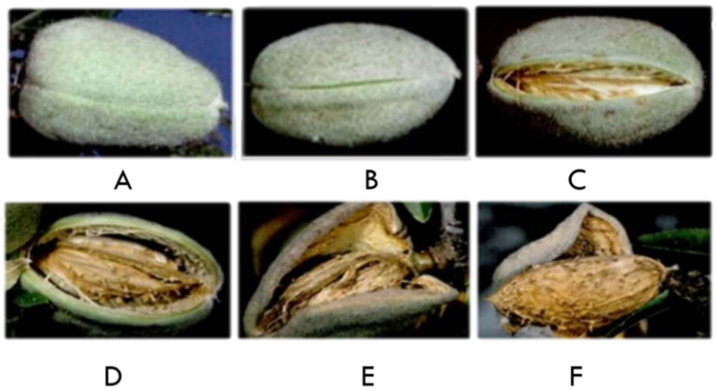

Figure 4. IPM hull split categories as per Strand (2002)

2.2 Almond moisture control – In field testing

In the 2017 almond harvest farm scale dehydration and rewetting of almonds was undertaken in stockpiles, containers and sheds, as shown in Figures 5 to 7, respectively.

Figure 5. Aeration for drying of almonds in stockpiles at Select Harvests' Amaroo Farm

Figure 6. 40' shipping container used for drying of rain affected re-shake almonds at Jubilee Almonds

Figure 7. Shed with aerated floor used for drying and rewetting of almonds at Bunyip Reach, Murtho

These facilities were instrumented with temperature and humidity sensors that fitted into a 25 mm diameter hole. A picture of the sensor is shown in Figure 8.

Figure 8. A temperature and humidity sensor in a mounting plug

From the 2017 experience, evaporative air conditioners were added to the fan inlets to both cool and humidify the inlet air. An example of how an evaporative cooler was attached to a stockpile is shown in Figure 9. It was found that the air conditioner fan was not sufficient to blow enough air through the almonds, so an additional fan was added, as shown in Figure 10.

Figure 9. QC48 Evaporative cooler fitted to the aeration duct. Select Harvests' Allinga Farm

Figure 10. Additional fan added to evaporative cooler. Select Harvests' Allinga Farm

In a similar manner an evaporative cooler was added to one fan at the aerated shed, as shown in Figure 11. In this case the existing fan had enough capacity to blow air though the almonds.

An automated system was developed to control the relative humidity of the air leaving the evaporative cooler to a set point by controlling the flow of water over the cooling pads.

Figure 11. Evaporative cooler added to the fan inlet at Bunyip Reach, Murtho

For 2018, commercial temperature and humidity sensors were sourced that were mounted on spears that could be placed into the bulk almonds. The spears allowed the sensors to be placed to suit the stockpile size and were portable to check multiple locations. Examples of the sensor and spear are shown in Figure 12. The transmitter needed to be out of the stockpile so it was fitted into the handle of the spear.

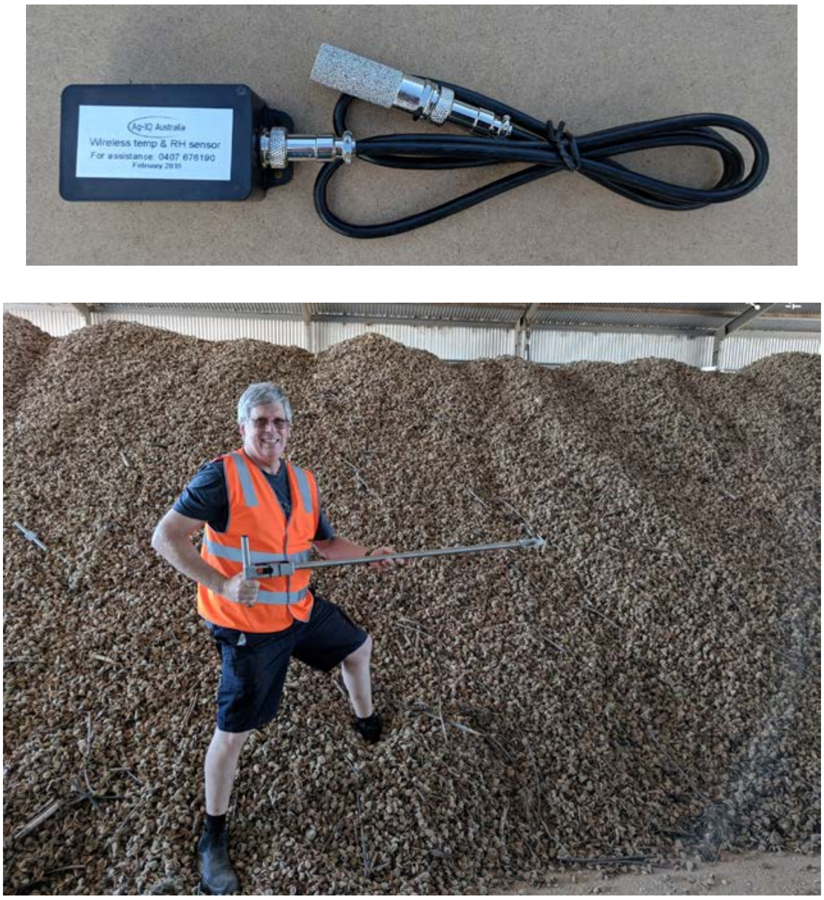

Figure 12. Commercial temperature and humidty sensor (top) and Professor John Fielke with it mounted into a spear (bottom)

2.3 On-farm hulling of almonds – Detachment of hulls

2.3.1 Progression of designs

The on-farm hulling of almonds was developed in a series of steps. Firstly, a set of shear rollers was tried for the hulling of almonds in a range of maturities from hull split to fully dried. The result of these tests showed that due to the varying sizes of the almonds and the fixed roller gap that no more than 40% of the batch could be converted into inshell almonds without producing a lot of shelled kernel.

Next, impact hulling was investigated, first with a rotating impact tester, as shown in Figure 13. These tests showed the values of critical impact energies to both detach the hull and break the kernel from the shell. Results showed there was less energy required to detach the hull than to release the kernel from the shell.

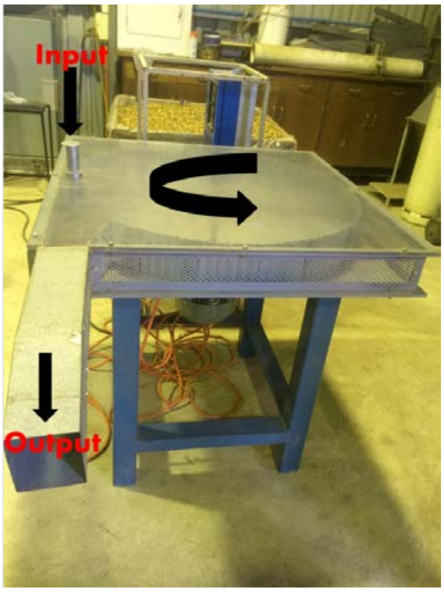

Figure 13. Impact testing machine used for the first impact hulling tests

Based on this information a prototype impact huller and sheller was developed (see Figure 14) and three styles of impellors were tested (Fielke, Coates and Shirmohammadi, 2016). This was very successful in hulling the almonds to create inshell almonds and for shelling the almonds to create flawless kernel (no chips or scratches). However, it had the issue that up to 50 passes were required to achieve a good result of a high percentage of inshell almonds for the hulling operation and a high percentage of flawless kernel from the shelling operation.

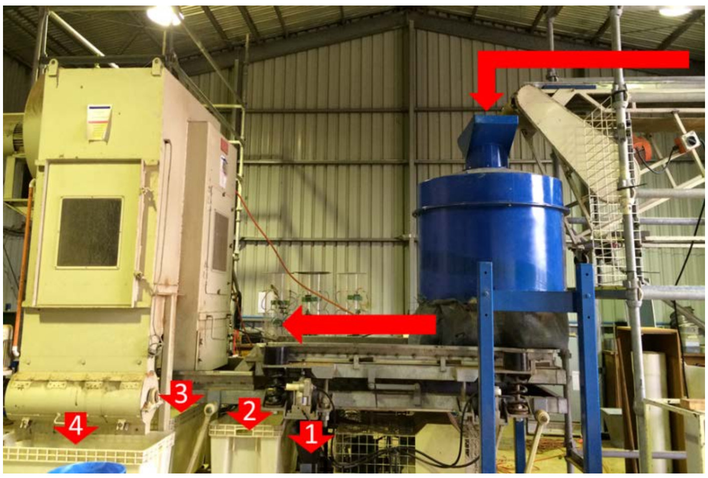

Figure 14. Impact thresher and screen separator used to process almonds with four outputs for (1) small pieces of shell and hull, (2) kernel, (3) in-shell and in-hulls passing over the screen and (4) light waste separated by air cleaner

From this success, the research looked at a method of creating multiple low energy impacts. This was first achieved using PVC pipes and a blower/fan with a venturi inlet for the almonds. Various numbers of impacts and energies were evaluated. The system shown in Figure 15 was very effective for both hulling and shelling but due to the round pipe being used it would not be scalable for various flow rates from 1 to 100 t/h, as required by industry.

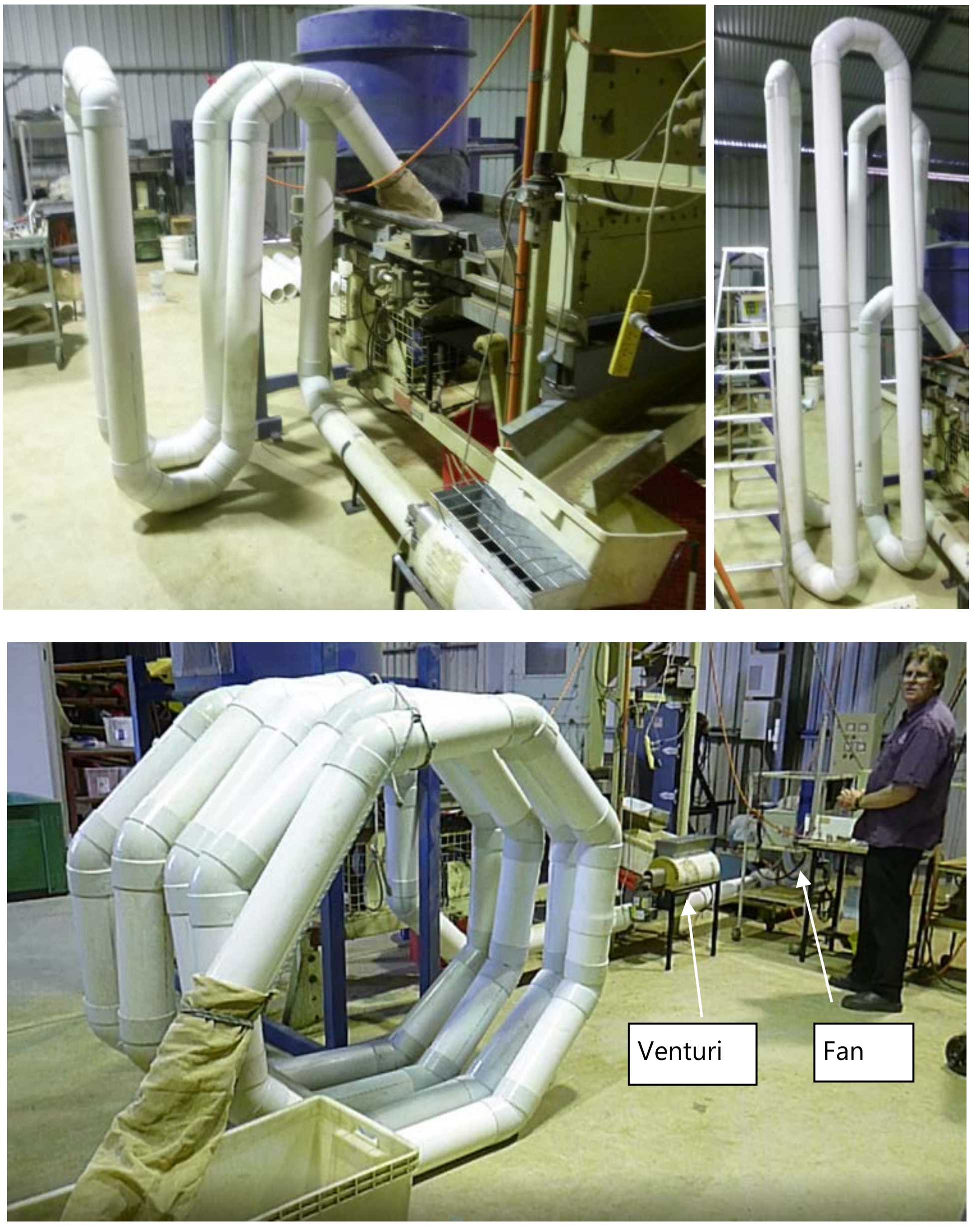

Figure 15. Various arrangements for impact hulling and shelling using a PVC pipe with venturi infeed

To make the process scalable in product throughput a 2-dimensional design was developed and this was subsequently used in the hulling patent application.

The first prototype of the 2D huller is shown in Figure 16. The 1 m height huller was able to detach the hulls from both soft and hard shelled almonds.

Figure 16. Prototype huller with clear face to observe performance

To supply the air flow for the prototype huller and sheller, a comercial grain pneumatic conveyor was purchased which was powered by a 35 kW diesel motor. A diesel motor was selected to allow for off-site use. It has a blower, cyclones and a rotary valve to transfer the product from the suction side of the blower to the blowing side of the blower. The pneumatic conveyor (Figure 17) had the following specification:

Zhengzhou Double Birds Machinery Co.,Ltd Model QC-20

30 kW Wechia diesel motor
20t/h of cereal grain with a transport distance of 400 m
Conveyor pipe diameter 125 mm
Airflow 1800 m^3/h (500 l/s) @ engine 1500 rpm = hose air speed of 40 m/s
Mass 2,200 kg
Fan pressure 21.6 kPa (3 psi)

Figure 17. Pneumatic conveyor used to convey the almonds through the huller and separator

2.3.2 Final design

After successful operation of the prototype huller and sheller a commercial style version was designed and constructed (Figure 18) which had:-

- Stainless steel construction for hygiene
- Modular design to allow for more/less impacts (2 modules are shown in Figure 18)
- Easily opened and removable doors for cleaning
- Easy to use latches to open and lock closed the doors

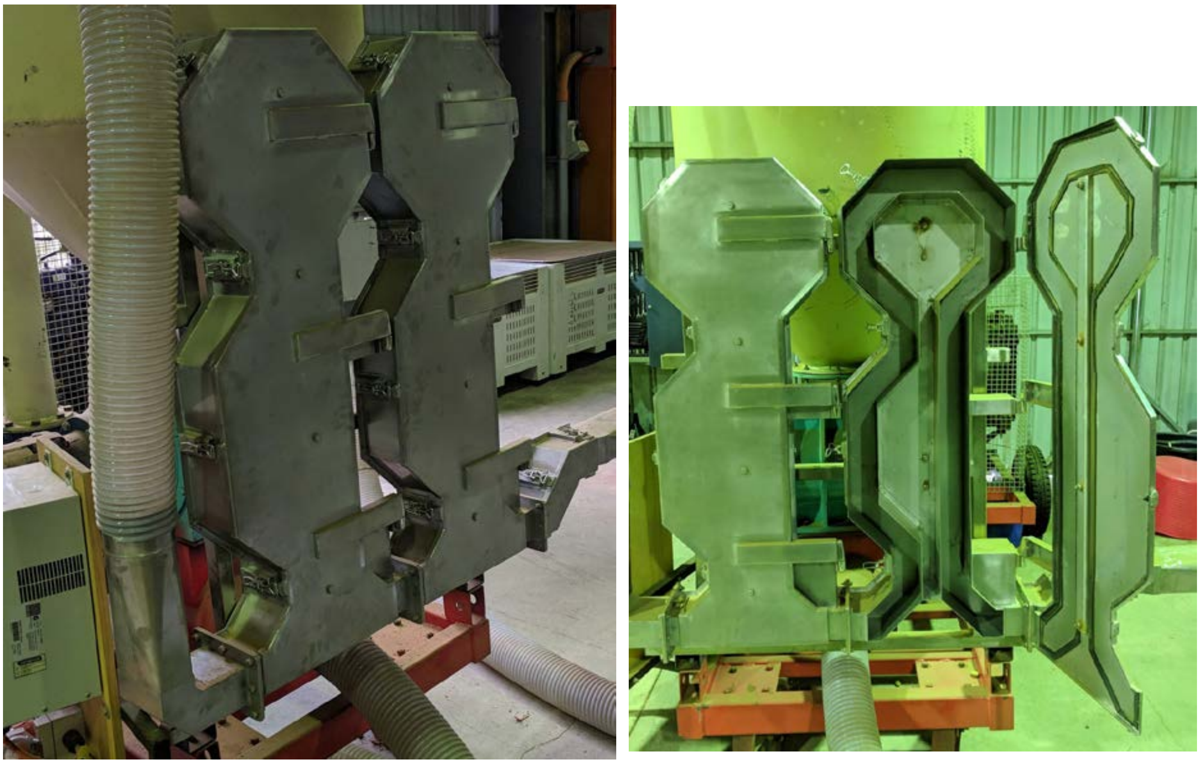

Figure 18. Commercial version of the huller/sheller. Right image shows door open for cleaning.

2.4 On-farm hulling of almonds – Separation of detached hulls

2.4.1 Progression of designs

Following the successful development of the huller, various arrangements for a detached hull separator were trialed using computer simulations and laboratory testing. Several of the iterations are shown in Figure 19.

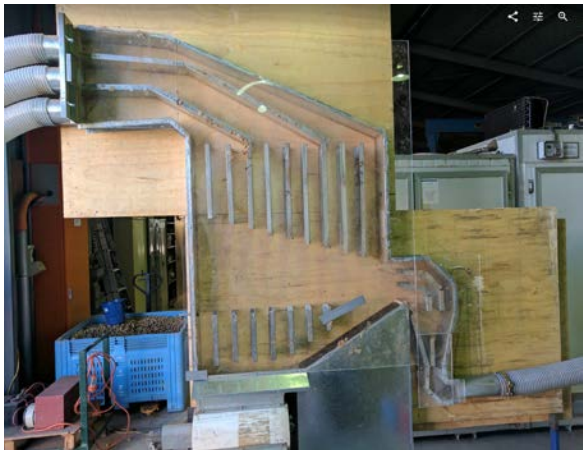

Figure 19. Several of the iterations toward the design of a detached hull separator

2.4.2 Final design

In the end a working prototype was found with an injection of almonds into a vertically upward flow of air.

The final prototype is shown in Figure 20. It was made of stainless steel. The design included an additional 7.5 kW Smallaire 22 Series fan with capacity of 2500 l/s.

Figure 20. Final design of the detached hull separator

2.5 Improved shelling of almonds

The impact hulling equipment shown in Figure 16 was also able to be used to shell soft shelled almonds. To create a large enough force to break the shell on a hard shelled almond a 3m height impact sheller was required (Figure 21) for the shelling of hard shelled almonds. The larger height allows the almonds to be accelerated for a longer time by the airflow over the longer distance to give much the higher impact energies needed to break the shell of the hard shelled almonds and release the kernels.

To make the impact shelling produce a large proportion of flawless kernel the almonds needed to be re-wet by soaking in water and then allowing them to drain for set periods of time. Tests looked at various soaking and sitting times before shelling to maximise the number of flawless kernels.

Figure 21. 3m high impact sheller for hard shelled almonds

2.6 Yield mapping of almonds

During the project several versions of an almond yield mapping system were trialed. An effective design was found that placed multiple laser transmitter/receivers (similar to that used on shop door bells) under the harvester elevator chain and directed the lasers up through the falling almonds towards a reflector mounted above the falling almonds (Figures 22 and 23). The trial system used 17 laser units across the 900 mm width of the elevator belt.

An Arduino based data logger was programmed to record the flow of almonds through each laser beam and logged the proportion of time the beam was broken. This provided a measure of the flow rate of almonds from the harvester into the surge cart. Using a GPS receiver and a wheel sensor on the harvester the position of the harvester along the row was able to be logged with the flowrate.

Figure 22. Yield mapping system fitted between harvester and surge cart (circled)

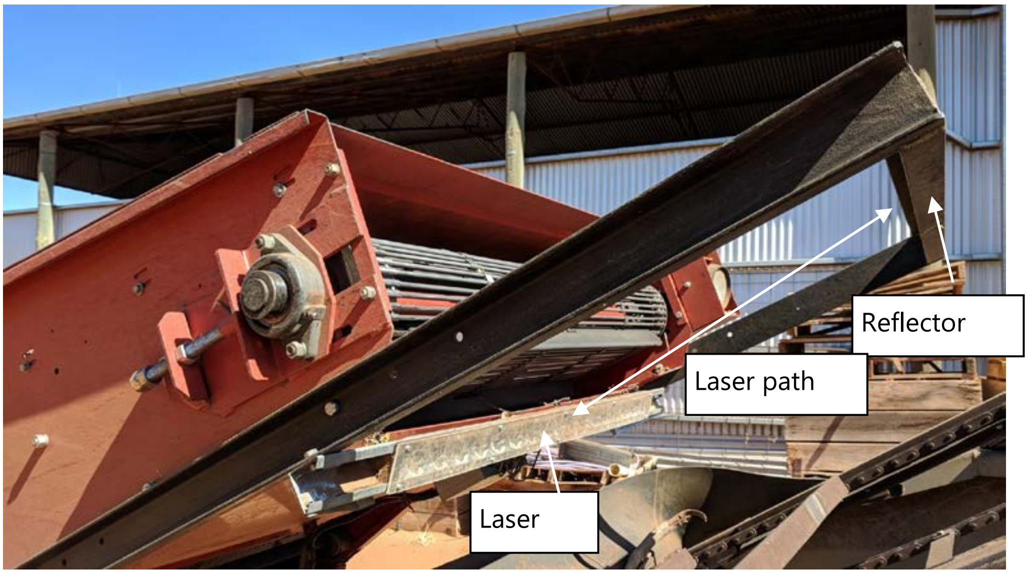

Figure 23. Details of yield mapping system fitted between harvester and surge cart

3. Outputs

3.1 PhD thesis of Dr Michael Coates

3.1.1 Overview of findings

The project has resulted in the PhD thesis of Dr Michael Coates titled “Defining and modelling the boundaries for mechanised dehydration to produce high quality almonds”. In summary his thesis showed:-

- Almonds can be harvested after hull split has formed (Category B and beyond – refer Figure 4) and mechanically dehydrated without loss of yield or nutritional quality.
- Almonds should not be heated and dried at more than 60°C to avoid skin flaking
- Almonds should be not be heated and dried above 40°C to avoid split cotyledons
- A higher probability of forming concealed damage occurs when wet almonds are held at 100% RH before and during drying.

3.1.2 Moisture contents and dry basis yield from early harvested almonds

Table 1 shows the range of moisture contents of the components of almonds as they progressively dry from Category A to F, as defined in Figure 4.

Table 1. Typical moisture content (w.b., %) vs hull split category of Nonpareil almonds collected from Walker Flat during 2016 harvest (Coates, 2018)

	A	B	C	D	E	F
In-hull	75.0 ± 2.6	75.2 ± 1.2	75.2 ± 1.2	67.4 ± 5.4	42.4 ± 14.7	18.7 ± 1.0
In-shell	n/a	62.7 ± 3.6	60.5 ± 4.7	46.1 ± 9.7	25.3 ± 11.9	9.9 ± 0.6
Hull	n/a	82.8 ± 0.7	82.5 ± 1.5	76.5 ± 3.8	51.2 ± 15.1	24.4 ± 1.5
Shell	n/a	80.5 ± 2.0	78.4 ± 3.7	61.9 ± 11.0	34.1 ± 16.6	14.8 ± 0.7
Kernel	38.9 ± 3.0	37.0 ± 1.9	36.4 ± 1.7	32.0 ± 3.0	19.7 ± 7.7	7.5 ± 0.6

n/a = hull not able to be separated from shell

The weekly progression of the proportion of each category of almonds shaken from a tree are shown in Figure 24. It shows that the almonds took over 7 weeks from the first to last almonds to dry (reach Category F) on the tree.

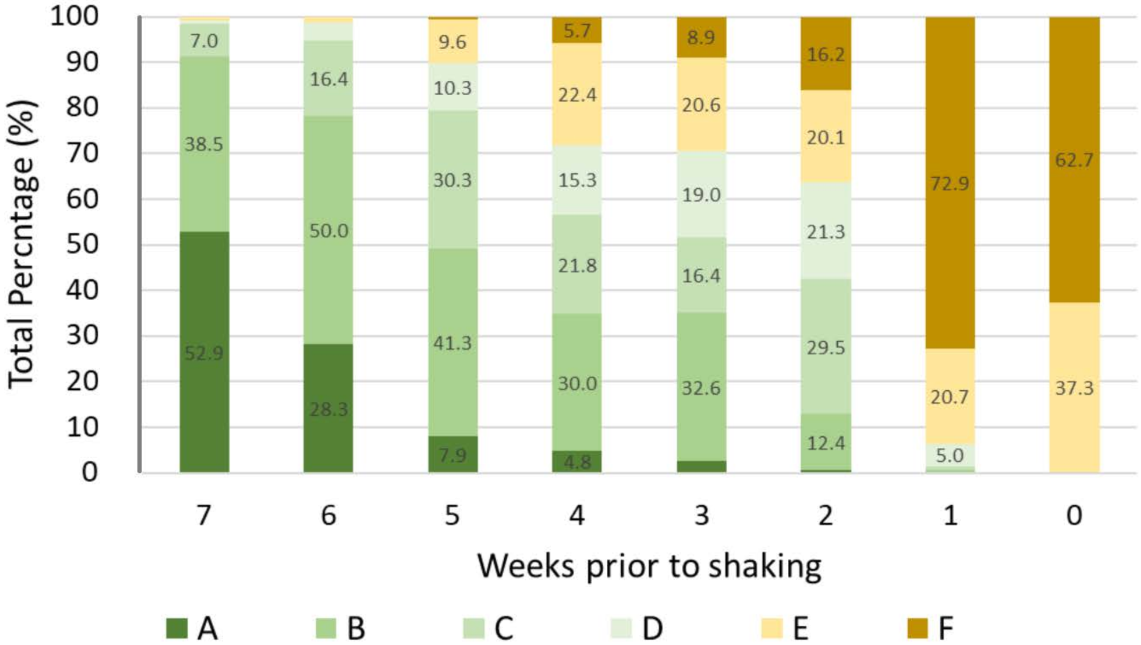

Figure 24. Typical proportion of hull split categories of Nonpareil almonds collected from Walker Flat during 2016 harvest (Coates, 2018)

As shown in Figure 25, the total dry mass of kernels per tree did not increase once most of the almonds had split. The work showed that in the last 4 weeks the final dry mass did not significantly change.

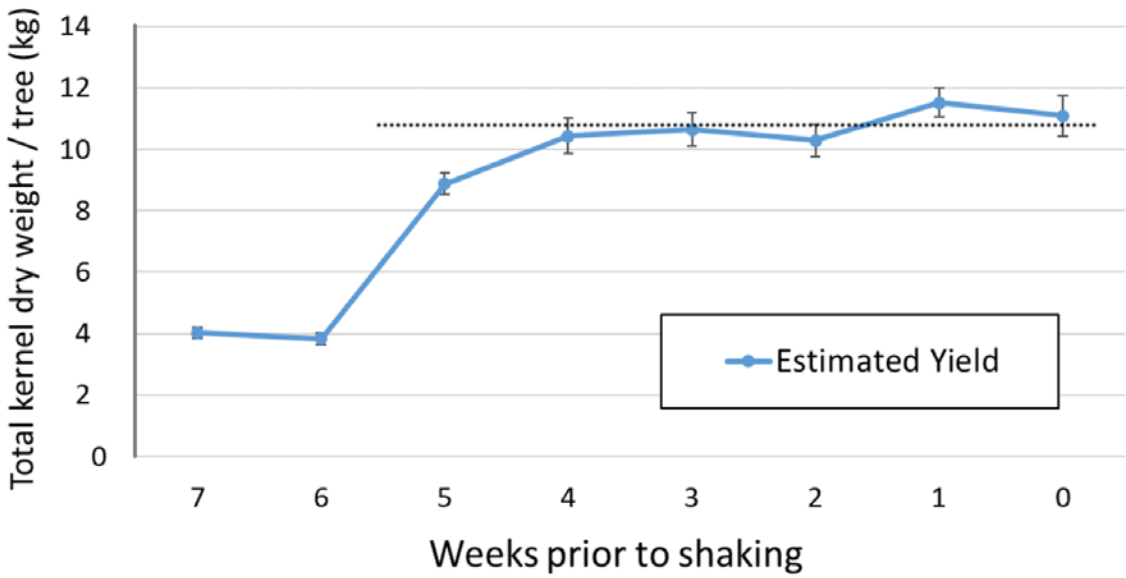

Figure 25. Change in total kernel dry weight trees as in-field drying progresses at Walker Flat in 2016 (Coates, 2018)

3.1.3 Drying times for early harvested almonds

The work of Coates (2018) undertook drying of early harvested Category B almonds. The moisture contents of the almonds collected at Walker Flat during the 2016 harvest and used in the dehydration study are shown in Table 2.

Table 2. Moisture content (w.b.) of Category B Nonpareil almonds used for drying trials (Coates, 2018)

Form	MC (%)	Mass, wet (g)	Mass, bone dry (g)	Mass, water (g)
In-hull	76 ± 1	14.04 ± 1.98	3.43 ± 0.46	10.61 ± 1.52
In-shell	64 ± 3	5.35 ± 0.71	1.92 ± 0.20	3.43 ± 0.51
Hull	83 ± 1	8.70 ± 1.30	1.51 ± 0.27	7.19 ± 1.03
Shell	81 ± 2	3.25 ± 0.58	0.61 ± 0.10	2.64 ± 0.48
Kernel	38 ± 2	2.10 ± 0.17	1.31 ± 0.11	0.79 ± 0.06

These various forms of the almonds were dried in a humidity controlled oven (Figure 3) at a constant 30% RH for a range of temperatures with the results shown in Figure 26 and 27.

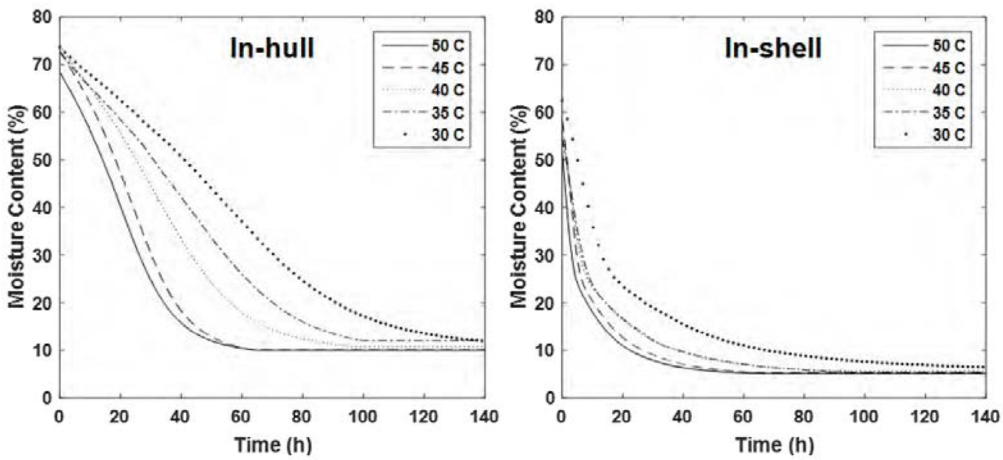

Figure 26. Drying times for Category B Nonpareil almonds from Walker Flat 2016 at 30% RH (Coates, 2018)

A comparison of drying times for the various forms are shown in Table 3. The results showed that as the temperature increased the drying time reduced. Taking the hull off the almond to create inshell did not reduce the drying time. This showed that the drying time is fixed by the migration of the water from the kernel through the shell.

The results show that to dry a 38% mc kernel to its equilibrium moisture content at 30°C and 30% RH takes 140 hours (6 days). Whereas, in the field these almonds may take around 4 weeks to dry. This means that almonds could be out of the orchard and dried 3 weeks earlier than current practice.

Table 3. Drying times (hours) for various forms of almonds at 30% RH (Coates, 2018)

	30°C	40°C	50°C
Inhull	140 (6 days)	100 (4 days)	60 (2.5 days)
Inshell	140 (6 days)	100 (4 days)	60 (2.5 days)
Kernel	70 (3 days)	60 (2.5 days)	30 (1.25 days)
Hull only	70 (3 days)	35 (1.5 days)	30 (1.25 days)
Shell only	20 (1 day)	12.5 (0.5 days)	7 (0.3 day)

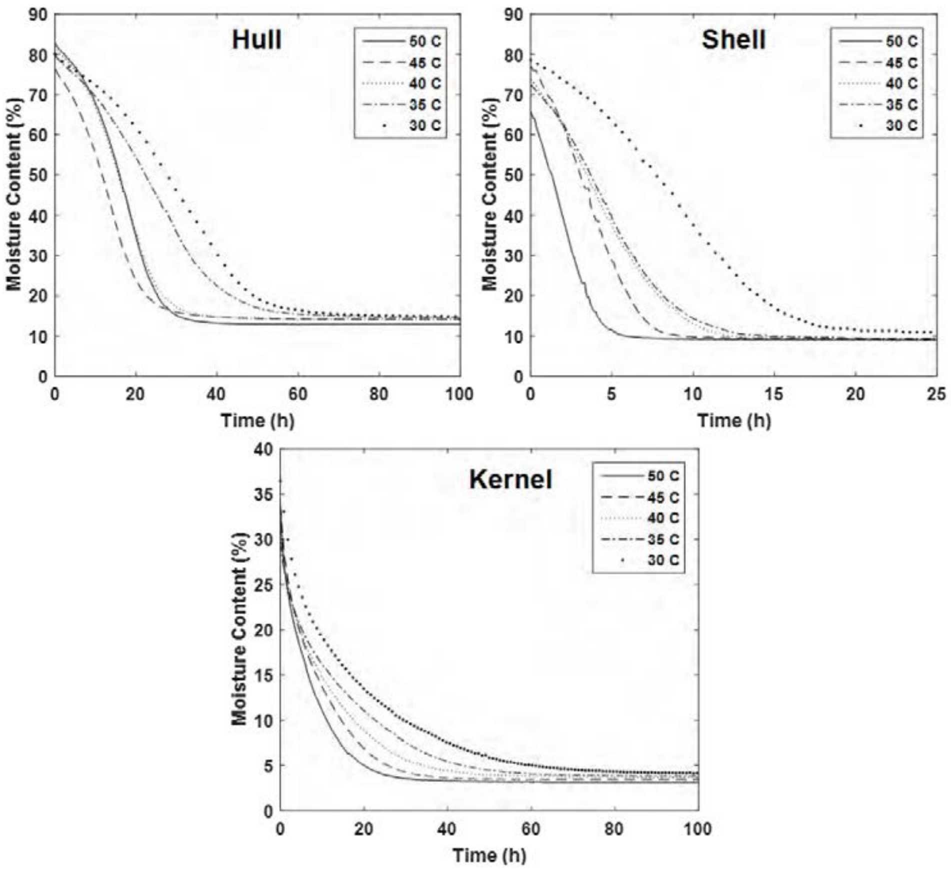

Figure 27. Drying times for Category B Nonpareil almonds from Walker Flat 2016 at 30% RH (Coates, 2018)

The presence of the shell around the kernel (inshell) is shown in Table 3 to virtually double the drying time by placing a barrier around the kernel that slows the drying. Drying of the Category B kernels out of their shell resulted in split cotyledons, as shown in Figure 28. This was due to the fast drying rate solidifying the outer surface before the centre had dried and then the later drying of the centre resulting in the centre drying toward the outside surface and hence the split cotyledons. This shows it is beneficial to dry high moisture content early harvested kernels in their shells to maintain their integrity.

Figure 28. Split cotyledons (left) when kernel was dried out of its shell. Solid kernels with joined cotyledons when the kernel was dried in its shell (right) (Coates, 2018)

3.2 Pressure and flow characteristics of inhull almonds and kernels

Coates (2018) dried almonds in the 3m high tower as shown in Figure 1. Pressure vs flow curves for inhull Nonpareil almonds harvested at Jubilee Almonds in 2015 are shown in Figure 29 (inhull curve). The results showed a proportional increase in pressure drop with height of almonds and an increase in pressure loss with increasing air flow rate.

In addition to the work of Coates (2018), further measurements were also made for airflow though kernels and Nonpareil inshell almonds. These results are also shown in Figure 29 (kernel and inshell). The results show it was easiest (least pressure drop) to blow air through inhull almonds.

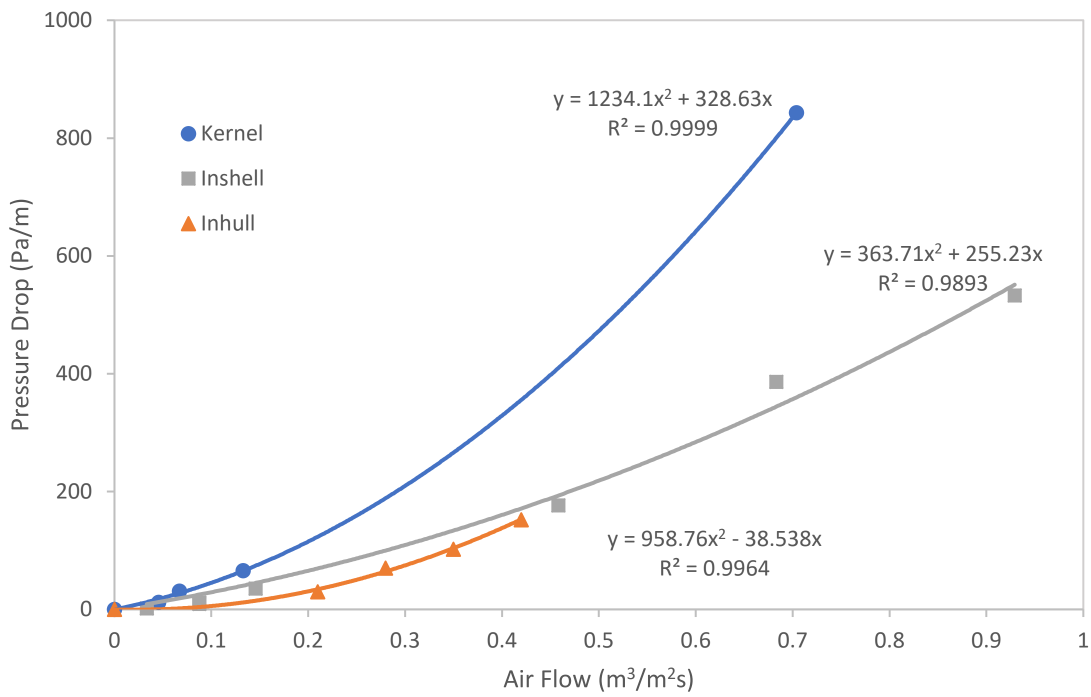

Figure 29. Pressure drop vs air flow rate for almonds

3.3 Patent application and performance of almond huller

The work above showed that almonds could be harvested and mechanically dried earlier without a loss of yield or quality. Hence, the project also concentrated on methods for the detachment of the hulls in-field to achieve a reduction in volume that needs to be transported, dehydrated and stored.

As a result of this work a patent application has been made for an improved almond huller.

The work commenced with the testing of an impact huller as shown in Figures 13 and 14. The results are presented in the paper Fielke et al. (2016). Table 4 shows the best results for impact hulling using a single impact for several almond varieties and moisture contents.

The results of Table 4 show that with a single impact a high number of inshell can be produced with less than 5% loose kernel being produced.

Table 4. Results of single impact hulling using a rotary impact thresher (Fielke, 2015)

	Kernel mc	Blade	Inshell	Loose Kernel
Nonpareil (soft shell)	3.8 %	Radial	41%	4%
Nonpareil (soft shell)	7%	Radial	55%	3%
Carmel (soft shell)	6%	Ultra backward	66%	3%
Carmel (soft shell)	31% (soaked and stand)	Ultra backward*	99%	0%
Marcona (hard shell)	6%	Backward**	91%	0%

Impact threshing was conducted on the fruit described in Table 1 and Figures 24 and 25. For these tests the patent pending multiple impact threshing equipment of Figure 16 was used. The results are presented in Fielke and Coates (2017) and showed that over 90% of inshell almonds were created when processing Category B-E fruit, as shown in Figure 30. For these results there was less than 1% loose kernel produced.

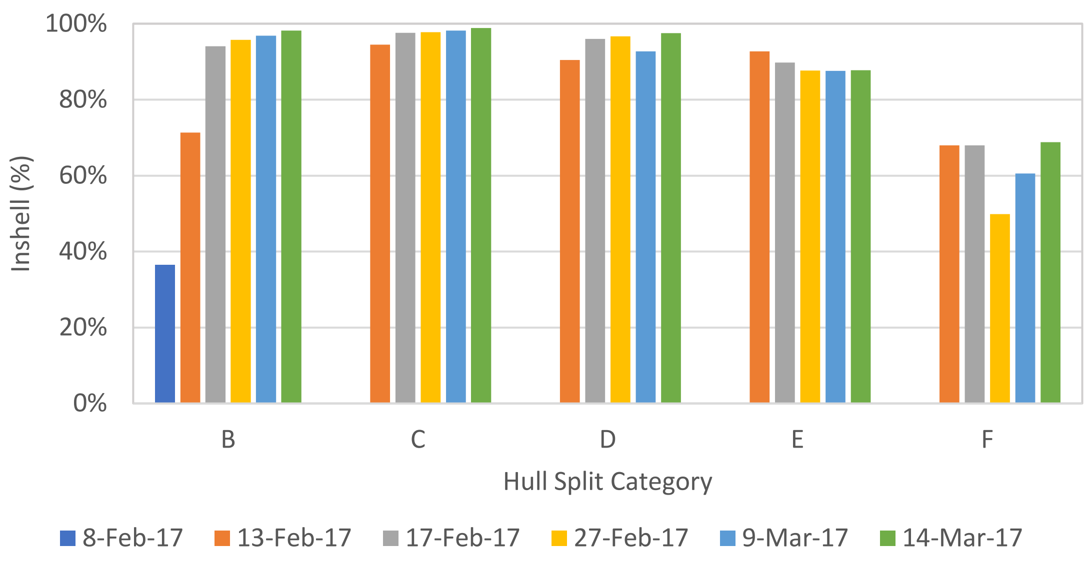

Figure 30. Results of inshell production for hull split categories and sampling dates (Fielke and Coates, 2017)

The data of Figure 30 is replotted against the date of harvest and shown in Figure 31. It shows that on a weekly basis that a large proportion of inshell fruit can be created.

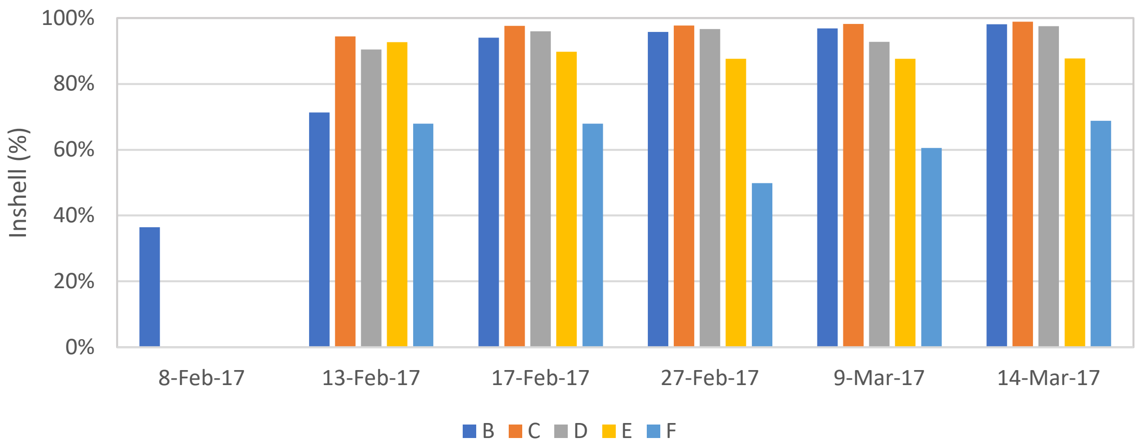

Figure 31. Results of inshell production for sampling dates

3.4 Patent application and performance of almond hull separator

In addition, to the very high recovery of inshell almonds from processing of early harvested fruit, Figure 32 shows the vertical air separator as shown in Figure 14 was able to give a high removal of the loose hulls, with the exception of category D and E fruit.

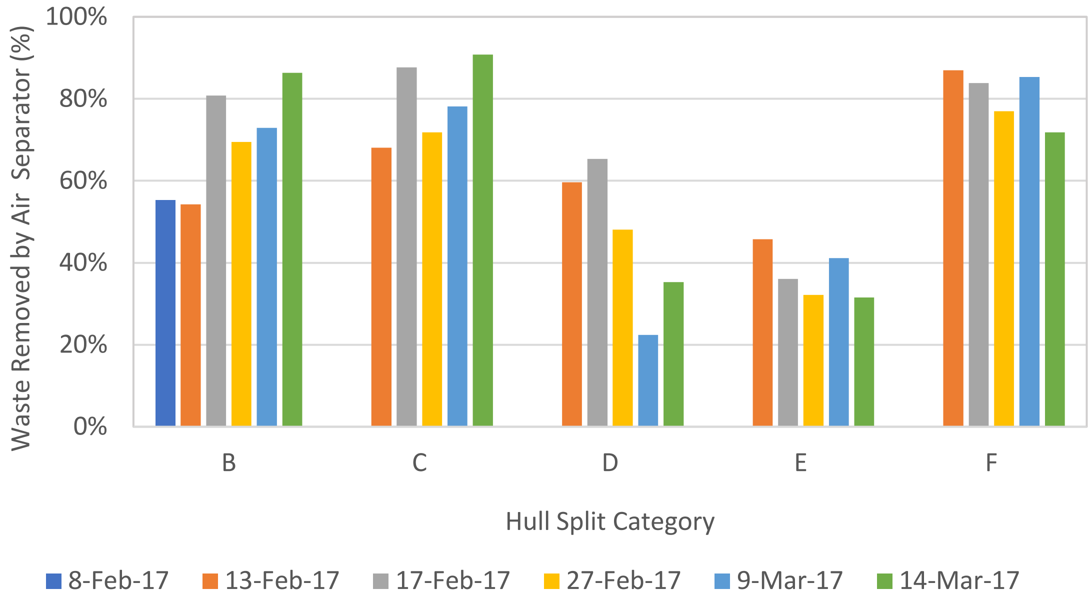

Figure 32. Percentage removal of waste using an air separator after impact hulling (Fielke and Coates, 2017)

The data of Figure 32 is shown in Figure 33 on a sample date basis. It shows that at least 50% of the detached hulls can be removed using air separation.

The traditional vertical air separator which provided the results of Figures 32 and 33 is bulky and has a limitation of flow of product through the airstream for separation of the light from heavy material. Hence, to overcome this issue a new concept was developed of using the entrained almonds in the air flow from the huller to be injected into a controlled upward flow of air. The equipment developed is shown in Figure 20. At the conclusion of this project the full capabilities of the separator have not yet been explored to their limits.

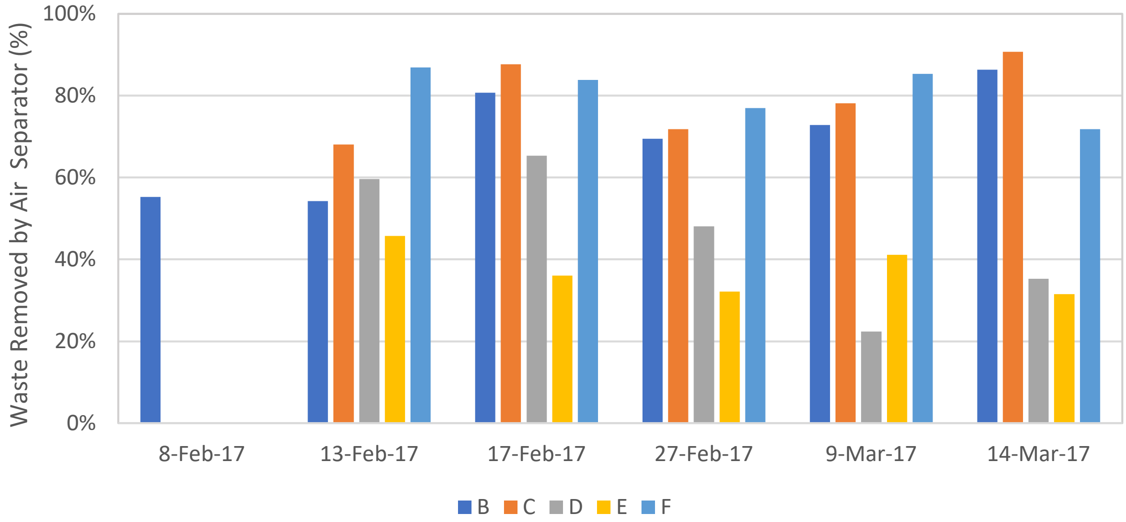

Figure 33. Results of inshell production for sampling dates

3.5 Patent Pending prototype huller and separator

The complete patent pending prototype huller and separator unit with the pneumatic conveyor is shown in Figure 34. As shown in the Figure 34, the total unit weighs 3 tonnes but this can be reduced with design and power source changes. The unit could be developed into a trailer mounted unit to be used in association with a silo dehydration and storage facility or in the future developed into an infield almond harvester.

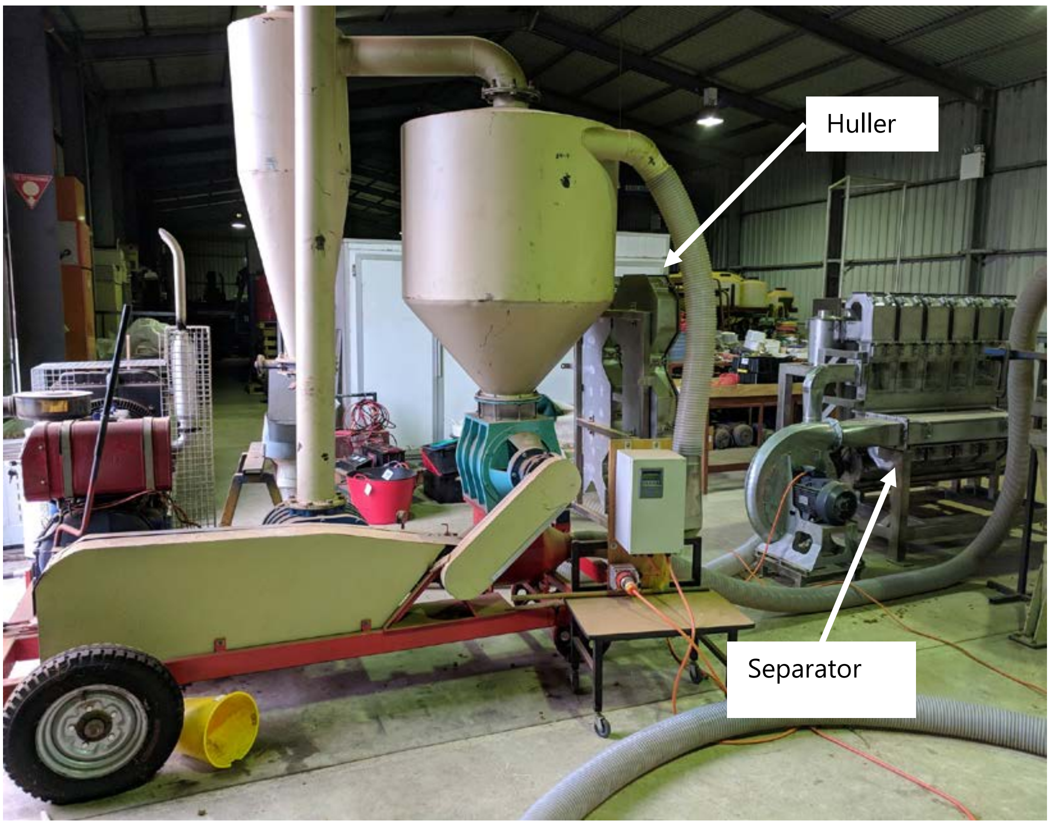

Figure 34. Prototype huller and separator at Mawson Lakes

3.6 Milling of the hulls and sticks

The patent pending Seed Terminator™ (www.seedterminator.com.au) is shown in Figure 35. It is a lightweight hammer mill designed to be fitted onto the chaff exit of a large grain harvester. It is used to mill the chaff to kill weed seeds and has been designed to handle foreign material entering the unit. Its rated capacity per mill is around 20 t/hour of chaff and requires about 40kW per mill. To suit the grain harvester it must have a long wear life and be lightweight, thus making it suitable for fitting on almond harvesters and conditioning equipment to mill both hulls and sticks.

Figure 35. Seed Terminator multi-stage hammer mill
(https://twitter.com/seed_terminator/status/910852788145369088)

Tests were conducted during 2018 that ran both dry and wet hulls, and sticks through the mill. The result of passing almond hulls and sticks through the Seed Terminator™ is shown in Figure 36. Nearly all of the product fitted through a 5 mm round hole sieve. An evaluation in an orchard is planned for late 2018.

Figure 36. Results of processing hulls and sticks using the Seed Terminator™.
Dry product (left) and wet product (right)

3.7 Method for producing flawless kernel

Results detailed in the paper by Shirmohammadi and Fielke (2017) showed that by wetting the almonds and resting them before impact shelling, that the amount of flawless kernel (no loss of skin) could reach over 91% for Nonpareil almonds and over 60% for hard shelled almonds.

Analysis of the shell strength showed it did not change with the wetting, but the kernel and its skin become less brittle and resisted scratching and breaking as its moisture content increased. Typically, the Nonpareil kernel moisture content increased from 5 to 10% to achieve this high recovery of flawless kernel. Work needs to continue into the future to develop this concept into a viable process.

3.8 Presentations

The project team of Professor John Fielke, Dr Michael Coates and Dr Maryam Shirmohammadi are shown in Figure 37. They have made regular presentations to various Australian and Californian almond industry workshops, forums and conferences, as follows.

Figure 37. Michael Coates, Maryam Shirmohammadi and John Fielke

Almond Board of Australia Conference, Adelaide 28-30 October 2014:-
    Maryam Shirmohammadi and John Fielke: Hulling and Shelling – Impacting the Boundaries
    Michael Coates: Storage Aeration and Dehydration of Almonds
Almond Board of Australia R&D workshop, Renmark 2015 (presentation – Advanced Processing of Almonds).
Almond Drying Field Day 17th June 2016 at Paringa and Murtho.
Almond Board of Australia Conference 2016, Melbourne - Poster
Almond Board of Australia R&D workshop 2017, Loxton (presentation – Advanced Processing of Almonds).

VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017 (papers and posters)

ASABE Annual International Meeting. Florida. 2016 (paper)
ASABE Annual International Meeting. Detroit 2018 (paper)

Almond Board of California Annual Conference 2013 (Dr Coates attended)
Almond Board of California Annual Conference 2015 (Dr Coates was invited presenter)
Almond Board of California Annual Conference 2016 (Professor Fielke was invited presenter - Almond Production for the Future – the Aussie Way)
Almond Board of California Annual Conference 2017 (poster)

4. Outcomes

4.1 Ability to control almond moisture content

The project has shown that almond moisture content can be controlled in aerated stockpiles (Figure 5), aerated shipping containers (Figure 6) and aerated sheds (Figure 7). These facilities can be used to both dehydrate wet fruit (early harvest or rain affected fruit) and rehydrate overdried fruit (young orchards and early season). Hence, the moisture content of bulk almonds can be controlled.

The work of Coates (2018) highlighted there are boundaries to the creation of quality fruit.

- If the fruit gets too hot during dehydration (>50ºC) there is **skin flaking.**
- If the fruit is held at high (100%) humidity in stagnant air there is **concealed damaged** (brown centres) which leads to **rancidity.**
- If fruit is dried too quickly the kernel outer walls dry first and there is **hollow centers** and split cotyledons.
- The highest temperature the fruit is exposed to during drying sets that **darkness** of the kernel skin.

All of the above detrimental conditions can occur naturally under various times of the season with some seasons worse than others. Hence, there is advantages of harvesting earlier to reduce these seasonal effects that create quality downgrades.

Importantly, the work of Coates (2018) showed that early harvested fruit can be hulled but should not be shelled before dehydration, as the shell slows drying of the kernels and limits the formation of hollow centres, as shown in Figure 38.

Figure 38. Cross section of Carmel fruit after dehydrating in-hull, in-shell and loose kernel (Coates, 2018)

Hence, to produce a high quality almond kernel the almond must be dried over several days with airflow past the fruit that keeps the humidity below 90% with the temperature not exceeding 50ºC.

There are two evolving technologies that can be used by almond growers and processors to measure moisture content.

- Taking temperature and humidity measurements of equilibrium moisture conditions and using published isotherms to calibrate these measurements to kernel moisture content. This does not need the kernels to be removed from the hulls and/or shells to get kernel moisture content. The currently used humidity sensors are damaged by fumigants such as phosphine, but laser based humidity sensors may soon to be available that should resist phosphine damage.
- Using the microwave transmission through almonds to measure the total volume of water in a sample. The USDA has patented a method and algorithms that determine intrinsic properties of materials to calibrate moisture content and apportion it to hull, shell and kernel in calibrated ratios.

The project work has shown that to get the best out of a moisture control system that the temperature and humidity of the incoming air must be controlled and set to the desired end point equilibrium conditions. For example, to minimise insect activity the temperature should be less than 15ºC and to achieve a 5% kernel moisture content the humidity of the incoming air should be set to 50% RH. On typical hot summer days in almond growing regions in Australia there are many hours of the day when an evaporative cooler fitted to an aeration fan can achieve these conditions. Without the humidity control the almonds cannot be brought to a uniform moisture and temperature condition within any large storage facility (stockpile, shed, silo, container etc).

Hence, when aeration is to be undertaken to control moisture content and temperature the conditions in the bulk almonds must be measured and the inlet aeration conditions of temperature and humidity must be controlled.

4.2 Ability to gain a high proportion of inshell almonds

Inshell almonds are the most valuable almonds to the industry with regards to the price earnt per mass of kernel.

The project has shown that impact shelling can be undertaken very effectively to produce over 70% inshell product in a single pass. This was achieved by using a large number of low energy impacts that are below the threshold for the release of the kernel from the shell.

Tests showed that for Nonpareil almonds that fruit harvested soon after hull split that close to 100% of the hulls can be detached using multiple low level impacts without the release of kernels from their shell.

In the short term, it is likely the process would first be adopted for use prior to silo storage of already dried almonds. This would double the capacity of kernels that fit into a silo.

Next, the process would be adopted for the hulling of fruit harvested before it is completely dried and the hulls are removed to maximise the amount of inshell that can be produced. The inshell could then be placed in the silos which would be used for finish drying of the almonds and then for storage until the almonds are scheduled for processing and final packing.

Finally, in order to gain the maximum efficiency benefits the hulling and separation equipment would be included into a new technology almond pick up. This would then have the harvester transferring only half of the current volume of product out of the orchard and leaving the milled hulls in the orchard.

4.3 Ability to efficiently separate loose hull from inshell almonds

Traditionally, air separators and screening decks handle only 2-3 tonnes per hour of product per 1 m of width. This project has developed and applied for a patent for a new style of air separator that injects at high speed a flow of material into a long separation chamber that has a vertical cross flow of air to achieve controlled separation of the hulls and light waste from inshell and inhull almonds. This separator aims to handle over 10 tonnes per hour of product for 0.1 m width. Further modification and testing is needed to demonstrate that this can be achieved.

4.4 Ability to efficiently mill almond hulls

The project has identified the Seed Terminator technology as being applicable for the milling of almond hulls using a lightweight hammer mill that is suitable for in-field milling of almond hulls. The Seed Terminator is manufactured in South Australia and is normally fitted onto grain harvesters to mill up to 20 tonnes/hour/mill of chaff exiting a grain harvester. It is lightweight (approx. 150 kg) and has a power consumption of approximately 30 kW.

Preliminary trials have been undertaken that shows the equipment can handle the hulls, sticks and other material with orchard waste. Further work is planning to attach this equipment below the discharge on an almond pick up and using it for winter orchard hygiene operations for swept up winter windfalls of mummies.

Upon talking with Californian almond orchard recycling researcher, Dr Brent Holtz, UC Cooperative Extension, Stockton USA in September 2018 he believes broadcasting the milled hulls over the soil surface would be the best use of the milled hulls as nutrient and organic matter for the orchard.

4.5 Knowledge that early harvest has benefits

The project has shown that earlier harvest (soon after hull split) is possible and has the following benefits:-

- The hulls are easier to detach before they are fully dried (Fielke, 2017)
- The yield is not compromised (Coates, 2018)
- The nutritional value is not reduced (Coates, 2018)
- Reduction in insect damage (Coates, 2018)
- Avoidance of rain damage (Coates, 2018)
- Fits with shake and catch and avoidance of dropping fruit onto the soil (Coates, 2018)

4.6 Silo storage of almonds is more affordable

The project has shown that the impediments to bulk storage of almonds in silos has reduced through the:-

- Use of on-farm hulling and cleaning of the almonds at the time of harvest to halve the volume of almonds that needs to be stored.
- Availability of sealed silos that will allow improved insect control using fumigation or controlled atmosphere storage.
- Knowledge of aeration parameters and the introduction of inlet humidity control that will allow effective moisture control of the almonds in storage.
- Removal of sticks with pre-cleaning prior to almonds being placed into a silo will allow the almonds to freely flow out of the silo.
- Availability of sensors that can be placed in a silo to measure temperature and humidity and by using isotherms their moisture content can be determined.

The benefits of using silo storage are:-

- Elimination of weather and insect damage during storage.
- Control of moisture content for optimum storage (4% kernel mc) and less chips and scratches during shelling (>5% mc).
- Cost of silo infrastructure is around 3c/kg of kernel in its inshell form over 20 years while a downgrade due to moulds and insect damage can reduce kernel value by $2.70/kg.

4.7 Ability to a make a large percentage of flawless kernel

Flawless kernel is defined as kernel that has its skin totally intact. It is desired by many top-end purchasers of kernel.

Currently, the compress and shear shelling process used for soft shelled almonds produces less than 50% of kernels that are flawless. These can be electronically sorted to produce a product with a high percentage flawless but there is a lot of rejects that still need to be sold.

This project has shown that by wetting up the almonds and using impact shelling that over 95% of Nonpareil almond kernels can be produced in a flawless condition without even a scratch on their skin. For hard shelled almonds this reduces down to 75% flawless with the remaining 25% being mainly split kernels.

The optimized wetting up process for soft shelled almonds is 10 minutes of soaking in water and then draining and standing for 3 hours before processing. For hard shelled almonds 3 hours of soaking is required and then draining and standing for 21 hours is the optimum. In both cases, the kernels reach a moisture content of 9-11% moisture content and become soft and flexible and hence are damaged less during the shelling process.

Wetting up the almonds before the currently used shear rollers and roller over belt process does not work as the kernel swells to fill the shell cavity and the compression and shear damages the kernels. However, wetting up works well for impact shelling as the impact force is applied to one side of the shell only and the impact fractures the shell without damaging the kernel.

5. Monitoring and evaluation

The project had a mid-term review undertaken on 1 February 2016 by Mr Grant Birrell (Nut Producers Australia) and Mr Ross Skinner (Almond Board of Australia). In summary, the main recommendations of the review were:-

- Focus work on the main variety of Nonpareil
- Direct effort into ways that industry can adopt hulling and shelling
- Use part of Voluntary Contribution (VC) funding to support breathable tarp work
- Ensure any in-field huller can handle the volumes of waste and contaminants
- Look at ways of getting industry to adopt the findings.

These recommendations were adopted and shaped the work from the review onwards.

The project had three main objectives:-

1. Develop on-farm hulling of almonds so that only half of the volume of almonds needed to be stored and transported for processing.
2. Develop new methods for the shelling of almonds to reduce chips and scratches.
3. Develop methods for effective aeration and dehydration of bulk almonds in silos/bunkers/sheds.

From a research point of view, each of these objectives have been achieved. The next stage is to assist transfer of the developed technologies to almond growers and processors. The path to adoption has started and the next stage is to encourage and support growers, processors and equipment manufacturers to take up the new technologies and extend the benefits to the broader industry.

6. Recommendations

In order to capitalize on the findings of this work it is recommended that the industry transition to:-

Recommendation 1: Storing almonds in silos to gain the benefits of:-

- Ability to be sealed to provide effective insect fumigation
- Protection from the weather and contamination
- Automated loading and unloading
- Aeration to control moisture content
- Ability to be fitted with sensors to monitor almond quality
- Conditioning almonds in preparation for long storage periods and conditioning for improved processability.

Recommendation 2: Undertaking on-farm hulling and cleaning of almonds to remove the hulls and contaminants in the field to:-

- Halve the volume of almonds that need to be stored and transported
- Retain nutrients and organic matter in the orchard
- Reduce the amount of material per unit volume of kernel that needs to have their moisture content modified.

Recommendation 3: Controlling the moisture content of almonds during storage using controlled aeration to set the temperature and humidity of the incoming air which will:-

- Conserve the nutritional value to its maximum if long term storage is undertaken at 4% kernel moisture content
- Minimise kernel chips and scratches during shelling when processed at 5.5 % kernel moisture content

Recommendation 4: Implementing temperature and humidity control in the warehouses that store processed almonds so that:-

- The stored almonds are equilibrated to the customer’s desired moisture content for consistent texture of the almonds
- There will be no more off specification moisture contents and reworking of processed almonds

Recommendation 5: In the longer term, the industry should consider ways of harvesting almonds earlier:-

- To maximise the nutritional content
- Remove the almonds from the risk of weather damage
- Achieve lighter colored kernels by avoiding exposure to high temperatures
- Control the dehydration rate to avoid splits, skin flaking and concealed damage/rancidity.

Recommendation 6: Continue funding the almond processing research at the University of South Australia to:-

- Monitor and optimise the adoption of the above
- Develop a practical method of preparing almonds for impact shelling so as to achieve a high percentage of flawless kernel
- Develop the first prototype infield huller and separator as the step from concept to a machine may be too large for a harvester manufacturer at this stage.

7. Refereed scientific publications

PhD Thesis

Coates, M.C. (2018). Defining and modelling the boundaries for mechanised dehydration to produce high quality almonds. School of Engineering, University of South Australia.

Journal articles

Shirmohammadi, M. and Fielke, J.M. 2017. Conditioning reduces kernel damage when impact shelling almonds. International Journal of Food Engineering. 2017; 20160324

Singh, CB and Fielke, JM (2017). Recent developments in stored grain sensors, monitoring and management technology. IEEE Instrumentation and Measurement Magazine, vol. 20, no. 3, Article no. 7951690, pp. 32-36.

Zheng, D and Fielke, JM (2014). Some physical properties of Australian Nonpareil almonds related to bulk storage. International Journal of Agricultural and Biological Engineering. Volume 7 pp 116-122.

Other publications

Papers in conference proceedings

Fielke, J.M (2018). Controlled drying and rehydrating of almonds on a farm scale in Australia. ASABE Annual International Meeting. Detroit, Paper No. 1800705.

Fielke, J.M. and Coates M.C . (2017). Lessons learnt from on-farm mechanical drying of almonds in 2017. VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017.

Fielke, J.M. and Coates M.C. (2017). The potential for infield hulling of early harvest almonds. VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017.

Fielke, J.M., Coates, M.C. and Shirmohammadi, M. (2016). Comparison of impact hulling of almonds using 3 impellor geometries. ASABE Annual International Meeting. Florida. Paper No. 162459940.

Posters at Conferences

Pearce, K., Coates, M., Fielke, J., Wirthensohn, and Coates, A. (2017). Does early harvesting affect the mineral and lipid profiles of almonds? VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017.

Coates, M.C. and Fielke, J.M. (2017). A model to prevent damage when mechanically drying bulk high moisture almonds. VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017.

McKeown, S., Fielke, J. and Mitchell, A. (2017). Calibration of microwave meter to measure kernel moisture content of inhull almonds. Almond Board of California Conference 5-7 December 2017.

Shirmohammadi, M. and Fielke, J.M. (2016). Advanced Processing of Almonds: Conditioning improves shelling of almonds. Australian Almond Conference, 8-10 November 2016.

Fielke, J.M. (2016). Advanced Processing of Almonds: On-farm hulling. Australian Almond Conference, 8-10 November 2016.

Coates, M.C. (2016). Advanced Processing of Almonds: Aeration and Drying. Australian Almond Conference, 8-10 November 2016.

Coates, M.C. and Fielke, J.M (2016). Early Harvest Studies: Nut Quality Effects. Almond Board of California Conference December 2016.

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Coates, M.C. (2018). Defining and modelling the boundaries for mechanised dehydration to produce high quality almonds. PhD Thesis, School of Engineering, University of South Australia.

Fielke, J.M., Coates, M.C. and Shirmohammadi, M. (2016). Comparison of impact hulling of almonds using 3 impellor geometries. ASABE Annual International Meeting. Florida. Paper No. 162459940.

Fielke, J.M. and Coates M.C. (2017). The potential for infield hulling of early harvest almonds. VII International Symposium on Almonds and Pistachios (ISHS), Adelaide. 5-9 November 2017.

Shirmohammadi, M. and Fielke, J.M. 2017. Conditioning reduces kernel damage when impact shelling almonds. International Journal of Food Engineering. 2017; 20160324

Strand, L. (2002). Integrated pest management for almonds, 2nd edn, University of California, Statewide Integrated Pest Management Project, Division of Agriculture and Natural Resources, Oakland, Calif.

9. Intellectual property, commercialisation and confidentiality

The project has developed and/or encouraged the development of the following IP.

9.1 Huller and Separator

The project has resulted in two patent applications. The two pieces of equipment are best operated together but could have applications where they could be used separately.

Technology readiness level (TRL): 6

At the end of the project, individual working prototypes were tested and optimized after which a full demonstration huller and separator was constructed and is undergoing testing and modifications to get it working ready for the 2019 almond harvest. Further funding is required if in-field testing is to be undertaken.

Investment readiness level (IRL): 5/6

The market has been validated as ready to invest in an almond huller and separator that can be used in conjunction with an almond silo storage facility. Hence, the technology could be licensed to a silo manufacturer to include with a silo storage system for almonds.

There are 4 distinct market segments which have been identified as potential licensees for the technology:-

1. Silo manufacturer(s) to include with an almond storage facility. The value proposition for on-farm hulling and silo storage can be viewed here.

   https://www.youtube.com/watch?v=3fGThkw75d4&t=9s

2. Californian based almond harvester manufactures to develop a new almond harvester that can pick up dried almonds in a conventional manner from windrows.
3. Californian and Spanish shake and catch harvester manufacturers to include with their machines.
4. Californian almond processing equipment suppliers.

Due to the diversity of the application of the technology the granting of multiple non-exclusive licenses is recommended.

9.2 Yield mapping sensor

The project has started to develop a laser based yield mapping sensor that measures the flow rate of almonds leaving the almond harvester and are being thrown into the surge cart. The technology used is an application of already known methods and would not be patentable.

Technology readiness level (TRL): 4

A prototype was developed and tested in 2018 harvest. Preliminary results indicate that it should meet the requirements. Further development is needed on the programing of the sensor based on the 2018 data. Once the principles are proven, then a commercial ready design needs to be developed.

Investment readiness level (IRL): 5/6

The technology would be supplied as a retro-fit kit for all conventional almond harvesters and made available as a factory supplied option for new equipment, both to be supplied via the existing almond harvester dealer networks.

It is recommended that the technology should be licensed to a company capable of developing a commercial version and working with the 4 main almond harvester manufacturers to include it in their product offerings for new and existing equipment.

10. Acknowledgements

This project was initiated by Ross Skinner and Ben Brown on behalf of the Almond Board of Australia. Their industry knowledge and foresight into future industry development needs was valuable in setting up and executing this project.

Special thanks to the University of South Australia staff who assisted with the project. Especially Andrew Burge and Dean Thiele.

This project would not have been possible without the assistance of many growers, processors and marketers of the Australian and Californian almond industry. In particular, thanks go to the staff at Almondco, Century Orchards, Costa Bros Hullers and Shellers, Jubilee Almonds, Laragon Hullers and Shellers, Mark Stoeckel, Walker Flat Almonds and Select Harvests for helping with various aspects of the project.

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Mr Lindsay Hall, withdrawn PhD
Dr Maryam Shirmohammadi, Post Doc

Mr Clement Labelieur, SIGMA France, 2018 20 week internship
Mr Lachlan Ahrens, 2018 final year project– yield mapping of almonds
Mr Lyndon Hill, 2018 final year project – aeration of almonds
Mr Paul Aiyadorai, 2018 final year project – milling of dry almond hull
Mr Mohamad Mohd Rozi, 2018 final year project – milling of wet almond hulls
Mr Luqman Yunos, 2018 final year project – case for microwave moisture meter

Mr Chen Tong, 2017 final year project – cleaning of almonds
Mr Imran Izzuddin Shah, 2017 final year project – case for microwave moisture meter
Mr Wan Reozma Aideel, 2017 final year project – electronics within microwave moisture meter case
Mr Sidney Simon, 8 week internship – modelling of cyclones for air cleaning of almond dust
Mr Xuebo Wei, 2017 final year project – modelling of dehydration fans
Mr Quentin Guillaud, SIGMA France, 2017 20 week internship – air separation of almond hulls
Mr Houssam (Sam) Abi Ali, 2016/17 8 week internship – moisture sensing of almonds
Mr Kamal Kumar, 2016/17 8 week internship – moisture sensing of almonds

Ms Mubinah Abdul Wasei Haruka Kimura, 2016 final year project – yield mapping of almonds
Mr Dusan Imaduwa Kariyawasam Gamage, 2016 final year project- yield mapping of almonds
Class of Mechanical Design Practice, 2016 – infield milling of almonds
Mr Zac Han Chow, 2016 final year project - infield milling of almonds

Ms Noradira Abdul Latiff, 2015 final year project – wireless temperature and humidity sensing
Mr Noradlee Ibrahim, 2015 final year project – yield mapping of almonds
Mr Basim Mohammed Abumaqas, 2015 final year project – breathable tarps for almonds

Mr Chanderbir Singh Bawa, 2014 final year project – Continuous flow almond dehydrator
Mr Khairi Akmal Abdul Razak, 2014 final year project – wireless temperature and humidity sensing
Mr Syakimahanim Ahmad, 2014 final year project – wireless temperature and humidity sensing
Mr Ezreen Aida Kamarulzaman, 2014 final year project – wireless temperature and humidity sensing