Horticulture Innovation Australia

Final Report

Developing harvest strategies to maximise walnut quality

Mr Michael Lang
Walnuts Australia

Project Number: WN11000

WN11000

This project has been funded by Horticulture Innovation Australia Limited with co-investment from Walnuts Australia and funds from the Australian Government.

ISBN 0 7341 3504 1

Published and distributed by:
Horticulture Innovation Australia Limited
Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

Project number WN11000

Developing harvest strategies to maximise walnut quality

Project Leader

Michael Lang

Walnuts Australia
148 Colinroobie Road
Leeton, NSW 2705
Australia

Phone +61 2 6951 3000
Fax +61 2 6951 3001

Key team members

Jennifer Whitney

Walnuts Australia
148 Colinroobie Road
Leeton, NSW 2705
Australia

Julie Sulcs

Walnuts Australia
Springs Road
Swansea, TAS 7190
Australia

31 January 2015

1. SUMMARY

The Australian walnut industry is undergoing rapid expansion with the potential to supply high quality nuts to local and export markets. Optimizing the quality of nuts is essential to maximise these opportunities. Major factors that determine nut quality are the absence of diseases and/or disorders of the kernel and shell. These factors can be adversely affected during walnut harvest.

The timing of fruit maturity was earlier in the semi-arid climate of NSW, than in the temperate climate of Tasmania, with the progression of kernel and hull maturity distinct between early (Serr), mid (Vina, Lara, Howard) and late (Chandler) maturing cultivars in NSW. In Tasmania, the timing of kernel maturity was earlier in Vina, Lara and Howard than in Chandler; however, hull maturity was similar between all cultivars. Walnuts mature in response to climate, and this may have influenced the temporal development of fruits between different growing regions in this study.

Delays in harvesting reduced the quality of nuts, with fewer extra-light and light kernels, and more amber kernels, yellow stained pellicles and kernel moulds, in nuts that were on soil beneath trees or in grass inter-rows for 4 or more days. Rainfall and/or soil moisture may have contributed to the reduction in nut quality, as the timing of these events corresponded to losses in nut quality. Nuts exposure to a constant 20°C, between harvesting and drying, also reduced kernel quality of Chandler and Lara nuts after 4 and 6 days, respectively. Additional research will provide further insight into the nature of these events.

Non-ventilated storage of walnuts for 24 or 48 h after harvesting reduced nut quality in Vina and Lara, compared to drying immediately after harvesting; however, nut quality of the later-maturing cultivars, Howard and Chandler, was less affected with storage. Temperatures in storage bins were higher, and elevated for longer in earlier- than in later-maturing cultivars i.e., maximum temperatures and time at 20°C or more with 48 h storage were 34°C and 34 h in Vina, and 19°C and 0 h in Chandler. In contrast to non-ventilated storage, temperatures with ventilated storage reduced or remained relatively constant. As prolonged exposure to elevated temperature can reduce nut quality, further investigations into ventilated storage are warranted.

Nut quality is maintained when nuts are harvested as soon as possible after kernel maturity. Foliar sprays of ethephon reduced the time delay between hull and kernel maturity, and increased the rate of nut-drop in NSW and Tasmania. The concentration of ethephon in kernels was higher, and peaked later in Tasmania than NSW. The use of ethephon was not considered detrimental to tree health, and did not reduce the size and weight of nuts after three consecutive years of use. Nut quality between different ethephon harvest strategies was similar; however, further monitoring will identify cultivar variations and improve this initial description.

2. KEYWORDS

fruit maturity, nut, kernel, packing tissue brown, hull dehiscence, kernel colour, shell stain, yellow pellicle, mould, delays, rainfall, temperature, ventilated storage, ethephon

3. INTRODUCTION

The Australian walnut industry is rapidly expanding, with import substitution and export opportunities predicted to generate an industry value of AU$64 million, and AU$72 million in exports, by 2020 (Australian Nut Industry Council, 2014). For these targets to be realised, nuts and kernels, the edible portion of the nut, must be of the highest quality. Major factors that determine nut quality are the extra-light and light colour of the kernel, the absence of diseases and/or disorders of the kernel and minimal staining or damage of the shell surface (Olson et al., 1998). All these factors can be adversely affected during walnut harvest.

Kernels are mature and lightest in colour when the packing tissue surrounding the kernel is brown in colour, whereas the separation and/or splitting of the hull from the nut, indicates hull maturity (Olson et al., 1998). For walnut harvest, both the kernel and the outer hull of the fruit need to be mature; however, cultivar and climatic differences influence the timing at which kernels and hulls mature (Olson et al., 1998). In Australia, kernel maturity can be up to 22 days prior to hull maturity, and this delay can lead to a reduction in kernel quality (Lang and Evans, 2010). Thus, mechanisms to synchronize hull and kernel maturity are needed to prevent significant losses in walnut quality.

Ethephon, which breaks down to the active metabolite ethylene, is a plant growth regulator applied pre-harvest to facilitate harvest in walnuts and many other fruit crops. In preliminary trials in Australia, ethephon significantly increased the rate at which hulls matured in early, mid- and late-harvested cultivars (Lang and Evans, 2010); however, the efficacy of ethephon was improved when applied at higher rates than those currently permitted. Furthermore, inadequate spray coverage has been identified as a major limitation with ethephon use in walnuts (Olson et al, 1998; Beade and Stanfield, 2001). Overall, the response to ethephon may depend upon the walnut cultivar and management practices, such as spray rates and coverage.

Delays in the harvesting operations can lead to significant loss in kernel and nut quality. In a preliminary study in Tasmania, delaying harvest significantly reduced kernel quality by reducing the number of nuts with extra-light kernels and increasing the number of nuts with yellow discoloured kernels (Lang and Evans, 2010). In the semi-arid environment of California, high ambient temperatures and the progressive shading of nuts through the season have been implicated in the loss of kernel colour, and increase in discoloured kernels respectively (Martin et al., 1973; Olson et al, 1998; Lampinen et al, 2007). In Tasmania, yellow discoloured kernels were associated with nuts that were located on the ground prior to harvest, and suggest that conditions underneath tree canopies may contribute to this condition (Lang and Evans, 2010). The effect of abiotic or biotic conditions on kernel quality is yet to be resolved.

This project will clarify the timing of kernel and hull maturity of major walnut cultivars in Australia, and develop harvesting strategies for producing high quality walnuts, by stimulating earlier and uniform hull split and hastening nut removal. The project will generate efficacy, crop safety and residue data to facilitate an amendment to the permitted use of ethephon in Australia.

4. METHODOLOGY

4.1 Terminology

At maturity, the walnut consists of the hull, shell and edible kernel (Pinney et al., 1998); the term ‘fruit’ refers to all three parts, whereas the shell and kernel is termed the ‘nut’.

Walnut harvest commences when both the kernel and hull are mature. Kernel maturity is attained when the packing tissue around kernels has turned brown, termed ‘packing tissue brown’, whereas hull maturity is defined by the separation of the hull from the shell (Olson et al., 1998). In this report, hull maturity is termed ‘hull-dehiscence’.

Walnut harvest involves a sequence of events, namely the mechanical shaking of trees to dislodge nuts, followed by the windrowing, picking-up, hulling and drying of nuts; in this report the terms ‘shaking, sweeping, harvesting, hulling and drying’, respectively, are used to describe this sequence of events.

4.2 Site descriptions

All trials were conducted in commercial hedgerow orchards in NSW, at Goolgowi (34°04’11”S, 145°42’47”E) and Leeton (34°30’00”S, 146°27’18”E), and in Tasmania at Swansea (42°03’55”S, 148°03’04”E) and Cranbrook (41°99’58”S, 148°08’12”E). Trees were *Juglans regia* cultivars grafted onto *J. hindsii* rootstocks, with inter- and intra-row spacing of 8 × 4 m, respectively, in NSW and 7 × 4 m, respectively, in Tasmania. Tree canopies were approximately 75 m^3 and 50 m^3 in NSW and Tasmania respectively. Trial plots were selected from areas of orchards with uniform tree growth. The cultural management of experimental sites was identical to that of commercial orchards.

4.3 Temporal development of kernel and hull maturity in walnuts

Up to 17 surveys per year were undertaken to study the temporal development of fruit maturity in NSW and Tasmania. Cultivars studied in NSW included Serr, Lara, Vina, Howard and Chandler. Serr is not grown commercially at Swansea or Cranbrook, Tasmania, hence Tasmania surveys included Lara, Vina, Howard and Chandler only.

Each survey was conducted in plots of 50 trees, made up of two adjacent tree-rows of 25 trees each, replicated four times. Two to three weeks prior to the anticipated date for all fruit to reach packing tissue brown (PTB), ten fruits per plot were removed and assessed for the presence or absence of PTB. The ten fruits consisted of one fruit per single-tree, from each of ten arbitrarily selected trees. Fruits were selected from lateral shoots only in the lower third of the tree canopy. Further assessments were conducted until 90%, or more, of fruits were at PTB.

From PTB until hull-dehiscence, fifty fruits per plot, consisting of ten fruits from each of five arbitrarily selected trees, were removed at 4-7 day intervals and assessed for the presence or absence of hull-dehiscence. Fruits were selected from the lower third of the tree canopy, from both terminal and lateral shoots. The presence of hull-dehiscence was recorded if 95%, or more, of the hull was removed after fruits were rolled by hand for 1-

2 s, with gentle downward pressure, on a steel grating mesh platform (Expamet Gridwalk WK2517, Melsteel Pty. Ltd., 132-134 Abbott Road, Hallam, Victoria, 3803).

4.4 Effects of delayed harvest on kernel and shell quality

4.4.1 Nut location between shaking and harvesting

A total of seven trials evaluated the effect of delayed harvest on nut quality. Trials were split-plot designs, replicated five times, in Serr, Lara, Howard and Chandler. Factors examined included nut location and soil moisture during harvest, and the length of time between shaking at harvest.

At each field site, cultivars are grown in distinct areas, or blocks, within the orchard. For trials, nuts were collected from each “cultivar block” and then transferred to a “trial block” adjacent to where nuts were collected. Walnut trees within trial blocks were already harvested and were in full-leaf for the duration of trials.

Prior to collecting nuts from cultivar blocks, prematurely dropped nuts were removed from beneath tree canopies to remove the possibility of degraded nuts being included in trials. Trees within the row of each cultivar block were then shaken with a mechanical tree shaker to promote nut-drop from trees. After shaking, dropped nuts were raked from the centre of the tree-row into inter-rows to form a single-row of nuts on either side of the tree-row. Samples of 800 hulled nuts, replicated five times, were then arbitrarily selected from the raked nuts. Each 800 nut sample was divided into three 250 nut samples and one 50 nut sample. The 50 nut sample was placed into a 1 kg breathable poly-mesh bag and dried until 8 to 9% moisture content (Day 0 sample).

Each 250 nut sample was then assigned to one of three treatments; tree, grass and ground or tree, dry ground and wet ground. Poly-mesh bags with “tree” located nuts were placed within the tree canopy, 1-2 m above ground level, so that nuts were in a single layer within the poly-mesh bag; “grass” located nuts were placed within tree inter-rows, with a 10-20 mm high grass and legume sward, so that all nuts were in contact with the sward foliage; and “ground” located nuts were placed underneath tree canopies so that all nuts were in contact with the ground. For dry- and wet-ground treatments, ‘dry-ground’ nuts were in contact with dry ground underneath tree canopies, and ‘wet-ground’ nuts in contact with wet ground from drip-line irrigation.

From each 250 nut sample, 50 nuts were then arbitrarily selected at one of five ‘time intervals, at 1, 2, 4, 8 and 16 days, placed into 0.5 kg breathable poly-mesh bags, and then dried to 8-9% moisture content. Nuts were then weighed and assessed for quality.

Temperature sensors were placed in poly-mesh bags within storage bins, in touch with sample nuts. Ambient temperature sensors were placed in weather screens, made from 150 mm long and 35 mm diameter white coloured polypropylene mesh tubing, and attached to the outside of storage bin doors. Sensors recorded at 5 min intervals for the duration of storage.

4.4.2 Storage temperatures between hulling and drying

The effect of temperature between hulling and drying on nut quality was examined in Lara and Chandler. Trials were split-plot designs, with four and three replicates in Lara and Chandler respectively. Factors examined included the temperature between hulling and drying, and the length of time from hull-dehiscence to drying.

In Lara, prematurely dropped nuts were removed from cultivar blocks and an arbitrary sample of nuts collected from beneath mechanically shaken trees, as previously described. In Chandler, commercially harvested nuts were arbitrarily selected immediately after the hulling process. In both Lara and Chandler, nuts were randomly divided into 3 l sample sizes, and then placed into separate 5 l sealed clear plastic containers. Containers were then assigned to one of two ‘temperature’ treatments, 5 and 20^{o}C, and removed at six ‘time intervals’ between 1 and 16 days. After removal, nuts were placed into 0.5 kg breathable poly-mesh bags, and dried to 8-9% moisture content. Nuts were then weighed and assessed for quality.

4.4.3 *STORAGE OF FRUIT AND NUTS BETWEEN HARVESTING AND HULLING*

One trial examined the effects of storage of fruits and nuts between harvesting and hulling on nut quality. The trial was a two-sample comparison design, replicated three times. Nuts with, and without, the presence of hull were stored in steel shipping containers, termed “storage bins”, between harvesting and hulling. Storage bins had a capacity of 34 cubic metres, with internal measurements of 5.9 m length, 2.4 width and 2.4 height. Ambient and storage bin temperatures were recorded, as previously described.

Nuts were selected immediately after harvesting and before hulling. A total of 200 nuts per replicate were arbitrarily selected and then divided into 100 nut samples. One sample of 100 nuts was placed into a 0.5 kg breathable poly-mesh bag and dried to 8-9% moisture content (0 hour sample). The remaining 100 nut sample was also placed into poly-mesh bags, then placed within storage bins so that sample nuts were in contact with other stored nuts. Storage bins were filled with commercially harvested nuts, to within 0.5 m of the ceiling. The stored samples were then assigned to one of two ‘time interval’ treatments i.e., 24 or 48 h. After this time interval, sample nuts were removed from the storage container and dried to 8-9% moisture content. Nuts were then weighed and assessed for quality.

4.4.4 *STORAGE OF NUTS ONLY BETWEEN HULLING AND DRYING*

Nine trials were undertaken to evaluate storage of nuts between hulling and drying on nut quality. Trials were two-sample comparison designs, replicated three times. Nuts were stored in storage bins, and temperatures recorded, as previously described.

Commercially harvested nuts were arbitrarily selected immediately after the hulling process. For each trial, 200 nuts per replicate were arbitrarily selected, divided into 100 nut samples, and placed into 0.5 kg breathable poly-mesh bags. Nuts were placed within storage bins in contact with commercially harvested nuts, removed at 0, 24 and 48 h intervals, and then dried, as previously described. Nuts were then weighed and assessed for quality.

4.4.5 *VENTILATED STORAGE BETWEEN HULLING AND DRYING*

One trial evaluated ventilated storage of nuts between hulling and drying on nut quality.

To ventilate storage, individual timber pallet boards were placed on the floor of storage bins in a regular repeating fashion, to form a ‘grate’ on which walnuts were stored after hulling. At the forward end wall of the storage bin one 400 mm diameter ventilation fan was linked to 'ventilation channels' within the pallet boards so that ventilation gases could reach all areas of the storage bin. The front opening of the storage bin was sealed around and above the ventilation fan, to within 1 m of the top of the storage bin, with 100 × 25 mm 'sealing boards'. To increase ventilation to the rear end of the storage bin, a horizontal baffle sheet was placed above the ventilation fan in the space between the sealing boards and storage bin doors. Storage bin doors were fixed with a 100 mm opening and ventilation gases injected into the storage bin at the lower portion of the forward end wall at a rate 62.9 m^3/h; gases were subsequently extracted at the upper portion of the forward end wall.

Walnuts were loaded directly onto the pallet boards from the hulling line, to within 1 m of the ceiling of the storage bin. Sample nuts were arbitrarily selected immediately after they were processed from the hulling line, divided into 100 nut samples and placed within storage bins, as previously described. Nuts were dried to 8-9% moisture content after sample selection (0 h sample) and 48 h storage (48 h sample). Nuts were then weighed and assessed for quality.

4.5 Efficacy and crop safety of ethephon in major walnut cultivars

Three or four trials per year were undertaken to examine foliar applied ethephon on hull maturity, crop safety and nut quality. Trials were randomized complete block designs with five replicates of single-tree plots of Serr, Lara, Vina and Howard. Ethephon was applied once only, with a calibrated air-sheer backpack mister (Stihl SR 400) at a spray volume of 2,000 l/ha. Single-tree buffers were located between plots to prevent ethephon overspray.

In 2012, three rates of ethephon were applied at 100% PTB to Serr and Lara in NSW, and to Lara in Tasmania. In 2013, three different rates of ethephon were applied to trees in NSW i.e., to Serr 11 days after 100% PTB, to Lara 3 days after 100% PTB and to Howard at 100% PTB. Ethephon was also applied at 100% PTB, and 10 days after 100% PTB, to different trees in Howard. In 2014, ethephon was applied to Serr 5 or 12 days after 100% PTB, and to Vina 2 or 10 days after 100% PTB, in NSW; nuts were harvested once or twice, between 10 and 20 days after ethephon sprays, dependent upon treatment. In each of the three years in NSW, three different rates of ethephon were also applied to the same Lara trees to examine multiple year use of foliar ethephon on crop yield.

Post-treatment efficacy of ethephon was assessed 7-10 days after treatment on 25 fruits per tree. Fruits were arbitrarily selected from the lower third of the tree canopy, from both terminal and lateral shoots. After removal, the presence or absence of hull-dehiscence was assessed using methods described previously. Removed nuts were commercially dried and weighed, and then nut and kernel quality assessed.

Hull dehiscence and nut drop were assessed prior to commercial harvest. Single-tree plots were shaken with a mechanical tree shaker for 3.5 s at 1850 rpm to promote nut-drop. After shaking, dropped nuts were raked from the centre of the tree-row into inter-rows. The total number of dropped nuts per tree, and nuts remaining on trees were then counted to calculate percent nut drop. A sub-sample of 100-125 nuts were then arbitrarily collected from either side of the tree-row. After removal, the presence or absence of hull-dehiscence was assessed. Hulled nuts were then commercially dried, weighed and assessed for quality.

The health of trees after ethephon was assessed by visually measuring the percentage area of chlorotic leaves within the tree canopy and/or the percentage area of premature leaf drop within the tree canopy. Crop safety assessments were conducted concurrently with efficacy assessments.

4.6 Ethephon residue in walnut kernels

Three residue decline studies were conducted according to protocols outlined by the Australian Pesticides and Veterinary Medicines Authority. Trials were conducted in Lara (NSW and Tasmania) in 2013, and in Howard (NSW) in 2014. Non-replicated plots consisted of four to five trees within an orchard row. Three rates of ethephon were applied once only, when 95% of fruits were at PTB, with a calibrated air-sheer backpack mister at a spray volume of 2,000 l/ha.

To establish residue decline, approximately 1 kg of nuts were arbitrarily selected from each plot immediately after the spray had dried (day 0), and at 3, 7, 14 and 21 days after treatment. At days 0, 3 and 7 days, walnuts were sampled from high and low areas in the tree canopy, and from areas exposed and sheltered by foliage, in proportion to walnut distribution. After selecting from trees, the hull was removed from nuts with a sharp knife. Between the 7 and 14 day samples, a large proportion of nuts dropped from trees; hence, for the 14 and 21 day intervals, walnuts were sampled from underneath the tree canopy, in proportion to those remaining on the tree. Sample collection was completed for the non-treated plot before proceeding to the plot treated with the lower rate of ethephon and then the plot treated with the higher rate of ethephon.

All samples were placed in plastic zip-lock bags and stored within a freezer within 1 h of sampling. Samples were kept at -20ºC until residue analysis. Kernels were analysed for ethephon residue by Symbio Alliance (Eight Mile Plains, QLD). The study was conducted to guidelines outlined in the Organisation for Economic Co-operation and Development (OECD) Test No. 509: OECD guideline for the testing of chemicals – crop field trial (Published 07 September 2009).

4.7 Quality assessment

All nuts were sized and weighed, and shell and kernel defects determined as per guidelines in ‘United States standards for grades of walnuts (*Juglans regia*) in the shell’ (http://www.ams.usda.gov/AMSv1.0/standards). Nuts were also assessed for the presence or absence of 30%, or more, staining of the shell surface, and kernels for the presence or absence of yellow ‘stained’ pellicle that surrounds the kernel.

Kernel colour was assessed as described in the ‘United States standards for grades of shelled walnuts (*Juglans regia*), with visual guidelines from the ‘United States Department of Agriculture, Consumer and Marketing Service walnut colour chart’ (http://www.ams.usda.gov/AMSv1.0/standards).

4.8 Weather monitoring

Temperature and rainfall sensors were located at orchards for each year. Temperature sensors were mounted in a Stevenson screen and positioned under a tree canopy, 1 m above ground level. Tipping bucket rainfall sensors were mounted 1.5 m above ground level, and positioned in a level site without surrounding vegetation within 100 m of temperature sensors. Sensors recorded at 5 min intervals for each growing year.

4.9 Data analysis

Temporal fruit development was calculated from the 1st January until the completion of kernel and hull maturity for each cultivar, year and location, and growth models fitted by linear regression analysis. The most appropriate model from the linearized forms of the linear, monomolecular and logistic model was selected by methods described in Campbell and Madden (1990).

Nut and kernel quality were calculated as mean percentages and then compared using analysis of variance (ANOVA). The mean quality of nuts for each treatment were subjected to ANOVA, using the General Linear Models procedure where appropriate, to determine statistically significant difference among treatment means. Means were separated at $P = 0.05$ using Fisher's least significance difference test.

5. RESULTS

5.1 Temporal development of kernel and hull maturity in walnuts

The onset of kernel maturity, or packing tissue brown (PTB) was earlier in NSW than Tasmania e.g., in NSW, 5% of fruits were at PTB 40 days after 1st January, almost 40 days earlier for the same cultivar in Tasmania (Figure 1).

The progression of PTB was distinct between early, mid and late maturing cultivars in NSW, with PTB in Serr 19 days earlier, and Chandler 16 days later, than other cultivars (Table 1). PTB in Lara and Vina was similar in NSW, with 95% of fruits at PTB within 3 days of each other, and Howard within 8 days of Vina. In Tasmania, PTB was similar between Lara, Vina and Howard, and concluded within 14 days, irrespective of cultivar.

The progression of hull maturity spanned 29 days in NSW, with Serr followed by Vina and Lara, and then Howard and Chandler (Table 1). Hull maturity occurred 4 days apart in Vina and Lara (69 and 73 days from 1st January respectively) and in Howard and Chandler (82 and 86 days respectively). In Tasmania, hull maturity of all cultivars occurred within 6 days, from 93 to 99 days of 1st January.

The time between kernel and hull maturity, or drop-time, was greatest in Serr and least in Chandler i.e., 16 and 0 days respectively in NSW (Table 1). The drop-time for Lara was greater than Vina in NSW i.e., 13 and 6 days respectively. In Tasmania, the drop time of all cultivars occurred within 7 days.

Temporal development of observed PTB between years and orchards was not significantly different in Serr (P=0.49), Lara (P=0.57), Vina (P=0.31) and Howard (P=0.33) in NSW, and in Lara (P=0.17), Vina (P=0.27), Howard (P=0.20) and Chandler (P=0.40) in Tasmania (data not presented). Similarly, the progression of PTB in Chandler in NSW was no different between orchards in 2013 (P=0.37) and 2014 (P=0.42). Hence, data was pooled for each cultivar and location so the number of days from 5 to 95% PTB could be predicted for each scenario.

Temporal development of PTB in Serr, Lara, Vina and Howard was strongly related to the number of days from 1st of January, irrespective of location (Table 2). Similarly, there was a significant relationship between progression of PTB in Chandler in NSW and 2013 and 2014. The time between 5 and 95% PTB was least in Serr (13 days) with Lara, Vina and Howard requiring a further 8 to 11 days (21-24 days). The time from 5 to 95% PTB in Chandler ranged from 20 to 30 days in NSW, and 28 days in Tasmania.

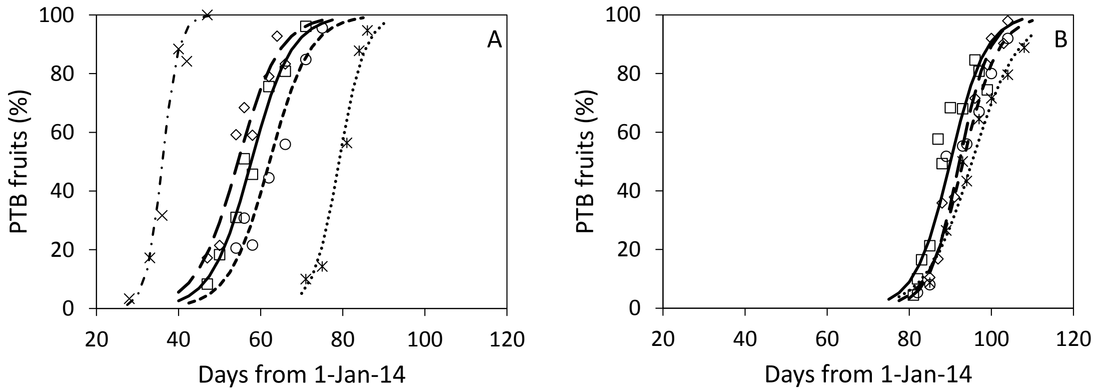

Figure 1. Progression of observed and predicted kernel maturity (PTB) in Serr (cross, dash and dot), Lara (diamond, long dash), Vina (square, solid) Howard (circle, short dash) and Chandler (star, dot line) at Goolgowi, NSW (A), and Swansea, Tasmania (B) in 2014.

Table 1. Mean number of days ± se (predicted) from 1st January for 95% of fruits at kernel maturity (PTB) and 80% of fruits at hull dehiscence (hullable), and the number of days (predicted) for fruits to go from 95% PTB to 80% hullable (drop-time) at Goolgowi and Leeton, NSW, and Swansea and Cranbrook, Tasmania.

Cultivar	NSW [Z YX]			Tasmania [Z]		
	95% PTB (days)	80% hullable (days)	Drop-time (days)	95% PTB (days)	80% hullable (days)	Drop-time (days)
Serr	41 ± 1	57 ± 1	16	-	-	-
Lara	60 ± 2	73 ± 5	13	87 ± 8	94 ± 3	7
Vina	63 ± 2	69 ± 3	6	86 ± 5	92 ± 2	6
Howard	71 ± 2	-	-	89 ± 6	93 ± 4	4
Chandler	87 ± 1	86 ± 0	0	100 ± 7	99 ± 4	0

[Z] Predicted values for each cultivar derived from simple linear regression models of observed PTB and hullable values, with logistic transformations ($\hat{y}=ln[1/(1-y))$), against the number of days from 1-Jan (x).
[Y] Grey shading indicates that 720 g/l ethephon was applied to Serr, at rates of 60 ml/100 l in 2012 and 2013 and100ml/100 l in 2014, and to Lara and Vina at 60 ml/100 l in all three years, at spray volume of 2000 l/ha. Ethephon was not applied to Howard and Chandler in NSW or to any cultivar in Tasmania.
[X] A dash indicates that the linear regression was not significant at $P < 0.05$; hence, a predicted value was not calculated.

Table 2. Regression statistics describing linearized logistic transformation of observed kernel maturity (PTB) and the number of days from 1st January, and the number of days (predicted) from 1st January for fruits to go from 5% to 95% PTB, in NSW and Tasmania. All models were statistically significant at *P*<0.0001.

Cultivar	Location	Year	Rate	Intercept ($\times 10^{-2}$)	R^2	Days from 5 to 95% PTB
Serr	NSW	2012-14	0.45	-10.00	0.96	13
Lara	NSW	2012-14	0.26	-9.46	0.94	23
Vina	NSW	2012-14	0.28	-3.56	0.96	21
Howard	NSW	2012-14	0.24	-5.30	0.95	24
Chandler	NSW	2013	0.20	0.08	0.95	30
Chandler	NSW	2014	0.29	2.49	0.94	20
Lara	TAS	2012,14	0.25	-8.71	0.89	24
Vina	TAS	2012,14	0.27	-10.30	0.89	22
Howard	TAS	2012,14	0.28	-5.06	0.95	21
Chandler	TAS	2012,14	0.21	2.10	0.91	28

5.2 Effects of delayed harvest on kernel and shell quality

5.2.1 NUT LOCATION BETWEEN SHAKING AND HARVESTING

Swansea, Tasmania

Nuts that were on the ground beneath trees, or in grass inter-rows, from 0 to 16 days after shaking had lower quality than nuts that remained on trees at Swansea, Tasmania.

In Serr, nuts on the ground or grass had fewer extra-light kernels than nuts in trees (Table 3); however, less than 14% had extra-light kernels, irrespective of location.

In Lara, nuts on the ground or grass had fewer extra-light kernels than nuts on trees i.e., 61, 58 and 73% respectively. Nuts on the ground and grass also had more light-amber kernels and yellow pellicles than tree located nuts (Table 3). More moulds were in nuts that were on grass than in trees.

In Chandler, ground and grass located nuts had fewer extra-light, and more light-amber kernels than nuts on trees (Table 3). Greater than 34 and 21% of nuts that were on ground and grass had stained shells and yellow pellicles respectively. A near 10% of grass located nuts had moulds, compared to 5% of tree located nuts.

Table 3. Mean percent of nuts, pooled from all sample dates, with extra-light, light, light-amber and amber kernels, shell staining, yellow pellicles and kernel moulds according to location (tree, ground and grass) for three cultivars at Swansea, Tasmania. For each cultivar, means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Cultivar Location	Extra-light (%)		Light (%)		Light-amber (%)		Amber (%)		Stained shell (%)		Yellow pellicle (%)		Kernel mould (%)	
Serr														
Tree	13.8	a	50.4	a	31.9	a	3.8	a	0.3	a	0.6	a	1.7	a
Ground	10.5	b	51.0	a	35.4	a	3.2	a	0.6	a	1.3	a	2.1	a
Grass	9.7	b	51.0	a	34.5	a	4.9	a	3.5	b	0.8	a	2.0	a
Lara														
Tree	72.7	a	22.0	a	3.3	a	1.7	a	21.1	a	1.0	a	1.8	a
Ground	61.1	b	26.9	b	9.0	b	2.5	a	29.4	a	8.4	c	3.8	ab
Grass	57.8	b	26.9	b	12.0	b	2.7	a	31.3	a	5.0	b	6.5	b
Chandler														
Tree	85.0	a	8.6	a	3.2	a	2.9	a	9.2	a	6.6	a	4.8	a
Ground	77.4	b	13.0	b	6.1	b	3.4	a	33.9	b	20.5	b	6.8	a
Grass	71.8	c	17.1	c	6.9	b	3.9	a	36.4	b	24.8	b	9.2	b

Delays in the harvesting of nuts from the ground underneath trees, or in grass inter-rows, reduced nut quality in Lara and Chandler at Swansea, Tasmania.

In Lara, ground and grass located nuts had fewer extra-light kernels after 8 days than from 0-4 days (Figure 2). Kernel colour degraded further after 8 days, with only 13 and 21% extra-light kernels in nuts located on grass and ground respectively. Ground and grass placed nuts had more light-amber kernels than tree located nuts, 8 or more days after shaking, and more stained shells and yellow pellicles after 4 days. Kernel moulds in nuts from grass inter-rows increased over time, with 13% incidence after 8 days.

In Chandler, ground and grass positioned nuts had fewer extra-light coloured kernels 8 and 16 days after shaking i.e., 49 and 35% at day 16 respectively (Figure 3). Nuts that were on ground or grass had more light-amber kernels than tree nuts after 16 days. Stained shells and yellow pellicles in ground or grass nuts increased after 4 days, with a near 60 and 100% respectively after 16 days. Kernel moulds in ground and grass located nuts increased over time, with 16 and 22% incidence, respectively, after 16 days.

Environmental conditions varied between Serr, Lara and Chandler in Tasmania.

Rainfall for the 16 days was less in Serr than Lara and Chandler i.e., 2, 44 and 63 mm rainfall respectively (Table 4). No rainfall occurred from 0-4 days in Lara and Chandler, and only 2 mm occurred for the same period in Serr. Mean ambient temperature ranged from 10 to 15^{o}C in Serr, 12 to 16^{o}C in Lara and 9 to 11^{o}C in Chandler.

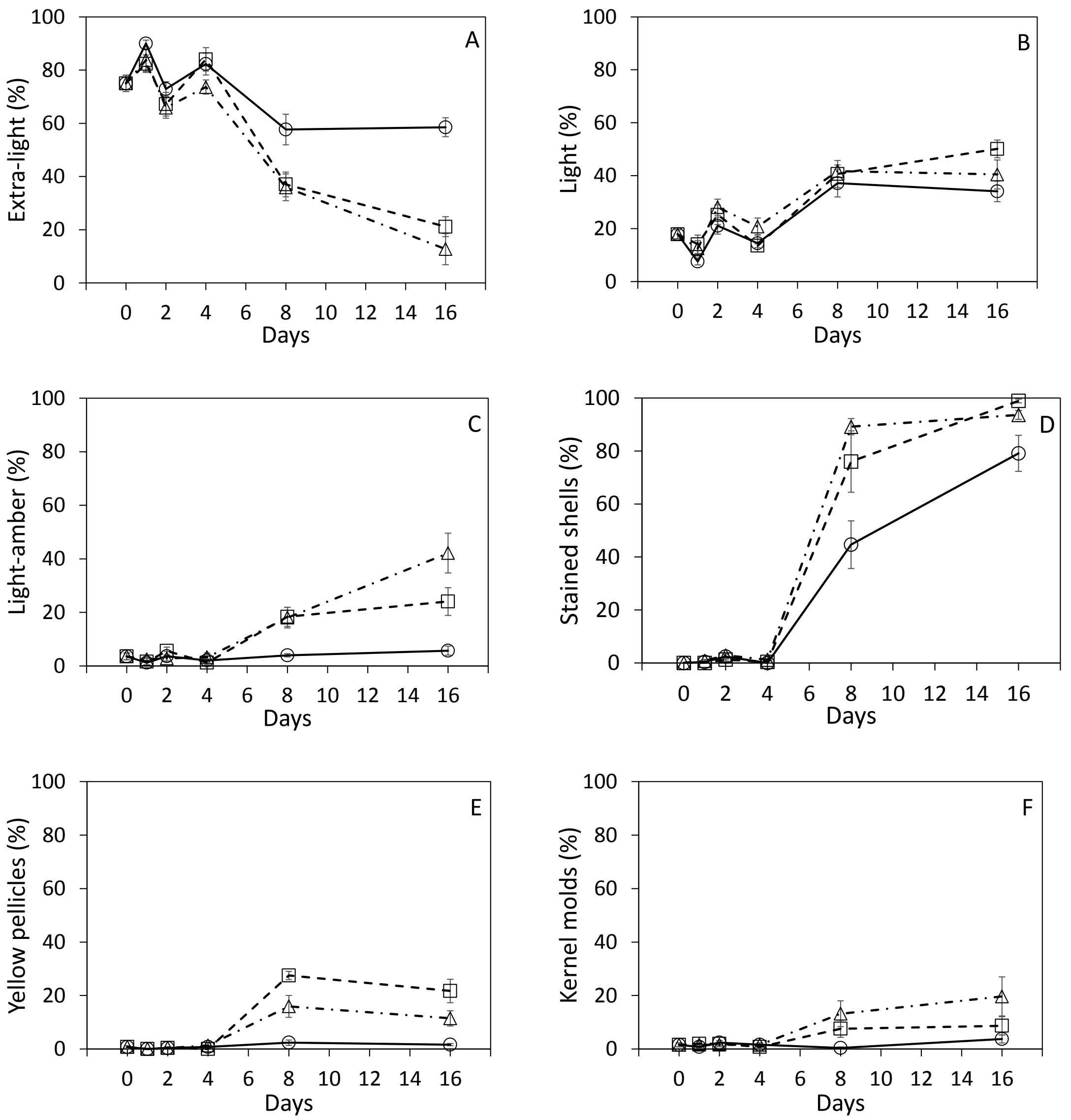

Figure 2. Mean percentage of Lara nuts with extra-light colour kernels (A), light kernels (B) light-amber kernels (C), stained shells (D), yellow pellicles (E) and kernel moulds (F) located on trees (circles, solid line), ground (squares, dashed line) and grass (triangles, dashed and dotted line) between shaking and harvesting from 0 to 16 days, at Swansea, Tasmania. Each data point represents the mean ± se of 5 replicates.

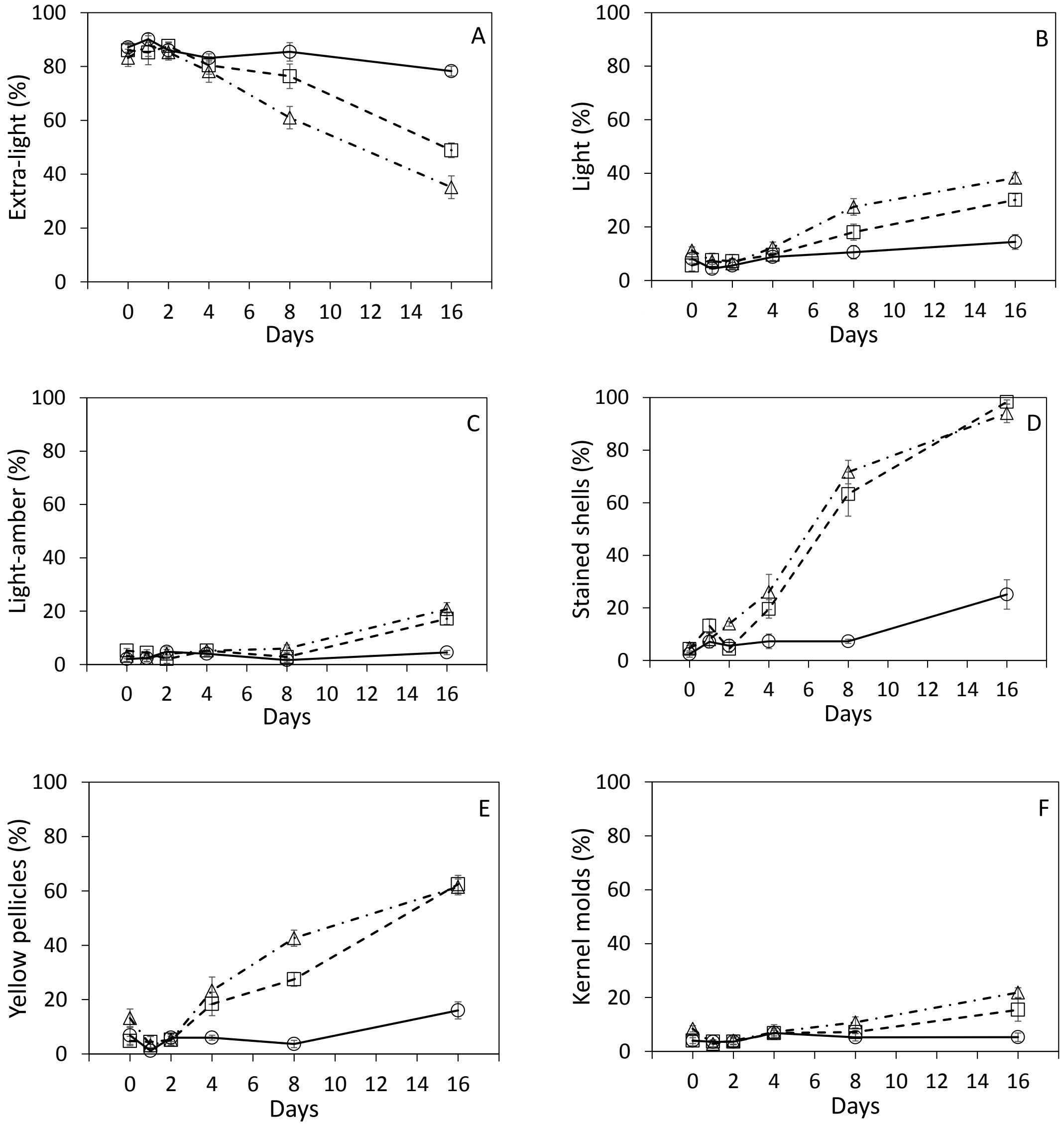

Figure 3. Mean percentage of Chandler nuts with extra-light colour kernels (A), light kernels (B) light-amber kernels (C), stained shells (D), yellow pellicles (E) and kernel moulds (F) located on trees (circles, solid line), ground (squares, dashed line) and grass (triangles, dashed and dotted line) between shaking and harvesting from 0 to 16 days, at Swansea, Tasmania. Each data point represents the mean ± se of 5 replicates.

Table 4. Rainfall, leaf wetness and mean ambient temperature per day for 0-16 days after harvest, and prior to drying, of Serr, Lara and Chandler nuts located on ground, grass and trees at Swansea, Tasmania.

Days[Z]	Serr		Lara		Chandler	
	Rainfall (mm)	Temperature (°C)	Rainfall (mm)	Temperature (°C)	Rainfall (mm)	Temperature (°C)
0-1	0	12.3	0	12.5	0	10.8
1-2	2	10.4	0	11.4	0	11.0
2-4	0	9.8	0	16.3	0	10.2
4-8	0	12.2	17	14.2	15	8.5
8-16	0	15.1	27	11.8	48	9.9
Total	2	12.0	44	13.2	63	10.1

[Z] Day 0 for Serr, Lara and Chandler was 21-Mar-12, 11-Apr-12 and 24-Apr-12 respectively

Goolgowi, NSW

Nuts that remained on the ground between shaking and harvest had lower quality than nuts that were positioned in trees, in Goolgowi, NSW.

In Chandler, ground located nuts had fewer extra-light and light colour kernels, and more light-amber and amber kernels than tree located nuts (Table 5). Nuts that were on the ground had three- to ten-fold more stained shells, yellow pellicles and kernel moulds than tree located nuts i.e., 47, 31 and 20% ground located nuts with stained shells, yellow pellicles and kernel moulds, respectively.

In Lara, ground positioned nuts had fewer extra-light and light coloured kernels than nuts on trees i.e., 48 and 43% respectively (Table 5). More kernel moulds were in ground positioned nuts than nuts on trees i.e., 24 and 19% respectively.

In Howard, nuts on dripper irrigated ground (wet ground) had fewer extra-light and light kernels, and more amber and mouldy kernels than nuts on non-irrigated ground (dry ground) and on trees (Table 5). Nuts on dry ground had similar quality to nuts on trees.

Table 5. Mean percent of nuts with extra-light and light, light-amber and amber coloured kernels, stained shells, yellow pellicles and kernel moulds according to location (tree, non-irrigated 'dry' ground and irrigated 'wet' ground) at Goolgowi, NSW. For each cultivar, means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Cultivar Treatment	Extra-light + light (%)		Light-amber (%)		Amber (%)		Stained shell (%)		Yellow pellicle (%)		Kernel mould (%)	
Chandler												
Tree	88.8	a	9.0	a	2.2	a	14.6	a	4.1	a	2.3	a
Ground	66.8	b	22.4	b	10.8	b	46.6	b	31.0	b	20.4	b
Lara												
Tree	48.3	a	46.5	a	4.9	a	5.5	a	1.3	a	18.7	a
Ground	42.7	b	51.2	a	5.7	a	5.8	a	1.5	a	23.6	b
Howard												
Tree	31.2	a	44.1	a	24.7	a	0.3	a	0.1	a	1.8	a
Dry ground	25.7	b	47.0	a	27.4	a	0.4	a	0.1	a	2.9	a
Wet ground	20.4	c	45.6	a	34.0	b	0.7	a	0.1	a	6.6	b

Delaying the harvest of nuts from the ground under trees reduced the quality of those nuts compared to nuts that remained on trees at Goolgowi, NSW.

In Chandler, a delay of 8 days and more reduced kernel colour of nuts i.e., from 78% extra-light and light kernels after 1 day to 20% after 16 days, 20-54% light-amber kernels after 8-16 days respectively, and 10-26% amber kernels after 8-16 days respectively (Figure 4). A delay of 8 days or more also increased the presence of stained shells, yellow pellicle and kernel moulds i.e., 9, 44 and 80% kernel moulds with 0, 8 and 16 days, respectively.

In Howard, nuts located on drip irrigated ground for 16 days had more kernel moulds than on non-irrigated ground and in trees i.e., 18, 4 and 2% respectively (Figure 5). Less than 4% of nuts on non-irrigated ground and in trees had kernel moulds, irrespective of the harvest day.

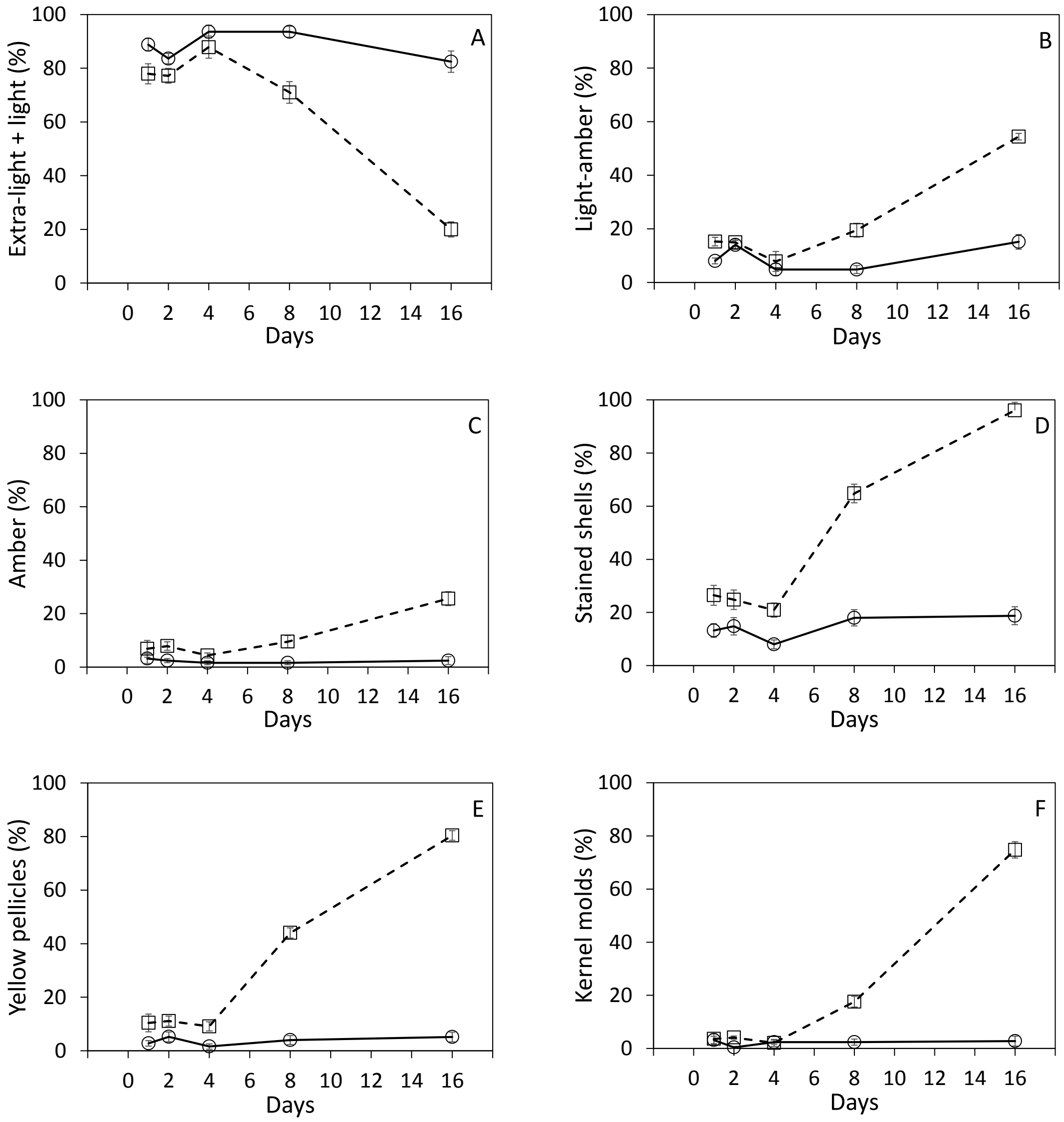

Figure 4. Mean percentage of Chandler nuts with extra-light and light colour kernels (A), (B) light-amber kernels (C), stained shells (D), yellow pellicles (E) and kernel moulds (F) located on trees (circles, solid line) and ground (squares, dashed line) between shaking and harvesting from 0 to 16 days, at Goolgowi, NSW. Each data point represents the mean ± se of 5 replicates.

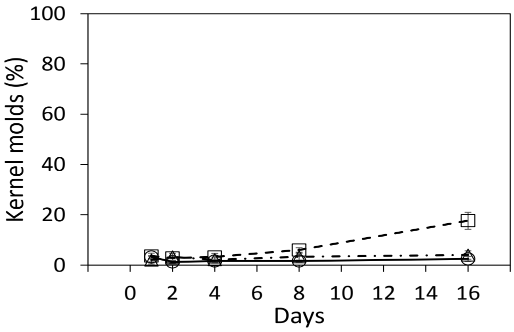

Figure 5. Mean percentage of Howard nuts with kernel moulds located on trees (circles, solid line) and ground (squares, dashed line) between shaking and harvesting from 0 to 16 days, at Goolgowi, NSW. Each data point represents the mean ± se of 5 replicates.

Weather conditions varied between Lara, Howard and Chandler in NSW.

No rainfall occurred in Chandler from 0-4 days, however, 14 mm was recorded from 5-8 days and 8 mm from 9-16 days (Table 6). Rainfall did not occur in Howard; however, the site ground was irrigated between 2 and 16 days i.e., 4 mm from 1-2 days, 5 mm from 2-4 days, 8 mm from 5-8 days and 5 mm from 9-16 days. Mean ambient temperature was higher in Howard than Chandler.

Table 6. Rainfall, irrigation and mean ambient temperature from 0 to 16 days after shaking and prior to harvest in Chandler and Howard trials sites at Goolgowi, NSW. Irrigation was applied at 1.0 mm/h for 2, 3 or 4 h. Day 0 was 10-Apr-2013 in Howard and 9-May-2013 in Chandler.

Days	Chandler rainfall (mm)	Chandler irrigation (mm)	Chandler temperature (ºC)	Howard rainfall (mm)	Howard irrigation (mm)	Howard temperature (ºC)
0-1	0	0	17	0	0	20
1-2	0	0	16	0	4	20
2-4	0	0	18	0	5	22
4-8	14	0	11	0	8	15
8-16	8	0	11	0	5	14
Total	22	0	15	0	22	18

5.2.2 STORAGE TEMPERATURES BETWEEN HULLING AND DRYING

Storing nuts at 20ºC between hulling and drying reduced the quality of nuts compared to storage at 5ºC.

In Lara, nuts stored at 20ºC had fewer extra-light and light kernels than storage at 5ºC (69 and 83% respectively) and more light-amber kernels in comparison to 5ºC (21 and 15% respectively) (Table 7). Nuts stored at 20ºC also had a three-fold increase in stained shells (21 and 7% respectively) and a four-fold increase in yellow pellicles (23 and 6% respectively) compared to nuts stored at 5ºC.

In Chandler, more nuts had yellow pellicles and kernel moulds after storage at 20ºC than at 5ºC i.e., 65 and 50% yellow pellicle, and 43 and 19% kernel mould, respectively (Table 7). A near two-fold increase in amber kernels occurred at 20ºC than 5ºC i.e., 20 and 9% respectively.

Table 7. Mean percentage of Lara and Chandler nuts, pooled from all sampling dates, with extra-light and light, light-amber and amber colour kernels, yellow pellicles, stained shells and kernel moulds according to temperature (20ºC and 5ºC) at Swansea, Tasmania. For each cultivar, means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Temperature	Extra-light + light (%)		Light-amber (%)		Amber (%)		Stained shell (%)		Yellow pellicle (%)		Kernel mould (%)	
Lara												
20ºC	68.9	a	21.1	a	10.1	a	21.1	a	22.9	a	16.9	a
5ºC	82.5	b	15.1	b	2.3	a	7.3	b	5.5	b	3.9	a
Chandler												
20ºC	45.5	a	34.5	a	19.5	a	80.3	a	64.5	a	42.8	a
5ºC	55.5	a	33.5	a	9.3	b	77.8	a	50.0	b	19.3	b

Nut quality in Lara and Chandler was reduced with 4 days or more of storage at 20ºC.

In Lara, kernel colour degraded between 2 and 16 days with storage at 20ºC i.e., from 91 to 7% nuts after 2 and 16 days respectively; in contrast, kernel colour was maintained until at least 8 days with storage at 5ºC (Figure 6). Nuts stored at 20ºC had more light-amber and amber coloured kernels after 4 and 16 days, respectively. Less than 6% of nuts had amber kernels with 5ºC storage.

The presence of stained shells, yellow pellicles and kernel moulds in nuts increased after 4 days storage at 20ºC, with 60% stained shells, 82% yellow pellicles and 62% kernel moulds after 16 days (Figure 6). At 5ºC, less than 1% of nuts had yellow pellicle or kernel mould after 8 days.

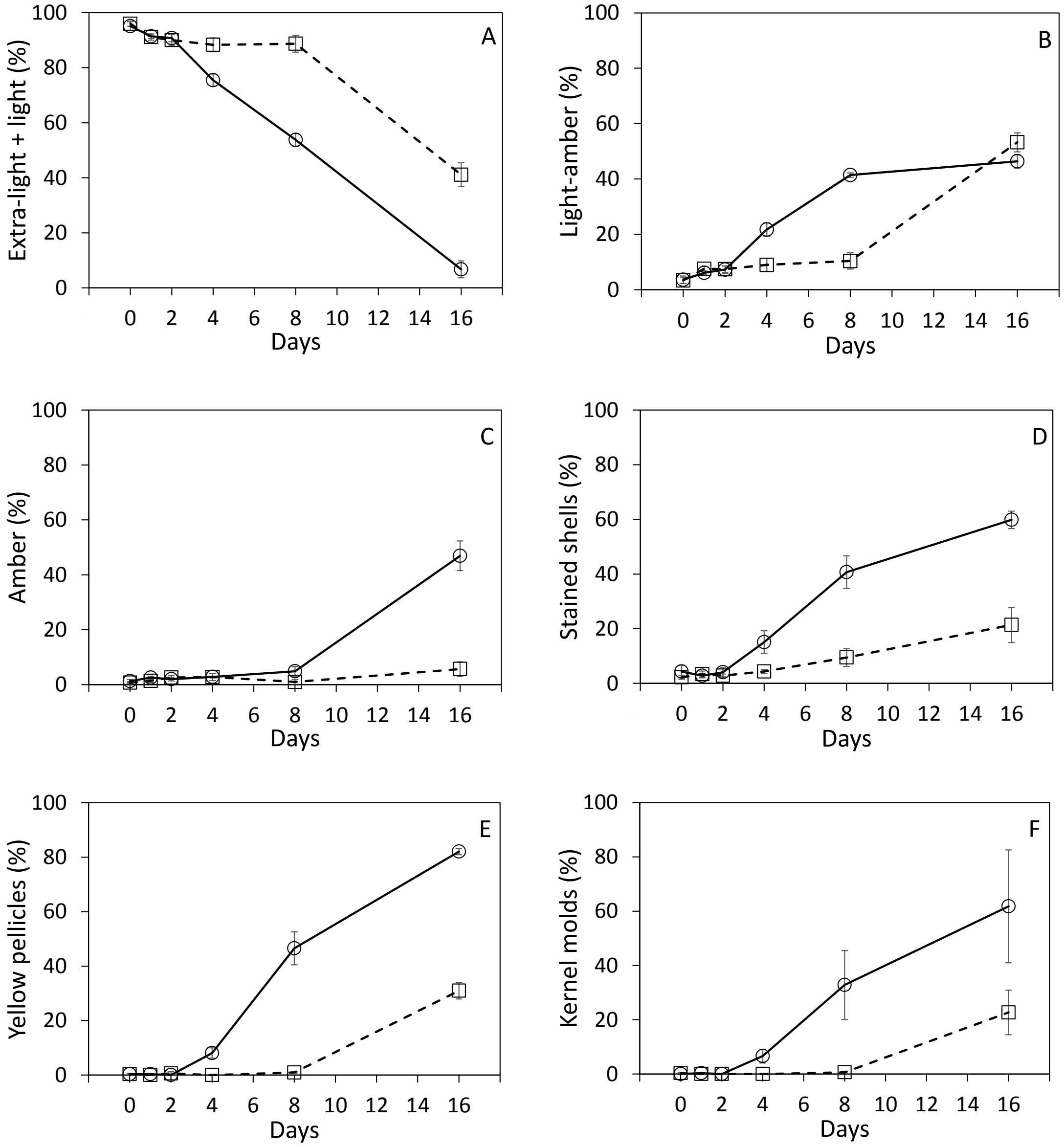

Figure 6. Mean percentage of Lara nuts with extra-light and light colour kernels (A), light-amber kernels (B) amber kernels (C), stained shells (D), yellow pellicles (E) and kernel moulds (F) after storage at 5ºC (squares, dashed line) and 20ºC (circles, solid line) between hulling and drying from 0 to 16 days. Each data point represents the mean ± se of 4 replicates.

In Chandler, kernel colour degraded in nuts stored at 20ºC after 4 days, or more i.e., from 66 to 3% extra-light and light kernels after 2 and 16 days respectively, and from 15 to 47% amber kernels after 6 and 16 days, respectively (Figure 7). Kernel colour was maintained when stored at 5ºC, irrespective of the duration of storage.

At 20ºC, yellow pellicles and kernel moulds increased after 2 and 6 days storage, respectively, with 90% or more of nuts with yellow pellicles and kernel moulds after 16 days (Figure 7). The rate of increase of yellow pellicles and kernel moulds was more gradual at 5ºC than 20ºC, with 87% yellow pellicles and 33% kernel moulds at 16 days.

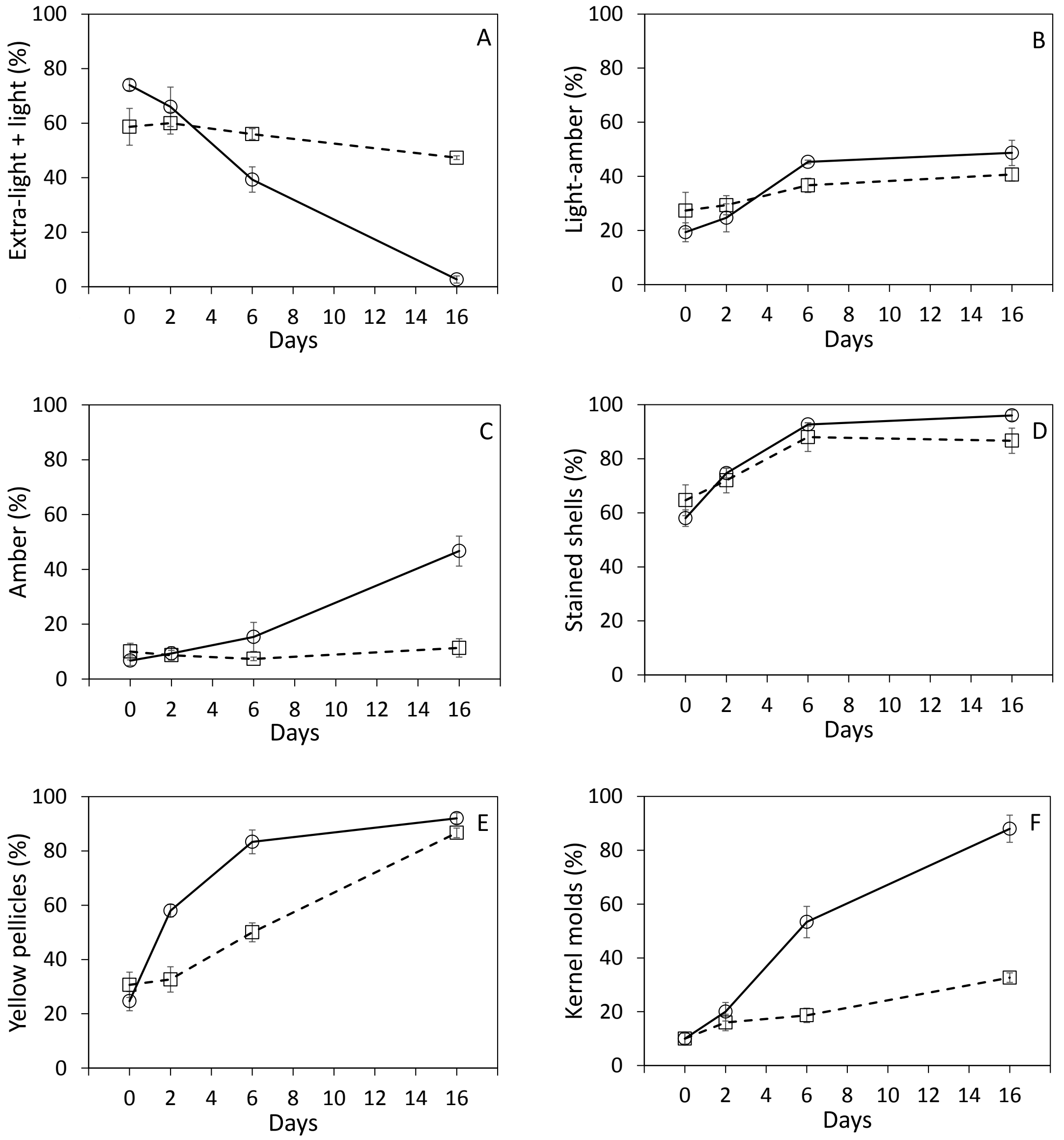

Figure 7. Mean percentage of Chandler nuts with extra-light and light colour kernels (A), light-amber kernels (B) amber kernels (C), stained shells (D), yellow pellicles (E) and kernel moulds (F) after storage at 5ºC (squares, dashed line) and 20ºC (circles, solid line) between hulling and drying from 0 to 16 days. Each data point represents the mean ± se of 3 replicates.

5.2.3 Storage of fruit and nuts between harvesting and hulling

Nut quality of Vina reduced with 24 and 48 h storage, in shipping or ‘storage’ containers, between harvesting and hulling.

Kernel colour degraded with storage time, from at least 55% extra-light and light kernels with 0 h storage to less than 37% with 24 or 48 h storage (Table 8). A two- and three-fold increase in amber kernels occurred with storage from 0 to 24 h (9 and 17% respectively) and from 0 to 48 h storage (6 and 17% respectively). The presence of stained shells increased markedly after 24 h and 48 h, from less than 32% after 0 h to more than 79% with 24 or 48 h storage.

Temperature within containers was greater than ambient, irrespective of the duration and timing of storage, and increased irrespective of ambient temperature (Figure 8). The maximum temperature in containers was 32 and 40°C, with 24 and 48 h storage respectively. Temperatures of 20°C or more occurred in containers for 24 and 36 h, with 24 and 48 h storage respectively.

Table 8. Mean percentage of Vina nuts with extra-light and light, light-amber and amber colour kernels, stained shells, yellow pellicles and kernel moulds with storage in containers between harvesting and hulling for 24 and 48 h at Swansea, Tasmania. For each time interval, means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Storage duration	Extra-light + light (%)	Light-amber (%)	Amber (%)	Stained shell (%)	Yellow pellicle (%)	Kernel mould (%)
0-24 h						
0	55.3 a	35.3 a	9.3 a	32.0 a	18.0 a	3.3 a
24	36.7 b	46.7 b	16.7 b	79.3 b	34.0 a	6.0 a
0-48 h						
0	66.7 a	27.3 a	6.0 a	9.3 a	12.0 a	2.0 a
48	37.3 b	46.0 a	16.7 b	88.0 b	19.3 a	3.3 a

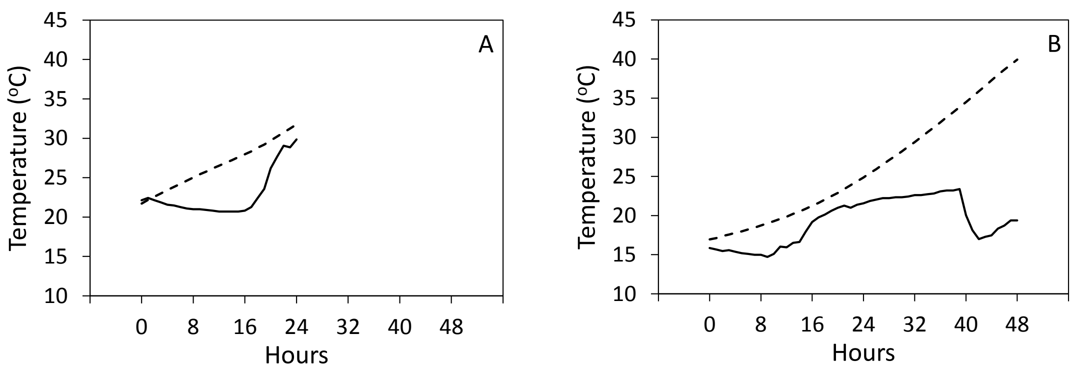

Figure 8. Ambient temperature (solid line) and mean temperature of Vina fruit within shipping ‘storage’ containers (dashed line) between harvesting and hulling for 24 h (A) and 48 h (B) at Swansea, Tasmania.

5.2.4 *STORAGE OF NUTS ONLY BETWEEN HULLING AND DRYING*

Storage of nuts between hulling and drying reduced nut quality in Vina and Lara.

In Vina less than 63% of nuts had extra-light and light kernels, and greater than 30% had light amber kernels, with 24 h or more storage; in comparison, 86% of nuts had extra-light and light kernels after 0 h (Table 9). Kernel moulds greatly increased with each time interval i.e., 0, 18 and 32% with 0, 24 and 48 h storage respectively. The incidence of yellow pellicle was greater after 48 h than 0 h.

In Lara 92% of nuts had extra-light and light kernels with no storage, compared to 72% after 48 h (Table 9). Stored nuts had a six-fold increase in light amber kernels (4 and 24% after 0 and 48 h respectively) and more amber nuts with 48 h storage than with 0 h.

Storage of Howard caused minimal loss of quality, with only a small increase in yellow pellicle after 48 h (Table 9). In Howard, a near 90% or more of nuts had extra-light and light kernels, irrespective of the duration of storage.

Nut quality in Chandler was not affected with storage, with a near 100% having extra-light and light kernels (Table 9).

Table 9. Mean percentage of nuts with extra-light and light, light-amber and amber colour kernels, stained shells, yellow pellicles and kernel moulds with storage in storage bins between hulling and drying for 24 and 48 h at Swansea, Tasmania. For each cultivar, means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Storage duration (h)	Extra-light + light (%)		Light-amber (%)		Amber (%)		Stained shell (%)		Yellow pellicle (%)		Kernel mould (%)	
Vina												
0	86.0	a	12.7	a	1.3	a	6.7	a	9.3	a	7.3	a
24	62.7	b	31.3	b	6.0	ab	18.0	a	12.7	a	18.0	b
48	60.0	b	30.0	b	10.0	b	10.0	a	29.3	b	32.0	c
Lara												
0	92.0	a	6.0	a	2.0	a	7.3	a	2.0	a	0.7	a
48	72.0	b	24.0	b	4.0	b	14.0	a	2.0	a	2.0	a
Howard												
0	93.0	a	5.7	a	1.3	a	2.7	a	1.3	a	1.3	a
24	91.3	a	8.7	a	0	a	9.3	a	3.3	a	4.0	a
48	89.3	a	9.3	a	1.3	a	10.7	a	9.3	b	5.3	a
Chandler												
0	98.9	a	0.9	a	0.2	a	2.0	a	2.7	a	0.2	a
48	99.3	a	0.4	a	0.2	a	6.0	a	4.7	a	0.2	a

Temperatures within storage bins had higher minimums and lower maximums than ambient (e.g., see Figure 9). Storage and ambient temperatures were highest in Vina (34 and 35ºC respectively) and lowest in Chandler (19 and 23ºC respectively) (Table 10). Temperatures of 20ºC or more occurred for longer in storage than ambient in all cultivars except Chandler, where storage temperature was below 20ºC.

In Vina, temperature increased 7°C with 24 h storage (20-27°C) and 17°C with 48 h (17-34°C) (Table 10). Temperatures at 20°C or more were greater with storage than ambient after 24 h (24 and 9 h respectively) and 48 h (34 and 32 h respectively).

In Lara, temperature within storage increased 10°C (15-25°C), although temperature range was greater in ambient (2-31°C) (Table 10). Temperatures at 20°C or more were greater with storage than ambient (21 and 14 h respectively).

In Howard, temperature increased 9°C with 24 h storage (15-24°C) and 14°C with 48 h (12-26°C) (Table 10). Temperatures at 20°C or more were greater with storage than ambient after 24 h (13 and 6 h respectively) and 48 h (19 and 8 h respectively).

In Chandler, temperature with 48 h storage increased 6°C (13-19°C) (Table 10). Ambient temperature ranged from 0-23°C with 28 h at temperatures of 20°C or more. Storage temperature did not reach 20°C or more in Chandler.

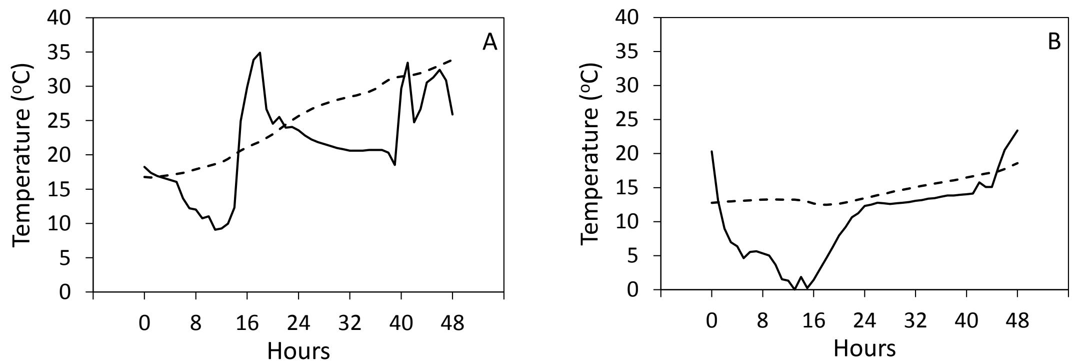

Figure 9. Ambient temperature (solid line) and temperature in storage bins (dashed line) containing Vina (A) and Chandler (B) nuts between hulling and drying from 0 to 48 h.

Table 10. Minimum, maximum and mean temperature, and the number of hours at 20°C or more, in storage bins containing nuts between hulling and drying for 24 and 48 h, and corresponding ambient temperatures.

Cultivar	Storage duration (h)	Storage bins min (°C)	Storage bins max (°C)	Storage bins mean (°C)	Storage bins hours ≥ 20°C	Ambient min (°C)	Ambient max (°C)	Ambient mean (°C)	Ambient hours ≥ 20°C
Vina	0-24	19.9	27.3	22.6	24	14.5	31.7	20.2	9
Vina	0-48	16.6	33.9	24.8	34	7.9	35.0	21.5	32
Lara	0-48	15.3	24.9	19.6	21	1.7	31.3	15.4	14
Howard	0-24	14.8	23.9	19.9	13	14.4	27.4	19.5	6
Howard	0-48	12.0	26.1	18.3	19	3.6	27.4	15.0	8
Chandler	0-48	12.5	18.6	14.4	0	-0.3	23.4	10.2	28

5.2.5 *VENTILATED STORAGE BETWEEN HULLING AND DRYING*

The quality of nuts stored with ventilation was no better than storage without ventilation with a near 100% with extra-light or light kernels and less than 15, 7 and 2% with stained shells, yellow pellicles and kernel moulds respectively (data not presented).

Ambient temperature ranged from 10-31°C, with 7 h at 20°C or more (Fig. 10). Temperature in non-ventilated storage increased by 13°C from 0-48 h (14-27°C), in contrast to ventilated storage where temperatures reduced by 3°C (14-11°C) from 0 to 16 h and increased by 1°C (17-18°C) from 30 to 40 h. For the same 0-16 h and 30-40 h periods, temperatures in non-ventilated storage increased by 2°C (14-16°C) and 3°C (20-23°C) respectively. Temperatures at 20°C or more occurred for longer with non-ventilation than ventilation i.e., 19 and 1 h respectively.

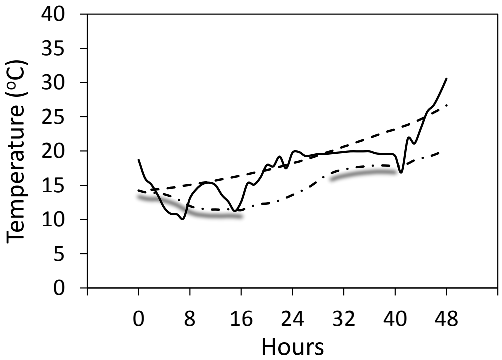

Figure 10. Ambient temperature (solid line) and temperature in non-ventilated (dashed line) and ventilated (dashed and dotted line) storage bins containing Chandler nuts between hulling and drying from 0 to 48 h. The ventilated storage bin was operated from 0-16 h and 30-40 h (shadow lines).

5.3 Efficacy and crop safety of ethephon in major walnut cultivars

5.3.1. *ETHEPHON RATES – EFFICACY, CROP SAFETY AND NUT QUALITY*

Ethephon at higher rates increased hull dehiscence and nut drop, and premature leaf chlorosis and leaf drop, compared to non-treatment.

In Serr (NSW – 2012) at least 87% of fruits were hullable 7 days after ethephon treatment compared to 62% with non-treatment (Table 11). At the two highest rates, more than 98% of fruits were hullable within 7 days. All fruits were hullable within 15 days of 100% PTB. Leaf chlorosis and leaf drop was greater i.e., 64% and 79% respectively with the highest rate of ethephon, than with lower rates and non-treatment.

In Serr (NSW – 2013) a near 100% of fruits were hullable, and more than 96% of nuts dropped from trees within 12 days of ethephon treatment at the two highest rates; in comparison, less than 93% were hullable with the lower rate or non-treatment (Table 12). Leaf chlorosis was greatest with the highest rate of ethephon, although less than 9% of leaves were chlorotic, irrespective of treatment.

In Howard (NSW – 2013) more than 95% of ethephon treated fruits were hullable after 8 days, compared to 81% of non-treated fruits (Table 13). Nut drop was greater with ethephon than non-treatment i.e., ≥ 96% and 89% respectively. More leaf drop occurred with the highest rate of ethephon (13%) than with lower rates and non-treatment.

In Lara (NSW – 2012) a near 90% of fruits treated with ethephon were hullable within 7 days of treatment; in contrast, only 56% of non-treated fruits were hullable (Table 14). Within 13 days more than 97% of all fruits were hullable. Leaf chlorosis increased with ethephon rate, from 2 to 71% respectively, with leaf drop greater at the highest rate.

In Lara (TAS – 2012) 94% of non-treated fruits were hullable 8 days after PTB; however, significantly more fruits were hullable with ethephon-treatment (Table 15). Leaf chlorosis was higher with ethephon i.e., 43 to 87% of the canopy with lowest to highest ethephon rates respectively, than with non-treatment.

Ethephon did not reduce nut quality i.e., kernel colour, kernel weight and nut weight, compared to non-treatment (data not presented). Mean extra-light and light kernel colour on nuts was 49% in Serr (NSW – 2012), 80% in Serr (NSW – 2013), 85% in Howard (NSW – 2013), 88% in Lara (NSW – 2012) and 98% in Lara (TAS – 2012). Mean nut and kernel weights were 13.1 and 7.0 g respectively in Serr (NSW – 2012), 11.0 and 6.3 g in Serr (NSW – 2013), 11.3 and 5.5 g in Howard (NSW – 2013), 15.1 and 6.7 g in Lara (NSW – 2012) and 13.5 and 6.3 g in Lara (TAS – 2012).

Table 11. Mean percentage of Serr with hullable fruits, leaf chlorosis and premature leaf drop 7 and 15 days after application (DAA) of Ethrel® 720 (720 g/L ethephon) at Leeton, NSW. Treatments were applied on 16-Feb-12 at 100% PTB. Mean percentage hullable fruits at the time of treatment were 12% ± 3.6 se. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Hullable fruits 7 DAA (%)	Hullable fruits 15 DAA (%)	Leaf chlorosis 7 DAA (%)	Leaf drop 15 DAA (%)
0	-	62.4 a	100 a	0 a	0.3 a
60	0	87.2 b	100 a	0.9 a	7.0 ab
100	0	97.6 c	100 a	7.3 a	16.6 b
200	0	100 c	100 a	63.9 b	79.0 c

Table 12. Mean percentage of Serr with hullable fruits, nut drop and leaf chlorosis 12 days after application (DAA) of Galleon® 720 (720 g/L ethephon) at Leeton, NSW. Treatments were applied on 20-Feb-13, 11 days after 100% PTB. Mean percentage hullable fruits at the time of treatment were 10% ± 1.6 se. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Hullable fruits 12 DAA (%)	Nut drop 12 DAA (%)	Leaf chlorosis 12 DAA (%)
0	-	89.4 a	93.5 ab	0 a
60	11	93.0 a	92.3 a	0 a
100	11	98.5 b	96.1 bc	2.0 a
200	11	99.1 b	98.6 c	9.0 b

Table 13. Mean percentage of Howard with hullable fruits, nut drop and leaf chlorosis 8 days after application (DAA) of Promote® 720 (720 g/L ethephon) at Leeton, NSW. Treatments were applied on 15-Mar-13, 10 days after 100% PTB. Mean percent hullable fruits at the time of treatment were 13% ± 1.6 se. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Hullable fruits 8 DAA (%)	Nut drop 8 DAA (%)	Leaf chlorosis 8 DAA (%)
0	-	80.8 a	88.9 a	0 a
60	10	95.2 b	96.0 b	0 a
100	10	99.6 b	96.8 b	3.0 a
200	10	100.0 b	98.5 b	12.5 b

Table 14. Mean percentage of Lara with hullable fruits, leaf chlorosis and premature leaf drop 7 and 13 days after application (DAA) of Ethrel® 720 (720 g/L ethephon) at Leeton, NSW. Treatments were applied on 24-Feb-12 at 100% PTB. Mean percent hullable fruits at the time of treatment were 26% ± 5.9 se. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Hullable fruits		Leaf chlorosis	Leaf drop
		7 DAA (%)	13 DAA (%)	7 DAA (%)	13 DAA (%)
0	-	56.5 a	96.6 a	0.0 a	0.0 a
60	0	89.6 b	97.6 a	2.1 b	0.6 a
100	0	88.7 b	96.7 a	16.6 c	5.7 a
200	0	92.8 b	100.0 a	70.7 d	42.7 b

Table 15. Mean percentage of Lara with hullable fruits and premature leaf drop 8 days after application (DAA) of Ethrel® 720 (720 g/L ethephon) at Swansea, Tasmania. Treatments were applied on 26-Mar-12 at 100% PTB. Mean percent hullable fruits at the time of treatment were 54% ± 7.9 se Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Hullable fruits 8 DAA (%)	Leaf chlorosis 8 DAA (%)
0	-	93.6 a	12.0 a
60	0	99.2 b	42.7 b
100	0	100 b	67.1 c
200	0	100 b	87.1 d

5.3.2 ETHEPHON TIMING – EFFICACY, CROP SAFETY AND NUT QUALITY

Ethephon applied at, or soon after, PTB increased hull dehiscence and nut drop, and premature leaf chlorosis and leaf drop, compared to later applications or non-treatment. Delayed harvest reduced nut quality compared to earlier harvest in all treatments.

In Howard (NSW – 2013) nearly all fruits were hullable, and 97% of nuts dropped with mechanical shaking of trees, with ethephon sprays that were applied at, or 10 days after 100% PTB (Table 21); in contrast, only 81% of fruits were hullable, and 89% fruits dropped with non-treatment. Leaf chlorosis was less than 3% of the tree canopy, irrespective of treatment.

Nut quality in Howard (NSW – 2013) declined with ethephon applied at 100% PTB, compared to later application and non-treatment (Table 22). Earlier treatment had fewer extra-light and light kernels than later treatment (65 and 88% respectively) and more light-amber kernels (29 and 7% respectively). The timing of ethephon sprays and harvesting did not reduce nut and kernel weight, compared to non-treatment.

In Serr (NSW – 2014) a near 100% of fruits were hullable, and 96% of nuts dropped, within 7 days of ethephon sprays that were applied 5 days after 100% PTB; in comparison, 57% of fruits were hullable with non-treatment (Table 23). Within 20 days of PTB, all ethephon treated fruits were hullable and 98% of nuts had dropped, compared to 93% and 96% respectively, with non-treatment. More leaf chlorosis and leaf drop occurred with ethephon than with non-treatment, and was greatest when ethephon was applied 12 days after 100% PTB i.e., 10 and 25% leaf chlorosis and leaf drop respectively.

Nut quality in Serr (NSW – 2014) was greater 12 days after PTB than after 20 days i.e., 80-85% and 51-64% extra-light and light kernels respectively, and 11-14% and 26-40% light-amber kernels respectively (Table 24). Ethephon reduced nut quality after 20 days compared to non-treatment, with fewer extra-light and light kernels (51-52 and 64% respectively) and more light-amber kernels (38-40 and 26% respectively). The timing of ethephon treatment did not affect nut quality when nuts were harvested 20 days after PTB. Nut and kernel weight were not adversely affected with ethephon sprays.

In Vina (NSW – 2014) all fruits were hullable, and a near 100% of nuts dropped, within 7 days of ethephon sprays that were applied 2 days after 100% PTB (Table 25). Nearly all fruits were hullable and dropped, with mechanical shaking of trees, 20 days after PTB, irrespective of treatment. Leaf chlorosis occurred with ethephon treatment i.e., 8 and 0% with ethephon and non-treatment respectively.

Nut quality in Vina (NSW – 2014) was greater 10 days after PTB than after 20 days i.e., 51-59% and 27-35% extra-light and light kernels respectively, and 1-7% and 12-15% amber kernels respectively (Table 26). The timing of ethephon sprays and harvesting did not affect kernel colour and nut and kernel weight, compared to non-treatment.

Table 21. Mean percentage of Howard at Leeton, NSW, with hullable fruits, nut drop and leaf chlorosis with application of Promote® 720 (720 g/L ethephon). Treatments were applied on 5-Mar-13 or 15-Mar-13, at 100% PTB or 10 days later respectively. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Hullable fruits (%)	Nut drop (%)	Leaf chlorosis (%)
0	-	18	80.8 a	88.9 a	0 a
100	0	18	100 b	96.8 b	0 a
100	10	18	99.6 b	96.8 b	3.0 b

Table 22. Mean percentage of Howard nuts at Leeton, NSW, with extra-light and light, light-amber and amber colour kernels, and nut and kernel weights with application of Promote® 720 (720 g/L ethephon). Treatments were applied on 5-Mar-13 or 15-Mar-13, at 100% PTB or 10 days later respectively. Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Extra-light + light (%)	Light-amber (%)	Amber (%)	Nut weight (g)	Kernel weight (g)
0	-	18	81.9 a	12.9 a	4.8 a	10.8 a	5.3 a
100	0	18	65.3 b	28.8 b	5.7 a	10.8 a	5.0 a
100	10	18	87.6 a	6.8 a	5.2 a	11.7 a	5.7 a

Table 23. Mean percentage of Serr at Leeton, NSW, with hullable fruits, nut drop, leaf chlorosis and leaf drop with Ethephon® 720 (720 g/L ethephon) application on 20-Feb-14 and 27-Feb-14, 5 and 12 days after 100% PTB. Nuts were harvested on 27-Feb-14 and 7-Mar-14, 12 and 20 days after 100% PTB (DAPTB). Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Hullable fruits (%) [Z]		Nut drop (%) [Z]		Leaf chlorosis (%) [Z]		Leaf drop (%) [Z]	
			12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB
0	0	20	56.8 a	92.9 a	- -	96.0 a	0 a	0.5 a	0 a	1.0 a
100	5	20	99.6 b	100 b	- -	98.4 b	10.5 b	1.0 a	2.5 b	9.0 b
100	5	12 and 20	98.4 b	100 b	95.5 -	99.6 c	10.5 b	1.0 a	2.5 b	11.0 b
100	12	20	66.8 a	100 b	- -	99.6 c	0 a	10.0 b	0 a	25.0 c

[Z] A dash indicates that data for that treatment were not collected for that time interval.

Table 24. Mean percentage of Serr nuts at Leeton, NSW, with extra-light and light, light-amber and amber colour kernels, and nut and kernel weights with Ethephon® 720 (720 g/L ethephon) application on 20-Feb-14 and 27-Feb-14, 5 and 12 days after 100% PTB. Nuts were harvested on 27-Feb-14 and 7-Mar-14, 12 and 20 days after 100% PTB (DAPTB). Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Extra-light + light (%) [Z]		Light amber (%) [Z]		Amber (%) [Z]		Nut weight (g) [Z]		Kernel weight (g) [Z]	
			12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB	12 DAPTB	20 DAPTB
0	0	20	84.6 a	63.6 a	12.3 a	26.4 a	3.2 a	10.1 a	12.2 a	11.8 a	7.0 a	6.8 a
100	5	20	81.9 a	50.6 b	11.3 a	40.1 b	6.9 b	9.2 a	12.5 a	12.4 b	7.0 a	7.0 a
100	5	12 and 20	79.7 a	- -	11.8 a	- -	8.5 b	- -	12.4 a	- -	7.0 a	- -
100	12	20	83.1 a	52.2 b	13.9 a	37.7 b	3.1 a	10.1 a	12.3 a	12.3 ab	7.1 a	7.1 a

[Z] A dash indicates that data for that treatment were not collected for that time interval.

Table 25. Mean percentage of Vina at Leeton, NSW, with hullable fruits, nut drop, leaf chlorosis and leaf drop with Ethephon® 720 (720 g/L ethephon) application on 15-Mar-14 and 23-Mar-14, 2 and 10 days after 100% PTB (13-Mar-14). Nuts were harvested on 23-Mar-14 and 31-Mar-14, 10 and 20 days after 100% PTB (DAPTB). Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Hullable fruits (%) [Z]				Nut drop (%) [Z]				Leaf chlorosis (%) [Z]				Leaf drop (%) [Z]			
			10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB	
0	0	20	97.6	a	97.6	a	-	-	98.1	a	0	a	-		0	-	-	
100	2	20	100	b	100	b	-	-	99.8	b	8.0	b	-		0	-	-	
100	2	10 and 20	100	b	100	b	99.2	-	100	b	8.0	b	-		0	-	-	
100	10	20	96.0	a	96.1	a	-	-	99.3	ab	0	a	-		0	-	-	

[Z] A dash indicates that data for that treatment were not collected for that time interval.

Table 26. Mean percentage of Vina nuts at Leeton, NSW, with extra-light and light, light-amber and amber colour kernels, and nut and kernel weights with Ethephon® 720 (720 g/L ethephon) application on 15-Mar-14 and 23-Mar-14, 2 and 10 days after 100% PTB (13-Mar-14). Nuts were harvested on 23-Mar-14 and 31-Mar-14, 10 and 20 days after 100% PTB (DAPTB). Means within each column accompanied by the same letter are not significantly different at *P* = 0.05.

Product rate (ml/100 l)	Spray timing (days after 100% PTB)	Harvest timing (days after 100% PTB)	Extra-light + light (%) [Z]				Light amber (%) [Z]				Amber (%) [Z]				Nut weight (g) [Z]				Kernel weight (g) [Z]			
			10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB		10 DAPTB		20 DAPTB	
0	0	20	51.4	a	31.4	a	45.8	a	56.5	a	2.9	a	12.1	b	13.6	a	12.7	a	6.6	a	5.9	a
100	2	20	55.0	a	34.9	a	43.8	a	49.9	a	1.2	a	15.2	b	13.8	a	12.5	a	6.8	a	5.8	a
100	2	10 and 20	58.7	a	-	-	37.3	a	-	-	4.0	a	-	-	13.9	a	-	-	6.8	a	-	-
100	10	20	51.7	a	26.6	a	40.8	a	58.6	a	7.4	b	14.8	b	13.7	a	13.1	ab	6.7	a	6.1	a

[Z] A dash indicates that data for that treatment were not collected for that time interval.

5.3.3 *CROP SAFETY – MULTIPLE YEARS USE OF ETHEPHON*

The size and weight of nuts from trees that had ethephon applied in 2012, 2013 and 2014 were not less than those nuts from non-treated trees (Figure 11). Nut size and weight, however, were less in 2013 than other years.

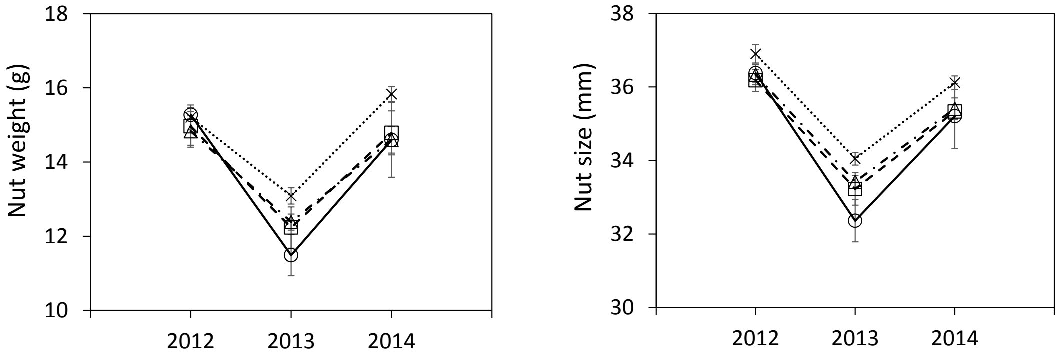

Figure 11. Mean weight and size of Lara nuts after application of 720 g/l ethephon at 60 ml/100 l (square, dashed line), 100 ml/100 l (triangle, dashed and dotted line) and 200 ml/100 l (cross, dotted line), and with non-treatment (circle, solid line) at Leeton (NSW) in 2012, 2013 and 2014. Treatments were applied at 100% PTB at spray volume of 2000 l/ha. Each data point represents the mean ± se of 5 replicates.

5.4 Ethephon residue in walnut kernels

Ethephon concentration in walnut kernels from NSW were below the MRL of 2.0 mg/kg, irrespective of the time after treatment or whether walnuts were treated with ethephon or not (Fig. 12). Non-treated walnuts had less than 0.01 mg/kg of ethephon in kernels, irrespective of the time from kernel maturity.

In Tasmania, walnuts treated with ethephon at 60 and 100 ml/100 l had concentrations below the MRL of 2.0 mg/kg (Fig. 13). At 200 ml/100 l, ethephon concentration was above 2.0 mg/kg after 3 and 7 days; however, ethephon rapidly degraded from 5.6 mg/kg at 3 days to be below 2.0 mg/kg within 14 days. Non-treated walnuts had less than 0.01 mg/kg of ethephon in kernels, irrespective of the time from kernel maturity.

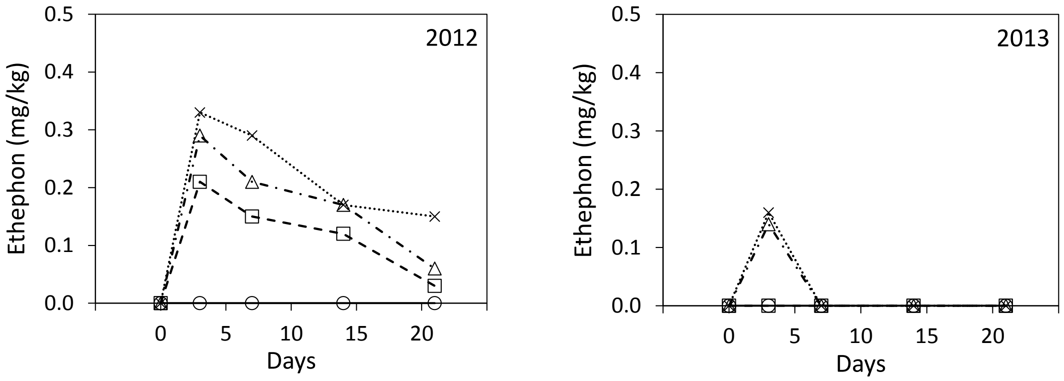

Figure 12. Concentration of ethephon (mg/kg) in walnut kernels 0, 3, 7, 14 and 21 days after application of 720 g/l ethephon at 60 ml/100 l (square, dashed line), 100 ml/100 l (triangle, dashed and dotted line) and 200 ml/100 l (cross, dotted line), and with non-treatment (circle, solid line) at Leeton (NSW) in 2012 and 2013. Treatments were applied at 100% PTB on 24-Feb-12 and 19-Mar-13 at a spray volume of 2000 l/ha.

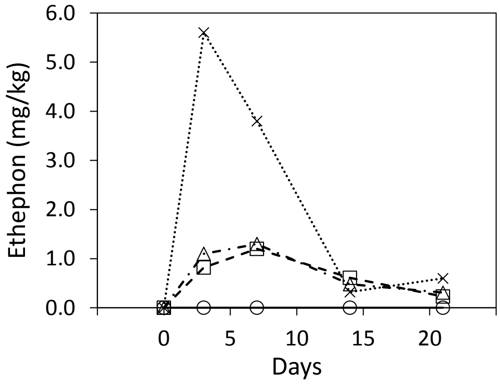

Figure 13. Concentration of ethephon (mg/kg) in walnut kernels 0, 3, 7, 14 and 21 days after application of 720 g/l ethephon at 60 ml/100 l (square, dashed line), 100 ml/100 l (triangle, dashed and dotted line) and 200 ml/100 l (cross, dotted line), and with non-treatment (circle, solid line) at Swansea, Tasmania, in 2012. Treatments were applied at 100% PTB on 26-Mar-12 at a spray volume of 2000 l/ha.

6. DISCUSSION

This study describes the temporal development of kernel and hull maturity of the Californian cultivars, Serr, Vina, Howard and Chandler, and the French cultivar, Lara, in semi-arid and temperate climates of Australia. The timing of kernel and hull maturity was earlier in the semi-arid climate of NSW, than in the temperate climate of Tasmania, with the progression of kernel and hull maturity distinct between early (Serr), mid (Vina, Lara, Howard) and later (Chandler) maturing cultivars. In Tasmania, the timing of kernel maturity was also earlier in Vina, Lara and Howard than Chandler; however, hull maturity was similar between all cultivars. In California, the development of hull maturity is more rapid in coastal areas, where moderate day-time temperatures and cool and humid nights predominate, compared to interior regions where warm day- and night-time temperatures and low humidity lead to rapid kernel maturity but delays hull maturity (Olson et al., 1998). This suggests that climate influences the development of walnuts grown in different regions of Australia.

This study found that delaying the harvest of nuts from the orchard floor can reduce nut quality. In summary, nuts that were on soil beneath trees or in grass inter-rows for 4 or more days after shaking had lower quality than nuts that remained in trees, with fewer extra-light and light kernels and more amber kernels, stained shells, yellow pellicles and kernel moulds. Rainfall and/or soil moisture may have contributed to the reduction in nut quality, as the timing of these events corresponded to losses in nut quality. In California, prolonged exposure of walnuts to damp soil reduced nut quality by staining the shell of the nut, and increasing the susceptibility of nuts to moulds, in comparison to those nuts that remained on the tree (Olson et al., 1998). Similarly, delayed pick-up of macadamia nuts increased external kernel discolouration and mould, with the extent of nut spoilage consistently higher for those nuts in contact with high moisture soils (Liang et al, 1996). The results are consistent with the conclusion that removal of nuts prior to rainfall and/or from soil moisture, should reduce or slow the rate of quality loss.

Higher temperature between harvesting and drying reduced the quality of nuts. In controlled temperature trials in Tasmania, kernel colour of Chandler and Lara nuts degraded within 4 and 6 days, respectively, at a constant temperature of 20°C. In California, loss of kernel colour is hastened when nuts are exposed to sunlight at ambient temperatures at, or above, 32°C, and at temperatures above 38°C when nuts are in the shade (Olson et al, 1998). In contrast, in the Van Lake Region of Turkey, there was no loss in kernel colour in nuts at controlled temperatures of 20°C and 30°C (Koyunku et al, 2003). The effect of temperature on kernel colour, under the range and duration of temperatures experienced during harvest in Australia, is still to be resolved.

As previously described, the presence of yellow stained pellicles increased in nuts that were on the orchard floor between shaking and harvesting in NSW and Tasmania. This confirms Lang and Evans (2010) study in Tasmania, where yellow stained pellicles were associated with nuts that were located on the ground for 7 or more days prior to harvest. In contrast, yellow stained pellicles in California are associated with the progressive shading of nuts within the tree canopy, from full sunlight early in the season through to shading later in the season (Lampinen et al., 2007). The regularity of yellow pellicles in nuts that were located on soil beneath trees or in grass inter-rows prior to harvest, suggests that abiotic or biotic conditions may contribute to the development of yellow pellicles of walnuts in Australia.

This is the first report of the effect of walnut storage during harvest on nut quality in Australia. In summary, storage of Vina nuts for 24 or 48 h after harvesting and before hulling and drying led to a marked reduction in the numbers of nuts with extra-light and light kernels, and a two- and three-fold increase in the number of amber kernels and stained shells, compared to drying immediately after harvest. Similarly, storage of nuts after hulling and before drying significantly reduced nut quality in Vina and Lara. In contrast to earlier cultivars, the nut quality of the later-season cultivars, Howard and Chandler, was less affected with storage.

Temperatures in 5.9 m long shipping containers, or storage bins, increased for the duration of storage, irrespective of the diurnal fluctuation associated with ambient temperature. Similarly, in pistachio, the temperature of hopper-bottomed trailers loaded with freshly harvested nuts increased during temporary storage between harvesting and drying, whereas ambient temperature reduced over the same period (Thompson et al., 1997).Temperatures in storage bins were higher, and elevated for longer, with non-hulled nuts and with earlier harvested cultivars than later cultivars. For example, the maximum temperature and length of time at 20^{o}C or more with 48 h storage was 34^{o}C and 34 h for Vina (early harvest), and 19^{o}C and 0 h for Chandler (late harvest), respectively. In controlled temperature trials, Lara and Chandler nuts lost more quality when stored at 20^{o}C for 4 or more days after harvesting, than storage at 5^{o}C, with fewer extra-light and light kernels and more kernel moulds and stained shells. Shell staining of unhulled pistachio nuts also increased when stored between harvesting and processing at 25^{o}C for 48 h or more, and substantial increases in shell staining occurred when stored at 30^{o}C for more than 18 h (Kader et al., 1978). The effect of storage on the quality of walnuts, at temperatures higher than those examined in the current study, is yet to be determined; however, prolonged exposure of walnuts to conditions associated with bulk handling, such as elevated temperatures, may reduce nut quality.

An important factor in storing produce successfully is to reduce the respiration rate, or heat from respiration, for a particular commodity. In this study, the temperature in ventilated 20’ shipping containers loaded with hulled walnuts reduced or remained relatively constant, between hulling and drying, whereas temperatures increased markedly in non-ventilated storage. Similarly, in pistachio the temperature increase in ventilated trailers loaded with freshly harvested nuts was less during transportation, from evaporative cooling, than with no transportation (Thompson et al., 1997). Further investigation into ventilated storage of harvested walnuts, and the metabolic reactions associated with quality retention, is warranted.

Ethephon is generally used in walnuts on early-harvested cultivars, although it has been used successfully on later-harvested cultivars in California (Olson et al, 1998). In this study, foliar applied ethephon significantly increased hull-dehiscence and nut drop in early- and mid-maturing cultivars, with nearly all Serr, Vina and Howard fruit hullable within 13 days of treatment; in contrast, less than 89% of Serr, 57% of Vina and 81% of Howard fruits were hullable with non-treatment. In addition, ethephon was not considered detrimental to the health of trees, and did not reduce kernel quality when harvested soon after treatment. Higher rates of ethephon (100 ml/100 l) were more efficacious in Serr than lower rates (60 ml/100 l); this concurs with previous trials in

NSW, where ethephon at 100 ml/100 l increased the rate at which hulls matured in Serr, compared to 60 ml (Lang and Evans, 2010). In California, ethephon also advanced hull-split in Serr and reduced the percentage of nuts with adhering hull at harvest (Beade et al, 1998, 1999, 2000; Beade and Stanfield, 2001). As such, foliar applied ethephon may minimise the potential loss of nut quality, by reducing the interval between kernel and hull maturity.

The concentration of ethephon in walnut kernels varied between NSW and Tasmania, treatment rates and the time since application. In general, ethephon concentrations were higher, and peaked later in Tasmania than in NSW. This concurs with previous ethephon residue decline studies conducted in Tasmania and NSW (Lang and Evans, 2010). As discussed by Lang and Evans (2010), the variation in temporal development and quantity of ethephon produced in Tasmania may have, in part, been due environmental conditions after the application of ethephon, as the decomposition of ethephon and hence, the release of its active form, ethylene, may be limited at temperatures similar to when ethephon was applied in Tasmania i.e., at 16^{o}C and lower there was little response to the decomposition of ethephon in sweet and sour cherry (Olien and Bukovac, 1978). However, research is required to determine the effect of temperature on ethephon residues in walnuts.

The effect of multiple-year ethephon use on crop safety in walnuts in Australia has not been reported previously. While the use of ethephon led to a slight yellowing of leaves and premature leaf drop in the season it was applied, nut size and weight was not significantly different between those trees sprayed with ethephon over a three year period compared to non-treated trees. Similarly, ethephon generally does not affect nut quality in macadamia in the season or following seasons (Trueman, 2003); however, nut yield may decline in the year following ethephon application. Macadamia yield has been correlated with canopy area (Chapman et al 1986), and premature leaf drop may reduce subsequent yield by reducing carbohydrate availability from stored photosynthate reserves (Trueman, 2003). In walnut, photosynthates are mobilized from senescing leaves to spurs and limbs (DeJong and Ryugo, 1998); these reserve food substances are then reutilized for new growth in spring. More than half of the fresh weight of walnut fruits, and most of the fruit length and width, occurs within 8 weeks of pistillate flower bloom (Pinney et al., 1998), thus interruption of photosynthate availability during this period may reduce nut size and quality (Lampinen et al, 2007). Further research is required to identify if ongoing ethephon use influences tree health and crop yield.

Ethephon is applied in two different harvest strategies in California: 1) a two-pass strategy, where ethephon is applied at 100% kernel maturity, and 2) a one-pass strategy, where ethephon is applied after kernel maturity approximately 10 days prior to harvesting (Olson et al., 1998). With a two-pass strategy, the first-pass collects approximately 90% of the crop and a later second-pass gathers the remaining nuts, whereas the majority of the crop is gathered after once only shaking, sweeping and harvesting in a one-pass strategy.

In this study, nut quality was similar with either one-pass or two-pass strategies; however, there were markedly more extra-light and light kernels in Vina and Serr with the first harvest of a two-pass strategy (80% in Serr and 59% in Vina) than with a later harvest (52% in Serr and 27% in Vina). A ‘mixture’ of one-pass and two-pass strategies, where ethephon is applied at 100% kernel maturity but harvest is delayed until the majority of the crop is gathered in one-pass, reduced walnut quality in some cultivars. For example, when ethephon was applied at 100% kernel maturity in Howard, but not harvested until 18 days later when the majority of fruits were hullable, there were fewer extra-light and light kernels (65%) and more light-amber kernels (29%) than with a one-pass strategy where ethephon was applied 10 days after 100% kernel maturity and harvested 8 days later (88% extra-light and light kernels and 7% light-amber kernels). In contrast, there was no difference in nut quality between a mixture of one- and two-pass strategies, and a one-pass strategy, in Serr and Vina. Further monitoring of nut quality with different harvesting strategies will clarify cultivar variations, and improve these initial findings.

7. RECOMMENDATIONS

1. Adopt strategies that maximise walnut quality at harvest

Adoption of the harvest strategies outlined in the Outcomes (Section 8.1) of this report, will contribute to the production of high quality nuts, and enable growers to capitalise on potential market opportunities.

2. Determine the cause of pre-harvest loss of kernel quality

This study observed a reduction in kernel quality of walnuts prior to hull maturity with, at times, a marked reduction in the number of nuts with extra-light and light kernels. Abiotic conditions may have contributed to the loss of kernel colour, although the mechanisms involved remain unknown.

3. Confirm the efficacy of ethephon in a range of weather conditions

In this study, foliar application of ethephon increased hull-dehiscence of walnuts grown in NSW and Tasmania. However, the uptake and decomposition of foliar applied plant growth regulators can be affected by weather conditions i.e., differences in ambient temperature and the presence or absence of rainfall. Hence, further research is required to determine the effect of weather variables on the efficacy of ethephon in walnuts.

4. Determine if ongoing ethephon treatment influences crop yield

This study did not consider foliar applied ethephon to be detrimental to the health of trees in the year it was applied, or to nut weight and size after multiple years of use. However, ongoing research is required to determine if ethephon use over multiple years has any detrimental effect on a greater range of cultivars than reported in this study.

5. Evaluate ventilated storage before walnut drying on nut quality

Cool storage of nuts between harvesting and drying maintained nut and kernel quality in this study. Furthermore, temperatures in ventilated storage of newly harvested nuts decreased, or were relatively stable with time, irrespective of the fluctuations in ambient temperature. Nut quality in ventilated storage was maintained; however, further research at a greater range of temperatures than provided in this report is required.

8. OUTCOMES

8.1. The development of harvest strategies to maximize the quality of walnuts.

- *Monitor temporal development of kernel and hull maturity*

  Fruit maturity can vary within and between orchards, with variations caused by cultivar and climatic differences. Harvest requires kernel and hulls to be mature. Monitoring fruit maturity identifies potential delays in harvest, and enables growers to develop strategies to mitigate potential losses of nut quality.

- *Foliar applied ethephon allows earlier than normal harvest*

  Nut quality can diminish between kernel and hull maturity. However, hulls often mature later than kernels, especially in warm-climates. Foliar applied ethephon enhances hull dehiscence and nut-drop, promoting earlier harvest and increasing potential crop value. Ethephon can cause slight yellowing of leaves and premature leaf drop in healthy trees; however, ethephon is not recommended for use in stressed trees because of the potential for excessive leaf drop.

- *Remove windfall and prematurely dropped nuts prior to commercial harvest*

  Windfall and prematurely dropped nuts are often of poor quality, with diminished kernel colour and a high prevalence of kernel moulds and shell staining. High quality grade walnuts require the minimal presence of kernel discolouration, kernel moulds and/or damage by other means. Hence, harvest strategies that optimise the quality of nuts, such as preliminary passes of sweepers and harvesters to remove lower quality nuts from beneath trees, are recommended.

- *Promoting nut-drop from trees should not proceed faster than harvesting capacity*

  The quality of nuts on trees was maintained for longer than nuts that were mechanically shaken, to promote nut-drop, and left on the ground under trees or in grass inter-rows Walnuts are less susceptible to moulds when in trees than when on damp ground, and are much cooler in trees than on the ground when exposed to direct sunlight. Hence, shaking nuts from trees should not proceed faster than harvesting and drying capacity.

- *Harvest as rapidly as practicable after nut-drop to reduce potential losses in quality*

  Walnuts left on the orchard floor can lose quality rapidly. Rainfall and/or soil moisture increases the likelihood of severely stained shells, yellow stained pellicles and kernel moulds, and hastens the loss of kernel colour. Walnuts also reportedly lose quality when left in direct sunlight at ambient temperatures of 32°C, and when left in the shade at 38°C, with the rate of loss exacerbated when hulls are still intact (Olson et al., 1998). Hence, delays in harvest are to be avoided when conditions of rainfall, high soil moisture and/or high ambient temperatures prevail.

- *Cool storage of nuts between harvesting and drying maintains nut quality*

  Delays in the drying of nuts after harvesting may necessitate storage of nuts for lengthy periods. Storing nuts at a cooler temperature between harvesting and drying maintains nut quality for longer periods than at higher temperatures. Prolonged exposure of walnuts to conditions associated with bulk handling, such as elevated temperatures, may reduce nut quality and should be avoided.

8.2. Adoption of harvest management protocols in the year following completion of the project, is expected to lead to an increase production of high quality nuts in major cultivars grown in Australia.

An increase in revenue of AUD 1,500.00 per ha from a 30% increase in crop quality is predicted, assuming a crop yield of 5 tonnes per ha, a AUD 5.00 per kg price for U.S. No. 1 grade, and a AUD 1.00 per kg differential between U.S. No. 1, 2 and 3 grades (United States Department of Agriculture, 1997).

8.3. Adoption of ethephon use for improving harvesting operations within the Australian walnut industry. The predicted area of walnut orchards that will have ethephon applications by 2016 i.e., within 2 years of the completion of the project, will cover at least 1615 and 250 ha in NSW and Tasmania respectively.

8.4. An amendment and renewal of the minor use permit for the use of ethephon in Australian walnut orchards, for the promotion of uniform nut fall in walnuts, granted by the Australian Pesticides and Veterinary Medicines Authority (APVMA), and in force between 12 February 2014 and 30 June 2019.

8.5. Ethephon efficacy, crop safety and residue decline data generated within WN11000 is available for submission to the APVMA for ethephon registration in all nut crops in Australia, if requested.

9. OUTPUTS

9.1. *'Walnuts – maximizing yield and quality'* presented at the 3rd Australasian Nut Industry Research Forum held in Brisbane, QLD, 21-Sep-12. Author: Lang MD. Accessible from the Australian Nut Industry Council at: http://nutindustry.org.au/files/nrteUploadFiles/222F102F2012123A003A14PM.pdf

9.2. *Delays in harvest reduce walnut quality in a cool-climate'* presented at the 7th International Walnut Symposium held in Fenyang, China, from 20-23 July 2013. Authors: Lang MD, Sulcs JA, Evans KJ. Accessible from the Australian Walnut Industry Association (AWIA) at: www.walnut.net.au.

9.3. '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014). Acta Horticulturae 1050, pages 309-314 (reprinted in Appendices).

9.4. *'Permit PER14390, to allow the minor use of ethephon for the promotion of uniform nut fall in walnuts'* in force between 12 February 2014 and 30 June 2019 (reprinted in Appendices).

9.5. Knowledge transfer with UNICOQUE personnel at Walnuts Australia orchards and processing facilities from 26-31 March 2014. UNICOQUE conducts RD&E and production of walnuts in South-western France.

9.6. *'Developing management strategies to maximise walnut quality at harvest'* presented at the AWIA orchard walk held in Swansea, Tasmania, from 16-18 January 2015. Accessible from the AWIA at: www.walnut.net.au.

9.7. Ongoing support and consultation to Walnuts Australia and AWIA members on strategies associated with maximizing nut quality during harvest.

10. REFERENCES

Australian Nut Industry Council (ANIC) (2014) Australia’s tree nut industry − growing for success. ANIC, Elanora, Queensland. www.nutindustry.org.au

Beade RH, Stanfield B (2001) Refining ethephon use in walnuts. See: http://walnutresearch.ucdavis.edu/2001/2001_209.pdf

Beade RH, Stanfield B, Padilla J (1998) Refining ethephon use in walnuts. See: http://walnutresearch.ucdavis.edu/1998/1998_151.pdf

Beade RH, Stanfield B, Padilla J, Gomes N (1999) Refining ethephon use in walnuts. See: http://walnutresearch.ucdavis.edu/1999/1999_157.pdf

Beade RH, Stanfield B, Padilla J, Tutschulte H (2000) Refining ethephon use in walnuts. See: http://walnutresearch.ucdavis.edu/2000/2000_155.pdf

Campbell CL, Madden LV (1990) Introduction to plant disease epidemiology. John Wiley & Sons, New York

Chapman KR, Bell HFD, Bell DJD (1986) Some methods for relating yield to tree size in macadamia. *Acta Horticulturae* 175, 43−38

DeJong TM, Ryugo K (1998) Carbohydrate assimilation, translocation and utilisation. In: *Walnut Production Manual* (Ed D.E. Ramos) pp. 109–114, University of California, Oakland, USA

Kader AA, Labavitch JM, Mitchell FG, Somner NF (1978) Quality and safety of pistachio nuts as influenced by postharvest handling procedures. The Pistachio Association Annual Report, Fresno California, 45-51

Koyunku MA, Koyuncu F, Bakir N (2003). Selected drying conditions and storage period and quality of walnut selections. *Journal of Food Processing Preservation*, 27, 87−99

Lampinen B, Grant J, Metcalf S, Negron C (2007) Walnut production and quality as influenced by orchard and within tree canopy environment See: http://walnutresearch.ucdavis.edu/2007/2007_115.pdf

Lang MD, Evans KJ (2010) Advancing hull split to maximise yield and quality of walnuts. Final report WN09000, Horticulture Australia Limited, Sydney, Australia

Liang T, Meng Q, Ji F (1996) Prediction of macadamia nut spoilage for harvest decision making. Journal of Agriculture Engineering Research, 63: 237-242

Martin GC, Sibbett GS, Ramos DE (1973). Effect of harvest delay on walnut kernel quality. See: http://walnutresearch.ucdavis.edu/1973/1973_19.pdf

Olien WC, Bukovac MJ (1978) The effect of temperature on rate of ethylene evolution from ethephon and ethephon-treated leaves of sour cherry. Journal of the American Society for Horticultural Science 103, 199-202

Olson WH, Labavitch JM, Martin, MC, Beede RH (1998) Maturation, harvesting and nut quality. In: *Walnut Production Manual* (Ed D.E. Ramos) pp. 273–276, University of California, Oakland, USA

Pinney K, Labavitch JM, Polito VS (1998) Fruit growth and development. In: *Walnut Production Manual* (Ed D.E. Ramos) pp. 139–143, University of California, Oakland, USA

Thompson JF, Rumsey TR, Spinogli M (1997) Maintaining quality of bulk-handled, unhulled pistachio nuts. Applied Engineering in Agriculture 13, 65-70

Trueman SJ (2003) Yield responses to ethephon for unshaken and mechanically shaken macadamia. Australian Journal of Experimental Agriculture 43, 1143-1150

11. ACKNOWLEDGEMENTS

This project is indebted to Walnuts Australia staff, namely Julie Sulcs, Jen Whitney, Carl Rademeyer, Colin Bruss, Rodney 'Kouj' Jones, Matt Hockings, Dave Jacobsen, Michele Valier, Simon McClure, Kirsty Philips, Merryn Gilham, Melissa Seymour, Phil Tenison, Derek Goullet and Chris Barnes.

The project team also acknowledges and thanks Victor Pittari and Anthony Febo, and staff, from Pittari AgriServices, Peter Dal Santo from AgAware Consulting Pty Ltd, Bruce Chen from Symbio Alliance, Steve Sibbett from the University of California and Perennial Horticulture Centre staff from the Tasmanian Institute of Agriculture, University of Tasmania.

Walnuts Australia and the Australian Walnut Industry Association also thank the contribution and support provided by team members from Horticulture Innovation Australia Limited and the Australian Pesticides and Veterinary Medicines Authority.

12. APPENDICES

Loss of Kernel Quality Associated with Harvest Delays in Tasmania, Australia

M.D. Lang[1,2], J.A. Sulcs[1] and K.J. Evans[2]

[1]Walnuts Australia, PO Box 417, Devonport, TAS, 7310, Australia
[2]Perennial Horticulture Centre, Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 98, Hobart, TAS, 7001, Australia

Keywords: walnut; walnut maturity; packing tissue brown hull split, kernel colour; yellow pellicle, mould.

Abstract

Knowledge of factors that adversely affect the quality of walnuts grown in Tasmania, Australia, is limited. Experiments over two years investigated the temporal development of fruit maturity and the effect of harvest delays on kernel quality. The progression of kernel maturity, or packing tissue brown (PTB), was similar in Lara and Vina, with 95% PTB predicted between 77 and 87 days after January 1. The onset of harvest, defined as 80% hullable fruits, was similar for the two cultivars, occurring within 5-days of each other. Delaying harvest beyond 95% PTB reduced kernel quality in both years. In 2009-10, delaying harvest significantly reduced the percentage of extra-light kernels for Vina, Howard and Chandler i.e., for Chandler, from 77% extra-light with no harvest delay compared to 63% a 7-day harvest delay. Delaying harvest by 7 days significantly increased the percent of kernels with yellow pellicle i.e., from less than 6% yellow pellicle with no delay to 24, 28 and 51% of Howard, Vina and Chandler nuts, respectively, with a 7-day harvest delay. Similarly, in 2011-12 Lara and Chandler nuts harvested 8 days or more after tree shaking had fewer extra-light kernels, and more yellow pellicle and mould, compared to nuts harvested earlier. Additional research will identify seasonal variations and improve the initial description of fruit maturity and factors affecting kernel quality.

INTRODUCTION

The Australian walnut industry has undergone rapid expansion with the potential to supply high quality nuts to local and export markets. Optimizing walnut quality is essential to maximise import and export opportunities. Major factors in determining nut quality are light kernel colour and low internal damage from insects and mould (Olsen et al., 1998); these factors are adversely affected by delays in harvest.

Walnut harvest requires both the kernel and the hull to be mature. Cultivar and climatic differences influence the rate at which kernels and hulls develop, and how well hull split coincides with kernel maturity. In the warm climate of California, the kernel of early maturing cultivars can mature up to 3 weeks before hull maturity (Olsen et al., 1998; Beede and Stanfield, 2001); in contrast, kernel maturity and hull split can occur at the same time under cool climates (Olsen et al., 1998).

Walnut harvest involves a sequence of events, namely the shaking of trees to dislodge nuts, followed by sweeping into windrows, collection from the orchard floor, hulling and drying of nuts. In California, the greatest loss of kernel colour occurs within

Figure A1 (page 1 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

the first 9 h of harvest, with ambient temperatures at or above 32°C accelerating the loss of kernel colour on nuts exposed to sunlight (Olsen et al, 1998); hence, in warm-climates it is important to collect, hull and dry nuts as rapidly as possible.

Knowledge of the timing of kernel and hull maturity in cool-climate regions of Australia is lacking; furthermore, understanding of the effect of delays in harvest on kernel quality is limited. Thus, the objectives of this study were to investigate the effects of temporal fruit maturity and harvest delays on kernel quality in a cool-climate region of Tasmania.

MATERIAL AND METHODS

Terminology

At maturity the walnut consists of the hull, shell and edible kernel (Pinney et al., 1998); the term fruit refers to all three parts, whereas the shell and kernel is termed the nut. For unshelled markets both the shell and kernel quality are important to consumers. For shelled walnuts, kernel quality is the primary concern. Kernel maturity is attained when the packing tissue surrounding the kernel turns brown, termed packing tissue brown (PTB), whereas hull maturity, or hullability, is defined as the splitting and separation of 95% or more of the hull, or husk, from the shell (Olson et al., 1998).

Site descriptions

Experiments were conducted in commercial hedgerow orchards at Swansea, Tasmania (42°03'55"S, 148°03'04"E). Experimental plots were selected from an area of the orchard with uniform tree growth. Trees were *Juglans regia* cultivars grafted onto *J. hindsii* rootstock, with canopies of approximately 50 m^3 when in full-leaf.

Weather monitoring

Temperature sensors (Gemini Data Loggers (UK) Ltd, Chichester, UK) were mounted in a Stevenson screen (Hastings Data Loggers Pty Ltd, NSW, Australia) within the tree canopy, 1 m above ground level. Ambient temperature was recorded at 5 min intervals during the experiments.

Temporal progression of fruit maturity

Two surveys were conducted each year in cultivars 'Lara' and 'Vina'. Each survey was conducted in plots of 50 trees, made up of two adjacent rows of 25 trees each, replicated four times.

From 2 to 3 weeks prior to the anticipated date for all fruit to reach PTB, ten fruit per plot were removed and evaluated for PTB. The ten fruits consisted of one fruit per single tree from each of ten arbitrarily selected trees. Fruits were selected from lateral shoots only in the lower third of the tree canopy. Further assessments were conducted until 90%, or more, of fruits were at PTB.

From PTB to hull split, fifty fruit per plot, consisting of ten fruits from each of five arbitrarily selected trees, were removed at 4-7 day intervals and evaluated to determine whether fruits were hullable or not. Fruits were selected from the lower third of the tree canopy, from both terminal and lateral shoots. To determine 'hullability', fruits with hulls were rolled by hand for 5 seconds, with gentle downward pressure, on a steel grating mesh platform or hulling table.

Figure A1 (page 2 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

Effect of harvest delays on nut quality

Experiments in Vina, Lara, Howard and Chandler were conducted as randomized complete block designs, replicated five times. Variables examined were the location of nuts after shaking of trees, and the length of time between shaking and collection of nuts from the orchard floor. Nuts dropping prematurely, before commercial harvest, were removed from beneath tree canopies to reduce the possibility of degraded nuts being included in evaluations.

Trees were shaken with a mechanical tree shaker to promote nut-drop from trees. After shaking, dropped nuts were raked from beneath tree canopies to form a single-row of nuts on either side of the tree-row. Nuts were then arbitrarily selected from the single-rows, hulled, and placed into 10 kg breathable poly-mesh bags, and then placed under tree canopies (ground), in grassed inter-rows (grass) or 1-2 m above ground level in the tree canopy (tree). Poly-mesh bags under tree canopies and in inter-rows were placed so that all nuts were in contact with the ground and grass respectively.

Samples of 50 nuts were then arbitrarily selected from each plot at prescribed collection intervals (0 to 28 days after shaking). Nuts were placed into 1 kg breathable poly-mesh bags and commercially dried to 8 - 9% moisture content. Drying commenced within 12 hours of sample collection and continued for a period of 24-36 hours. After drying, nuts were hand cracked and evaluated for kernel colour, yellow pellicle and mould. Standards for kernel colour are described in the USDA (United States Department of Agriculture) grades and standards for shelled walnuts (www.agfoodsafety.org) and USDA walnut colour chart (www.walnuts.org). The standards include 1) extra light 2) light 3) light amber and 4) amber. Extra light kernels are usually the most valuable and was the color standard evaluated in this experiment.

Data analyses

For fruit maturity, the number of calendar days from 01-Jan was regressed on the mean percentage of fruits at kernel and hull maturity, using simple linear regression methods. For experiments involving delayed harvest, the mean percentages of extra-light kernels, yellow pellicle and kernel moulds were compared using ANOVA. Means were separated at $P = 0.05$ using Fisher's least significant difference test.

RESULTS

Temporal progression of fruit maturity

In 2009-10, the progression of kernel maturity, or PTB, in Lara and Vina were distinct from each other, with 95 % PTB in Lara occurring earlier than for Vina and within 80 days of 1st January (Fig. 1). In contrast, progression of hull split in Vina was similar to that observed for Lara. In 2011-12, the onset of PTB was sooner in Lara and Vina but progression of hull split was similar in both cultivars.

The predicted time for cultivars to reach 95% PTB and 80 % hullable fruits was 4-5 days sooner in 2011-12 than 2009-10 (Table 1). The time between predicted 95% PTB and predicted harvest (80% hull split) was less in Vina than Lara i.e. 7 and 13 days respectively.

Effect of harvest delays on nut quality

1. Location of nuts. Ground located Vina nuts had significantly fewer extra-light kernels (28%) in comparison to nuts that were located in trees (36%) (Table 2). Similarly, fewer extra-light kernels were observed in Howard nuts located on the ground, and Lara nuts

Figure A1 (page 3 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* **Authors: Lang MD, Sulcs JA, Evans KJ, (2014).**

located on the ground or grass inter-row, compared to nuts located in trees (Tables 2 and 3). Ground and grass located Chandler nuts had fewer extra-light kernels in 2011-12; however, nut location did not affect kernel colour in 2009-10.

For both years, nuts located on the ground or grass inter-row had significantly more yellow pellicles in comparison to nuts located in trees (Tables 2 and 3). All four cultivars examined were susceptible to loss of kernel quality. Incidence of yellow pellicle was greater in 2009-10 (66%) than 2011-12 (25%) for Chandler.

Lara and Chandler nuts located in the grass inter-row had significantly more kernel moulds than tree and ground located nuts (Table 3). The incidence of kernel moulds was less than 9%, irrespective of cultivar or location.

2. Timing of harvest. Delaying the collection of nuts by 7 days or more resulted in fewer nuts with extra-light kernels. For Chandler, 77% of nuts had extra-light kernels if harvest was not delayed in 2009-10; in comparison, less than 63% had extra-light kernels if harvest was delayed from 7 to 28 days (Table 4). In 2011-12, 85% of Chandler nuts had extra-light kernels if harvest was not delayed, compared to 69 and 42% with a delay of 8 and 16 days respectively (Table 5). Similarly, fewer Vina and Howard nuts in 2009-10, and Lara nuts in 2011-12, had extra-light kernels with harvest delays of 7 or more days.

In both years, delaying harvest increased the incidence of yellow pellicle. In 2009-10, significantly more Vina, Howard and Chandler nuts had yellow pellicles with a 7 day delay in harvest (Table 4); furthermore, the incidence of yellow pellicle increased with further delays i.e., 6, 51 and 68% yellow pellicle for Chandler with 0, 7 and 14 day delays respectively. Similarly, the incidence of yellow pellicle increased from 9 to 62% from 0 to 16 days in Chandler in 2011-12 (Table 5). The incidence of kernel moulds increased with harvest delays (Table 5). With a 16-day delay, 22 % of Lara and 19% of Chandler nuts had moulds, compared to 2 and 6% with no delay after harvest.

Ambient temperatures

Maximum daily temperatures ranged between 22 and 11°C in 2009-10 and 25 and 12°C in 2011-12. Average daily temperatures ranged from 16 to 6°C in both years.

DISCUSSION

This study provides an initial description of the temporal development of kernel and hull maturity in Lara and Vina in a cool-climate region of Tasmania. Kernel maturity was earlier in Lara, although hull split was similar in both cultivars. As fruit maturation is influenced by cultivar and climatic differences (Olson et al., 1998), season-to-season variation may illustrate greater variation than observed in this study.

Delaying walnut harvest reduced kernel quality by reducing the number of nuts with extra-light kernels. In California, ambient temperatures at or above 32°C greatly speeds the loss of kernel colour on nuts exposed to sunlight, with the greatest loss of colour within the first 9 hours of harvest (Olsen et al, 1998). Within 72 hours of harvest, quality loss may be less severe when nuts are shaded compared to when in sunlight (Martin et al., 1973). In Tasmania, Lara and Chandler nuts did not lose extra-light kernel colour until between 4 and 8 days after the start of harvest. In these experiments, maximum daily temperatures of between 12 and 25°C were markedly lower than those experienced in Californian orchards, and may have reduced the rate of colour change.

In California, nuts with yellow pellicle, similar to those observed in Tasmania, have been observed in Chandler (Lampinen et al., 2007). In California, yellow pellicle has been associated with the progressive shading of nuts, from full sunlight early in the

Figure A1 (page 4 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

season through to shading within the tree canopy later in the season. In this study, 'ground', 'grass' and 'tree' located nuts were arbitrarily selected from nuts that had been shaken from tree canopies; hence, the progressive shading of nuts was the same for nuts selected from the ground, grass or tree treatment. Yellow pellicles were associated with nuts that were located on the ground and grass prior to harvest and suggests that conditions underneath tree canopies and tree inter-rows may contribute to the development of yellow pellicles of walnuts in Tasmania.

In this study, kernel mould was more apparent in nuts located underneath tree canopies and in grass inter-rows. The presence of moulds also increased when nuts were on the ground or in grass for longer time periods. In California, prolonged exposure of walnuts to damp soil reduces nut quality by increasing mould, compared to nuts that remain on trees (Olsen et al, 1998). Studies on the effect of frequency and duration of damp soils during harvest on nut quality in Tasmania are warranted.

ACKNOWLEDGEMENTS

This project was facilitated by Horticulture Australia Limited (HAL) in partnership with Walnuts Australia. The Australian Government provides matched funding for all HAL's research and development activities. In-kind support was provided by the Tasmanian Institute of Agriculture and University of Tasmania.

Literature Cited

Beede, R.H. and Stanfield, B. 2001. Refining ethephon use in walnuts. http://walnutresearch.ucdavis.edu/2001/2001_209.pdf

Lampinen, B., Grant, J., Metcalf, S. and Negron, C. 2007. Walnut production and quality as influenced by orchard and within tree canopy environment. http://walnutresearch.ucdavis.edu/2007/2007_115.pdf

Olsen, W.H., Labavitch, J.M., Martin, G.C. and Beede, R.H. 1998. Maturation, harvest and nut quality. p. 273-276. In: D.E. Ramos (ed.), Walnut Production Manual. University of California, Oakland.

Pinney, K., Labavitch, J.M. and Polito, V.S. 1998. Fruit growth and development. p. 139-143. In: D.E. Ramos (ed.), Walnut Production Manual. University of California, Oakland.

Figure A1 (page 5 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

Tables

Table 1. Number of days (predicted), from 1st January, for 95% of fruits to have mature kernels (PTB) and 80% of fruits to have hull dehiscence (hullable) for two years at Swansea, Tasmania. The drop-time is the difference between the predicted number of days for 95% PTB and 80% hullable fruits.

Year	Cultivar	95% PTB (days)[1]	80% hullable (days)[1]	Drop-time (days)
2009-10	Lara	81	94	13
	Vina	87	94	7
2011-12	Lara	77	90	13
	Vina	82	89	7

[1] Predicted values were derived from simple linear regression models of the observed values (y) against the number of days from 1-Jan (t) for each cultivar.

Table 2. Mean percentage of nuts, pooled from all sample dates, with extra-light and yellow pellicles according to location within the tree canopy (tree) or underneath the tree canopy (ground), for three walnut cultivars at Swansea, Tasmania, in 2009-10.

	Vina				Howard				Chandler			
Location	extra-light kernel (%)[1]		yellow pellicle (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]	
Tree	36.0	a	11.3	a	51.6	a	10.8	a	65.7	a	29.0	a
Ground	27.9	b	35.6	b	45.1	b	34.0	b	60.7	a	65.8	b

[1]Means followed by the same letter are not significantly different at $P < 0.05$.

Table 3. Mean percent of nuts, pooled from all sample dates, with extra-light kernels, yellow pellicles and kernel moulds according to location within the tree canopy (tree), underneath the tree canopy (ground) or in the grassed inter-row (grass) for two cultivars at Swansea, Tasmania, in 2011-12.

	Lara						Chandler					
Location	extra-light kernel (%)[1]		yellow pellicle (%)[1]		kernel mould (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]		kernel mould (%)[1]	
Tree	72.7	a	1.0	a	1.8	a	85.0	a	6.6	a	4.8	a
Ground	61.1	b	8.4	c	3.8	ab	77.4	c	20.5	b	6.8	a
Grass	57.8	b	5.0	b	6.5	b	71.8	b	24.8	b	9.2	b

[1]Means followed by the same letter are not significantly different at $P < 0.05$.

Figure A1 (page 6 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

Table 4. Mean percentage of hulled nuts with extra light and yellow pellicles for nuts located on the ground under the tree canopy from 0 to 28 days after kernel maturity for three walnut cultivars at Swansea, Tasmania, in 2009-10.

	Vina				Howard				Chandler			
Days	extra-light kernel (%)[1]		yellow pellicle (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]	
0	46.0	a	4.8	a	57.8	a	6.2	a	77.3	a	6.4	a
7	29.7	b	28.4	b	46.0	b	24.0	b	62.4	b	50.7	b
14	31.2	b	32.8	b	44.8	b	32.8	c	56.8	b	67.6	c
21	25.4	b	26.2	b	43.2	b	30.8	bc	62.8	b	71.3	c
28	25.2	b	54.9	c	46.2	b	48.3	d	60.8	b	73.4	c

[1]Means followed by the same letter are not significantly different at $P < 0.05$.

Table 5. Mean percentage of hulled nuts, pooled from nuts located on the ground underneath the tree canopy and within the grassed inter-row, with extra-light kernels, yellow pellicles and kernel moulds from 0 to 16 days after kernel maturity for two walnut cultivars at Swansea, Tasmania, in 2011-12.

	Lara						Chandler					
Days	extra-light kernel (%)[1]		yellow pellicle (%)[1]		kernel mould (%)[1]		extra-light kernel (%)[1]		yellow pellicle (%)[1]		kernel mould (%)[1]	
0	75.0	b	0.8	a	1.6	a	84.6	ab	9.0	a	6.2	ab
1	82.4	a	0.0	a	2.0	a	86.6	a	3.8	a	3.2	a
2	67.2	c	0.4	a	2.0	a	86.4	ab	5.2	a	3.8	a
4	84.0	ab	0.0	a	0.8	a	79.3	b	20.9	b	7.0	ab
8	37.0	d	27.5	c	7.6	b	68.7	c	35.0	c	9.0	b
16	21.1	e	21.7	b	8.7	b	42.0	d	62.0	d	18.6	c

[1]Means followed by the same letter are not significantly different at $P < 0.05$.

Figure A1 (page 7 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

Figures

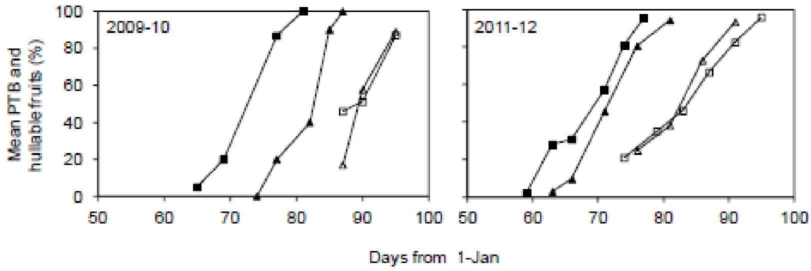

Fig. 1. Temporal progression of observed kernel maturity (PTB) (closed symbols) and hullable fruits (open symbols) in Lara (squares) and Vina (triangles) for two years at Swansea, Tasmania. Each data point represents the mean of four replicates.

Figure A1 (page 8 of 8). '*Loss of kernel quality associated with harvest delays in Tasmania, Australia'* Authors: Lang MD, Sulcs JA, Evans KJ, (2014).

Australian Government
Australian Pesticides and Veterinary Medicines Authority

PERMIT TO ALLOW MINOR USE OF AN AGVET CHEMICAL PRODUCT

FOR THE PROMOTION OF UNIFORM NUT FALL IN WALNUTS

PERMIT NUMBER - PER14390

This permit is issued to the Permit Holder in response to an application granted by the APVMA under section 112 of the Agvet Codes of the jurisdictions set out below. This permit allows a person, as stipulated below, to use the product in the manner specified in this permit in the designated jurisdictions. This permit also allows any person to claim that the product can be used in the manner specified in this permit.

THIS PERMIT IS IN FORCE FROM 12 FEBRUARY 2014 to 30 JUNE 2019.

Permit Holder:
WALNUTS AUSTRALIA LTD
c/- AGAWARE CONSULTING P/L
21 Rosella Avenue
STRATHFIELDSAYE VIC 3551

Persons who can use the product under this permit:
Persons generally.

PER14390 Permit Version 1 Page 1 of 3

Figure A2 (page 1 of 3). Permit to allow minor use of ethephon for the promotion of uniform nut fall in walnuts (APVMA permit no. PER14390)

CONDITIONS OF USE

Products to be used:
NUFARM GALLEON GROWTH REGULATOR
FARMOZ PROMOTE 720 GROWTH REGULATOR
PLUS OTHER REGISTERED PRODUCTS
Containing: 720 g/L ETHEPHON as the only active constituent.

Directions for Use:

Crop	Purpose	Rate
WALNUTS	To aid harvesting by promoting uniform nut fall	20 - 100 mL product / 100 L water. Apply using a spray volume up to 2,000 L water depending on tree size and foliage density.

Critical Use Comments:

- **DO NOT** spray trees if they are stressed.
- Vary rate[1] according to degree of loosening required and prevailing climatic conditions.
- Use the higher rates for warm-temperate climates and early harvest cultivars (e.g. Serr).
- Apply by airblast sprayer or equivalent equipment up to volume of 2,000 L diluent spray mixture per hectare; depending on tree size and foliage density. Use higher water rates for trees greater than 4 m in height.
- Ensure thorough coverage of foliage and nuts.
- Addition of wetter is not recommended at this stage.
- Nuts will be stimulated to fall within 7 - 14 days after spraying.
- Mechanical shaking may be used 7 - 14 days after spraying.
- Note the ADDITIONAL CONDITION about initial testing for crop/tree damage: Not all walnut cultivars have been tested and crop/tree damage may result.
- Some leaf drop is associated with treatment.

Note 1. United States experience is that ethephon works most efficiently on walnuts (i.e. the lower-end rate can be used), when humidity is high and temperature is between 15.5 - 32°C.

Withholding Period:
DO NOT HARVEST FOR 7 DAYS AFTER APPLICATION.

Jurisdiction:
TAS, NSW & WA only.

Additional Conditions:

This PERMIT provides for the use of a product in a manner other than specified on the approved label of the product. Unless otherwise stated in this permit, the use of the product must be in accordance with instructions on its label.

PERSONS who wish to prepare for use and/or use products for the purposes specified in this permit must read, or have read to them, the DETAILS and CONDITIONS of this permit.

PER14390 Permit Version 1 Page 2 of 3

Figure A2 (page 2 of 3). Permit to allow minor use of ethephon for the promotion of uniform nut fall in walnuts (APVMA permit no. PER14390

TO AVOID CROP DAMAGE:
The sensitivity of some cultivars of walnut trees to be treated under this permit has not been fully evaluated under all growing conditions. It is advisable, therefore, to only treat a small number of trees to ascertain their reaction before treating a larger part or the whole plantation. Slight premature yellowing of leaves and/or leaf-drop may occur following treatment, especially at the higher spray rates. Discontinue ethephon applications when any more severe symptoms post-treatment are observed.

EXPORT OF PRODUCE:
To allow treated produce to be supplied or otherwise made available for consumption, a temporary MRL of T5 mg/kg has been established for Ethephon on Walnuts. This TMRL applies only to produce marketed and consumed in Australia. Where ethephon treated produce is to be exported, due account should be taken of the residue definition and residue limits/import tolerances of importing countries, and that any residues must not exceed those requirements of the importing country.

Issued by

Delegated Officer

PER14390 Permit Version 1 Page 3 of 3

Figure A2 (page 3 of 3). Permit to allow minor use of ethephon for the promotion of uniform nut fall in walnuts (APVMA permit no. PER14390