Adoption of quality management systems in macadamia

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NSW Department of Primary Industries (NSW DPI)

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FINAL REPORT

Adoption of quality management systems in macadamia

MC03008

March 2008

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Australian Macadamias

University of the Sunshine Coast Queensland, Australia

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Project Details

Project title:	Adoption of quality management systems in macadamias
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Purpose of the report:
Macadamia quality significantly affects profitability for growers. Here we review the factors affecting quality management of macadamias and identify areas in the production chain where quality can be significantly affected. Then we survey growers' attitudes and aspirations towards quality management and analyse the economic implications of farming practices on macadamia quality. Finally, we develop a tool help growers manage quality economically.

Aims of the project:

1) Better understand the on-farm practices affecting macadamia quality.
2) Understand the attitudes and aspirations of growers towards quality management.
3) Quantify the economic effects of farming practices on macadamia quality.
4) Develop a simple tool to allow growers to make re-sorting decisions based on real data.

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Date of report: March 2008

Summaries

Media Summary

The Australian macadamia industry has conducted considerable research on the effects of on-farm practices on macadamia nut in shell (NIS) and kernel quality. These include studies of nut drying, storage, handling and harvesting and agronomic practices. The adoption of these findings provides quality benefits for processors, marketers and consumers, but not necessarily for growers. The adoption of the practices may involve significant additional investment in on-farm infrastructure and major changes in production practices. Without sound economic information relating to the costs and benefits of these changes, growers have found it difficult to justify the investment of money and time. As a result, the adoption of these research findings has been limited and extremely slow.

This project aimed to examine the entire production chain but due to difficulties in accessing processing information, the surveying and examination of the benefits ended at the farm gate. There were still considerable potential economic benefits.

Some major findings from this work are:

1) Harvest frequency has a strong relationship to the quality of NIS. Frequent harvesting (less than or equal to every 4 weeks on average) gave a mean sound kernel recovery (SKR) of 34.2%, while harvesting intervals longer than every 4 weeks, gave a mean sound kernel recovery of 31.6%. This difference of 2.6 % SKR, using current payment scales that award 10c per kg for each 1% increment increase in SKR, results in a difference of $260 per tonne delivered to the factory. On a 40 tonne NIS farm, this equates to $10,400 in additional revenue. The actual payment received could be higher or lower, depending on the reject/bonus category it puts the NIS consignment within.

2) There is also the added advantage from harvesting more frequently of reducing shed losses. Frequent harvesting resulted in shed reject levels of 4.6% of harvested yield while long harvest intervals resulted in shed reject levels of 8.3%. For a 40 tonne NIS farm, this is an extra 1.5 tonne of NIS delivered to the factory.

3) Smaller silos (less than or equal to 20 tonnes) were found to reduce unsound kernel recovery (UKR) on average by 0.34%, compared with larger, taller silos (greater than 20 tonnes). The main effect is on reducing internal discolouration of kernel and this has been identified as a serious problem by the industry. This reduction using current payment scales that awards 10c per kg for each 1% increment increase in SKR, results in a difference of $34 per tonne delivered to the factory. There are also advantages of smaller silos reducing the consignment moisture content of NIS delivered leading to reduced external discolouration of the kernel.

It is clear from these results that there are significant financial rewards from adopting management practices and investing in infrastructure and capital equipment that facilitate these improvements. It must be remembered that the extent of these benefits will vary from farm to farm and each grower must assess their own situation before embarking on changes.

A strong focus upon an extension program to deliver the findings from this and other work relating to quality management would benefit the Australian macadamia industry. This program would need to focus upon the economic costs and returns from adopting these practices. Part of this program would need to promote the use of the re-sort decision support tool developed for growers during this project. The re-sort decisions tool improves the economic basis of re-sort decisions and also has the potential to improve the quality of NIS through reducing on-farm storage times. Consideration should be given to research and development of the factors causing many of the quality issues and quantifying their significance so management strategies can be developed that target these issues. Any future research work carried out into quality management needs to quantify the costs and benefits of changing management practices or investing in capital improvements that address the causes.

Technical Summary

Considerable research has been conducted on the effects of on-farm practices on the quality of macadamia NIS and kernel; however the adoption of these findings has been somewhat slow. A major impediment to adoption is that implementing the recommendations of quality research often produces benefits to processors, marketers and consumers, but not necessarily growers. This can involve significant additional investment in on-farm infrastructure and major changes in production practices. Many growers have expressed the opinion that it is difficult justifying the expenses when they do not see a direct economic benefit to their business.

This project aimed to examine the entire production chain but due to difficulties in accessing processing information, the surveying and examination of the benefits ended at the farm gate. There were still considerable potential economic benefits.

Five main sections of work were undertaken in this project, all designed to deliver information about the quality management of macadamias. They were:

1. The literature review gives an overview of the published research information, highlighting the significant findings.
2. A quality management chain was constructed for macadamia production and processing to determine the likely areas where quality would be affected.
3. The grower attitudes, practices and aspirations survey gives some benchmark information on what is currently occurring on-farm. This survey provides some insights into the current situation of macadamia farming operations in relation to quality.
4. The economic analysis section provides information on the effects of current on-farm practices upon quality, and how growers can achieve benefits from adopting practices that improve quality. Only those practices that provide direct benefit to growers were examined.

The major findings from the economic analysis work are:

a. Harvest frequency has a strong relationship with NIS quality. Frequent harvesting (less than or equal to every 4 weeks on average) gave an average sound kernel recovery of 34.2%, while harvesting intervals longer than every 4 weeks, gave an average sound kernel recovery of 31.6%. This difference of 2.6 % SKR, using current payment scales that award 10c per kg for each 1% increment increase in SKR, results in a difference of $260 per tonne delivered to the factory. On a 40 tonne NIS farm, this equates to $10,400 in additional revenue. The actual payment received could be higher or lower, depending on the reject/bonus category it puts the NIS consignment within.

b. There is also the added advantage from harvesting more frequently of reducing shed losses. Frequent harvesting resulted in shed reject levels of 4.6% while long harvest intervals resulted in shed reject levels of 8.3%. For a 40 tonne NIS farm, this is an extra 1.5 tonne of NIS delivered to the factory.

c. Nuts stored in smaller silos (less than or equal to 20 tonnes) were found to have reduced UKR by an average by 0.34%, compared with larger silos (greater than 20 tonnes). The main effect is on reducing internal discolouration of kernel and this has been identified as a serious problem by the industry. This reduction using current payment scales that award 10c per kg for each 1% increment increase in SKR, results in a difference of $34 per tonne delivered to the factory. There are also advantages of smaller silos reducing the consignment moisture content of NIS delivered and the effect that this has on external discolouration of the kernel.

5. Last, an extension to the project examined further the effects of harvest frequency on kernel quality. A re-sorting decisions calculator was developed to help growers objectively assess the costs and financial benefits from re-sorting NIS on-farm.

It is clear from these results that there are significant financial rewards from adopting management practices and investing in infrastructure and capital equipment that facilitate these improvements. It must be remembered that the extent of these benefits will vary from farm to farm and each grower must assess their own situation before embarking on changes.

A strong extension program to deliver the findings from this and other work relating to quality management would benefit the Australian macadamia industry. This program would need to focus upon the economic costs and returns from adopting these practices. Consideration should be given to research and development of the factors causing many of the quality issues and quantifying their significance so management strategies can be developed that target these issues. Any future research work carried out into quality management needs to quantify the costs and benefits of changing management practices or investing in capital improvements that address the causes.

Chapter 3

Review of quality management in the macadamia industry

David Walton and Helen Wallace

Introduction

The macadamia has achieved a reputation as one of the most highly regarded nuts in the world (Nagao and Hirae, 1992), and the roasted kernels of macadamia are considered by many to possess the finest flavours of all the confectionery nuts (Crain and Tang, 1975). In addition, recent studies have emphasised the healthful qualities of the food due to the high content of monounsaturated oil (Ako *et al*., 1994). Rapidly increasing production of macadamia kernel has shifted emphasis from improving yield to improving quality of product so as to enhance marketing of the product (Swanepoel, 1998).

There is a great deal of information available concerning how quality of macadamias can be maintained on-farm. There is less information on maintaining quality at processors, partly because of closely guarded commercial interest. Kernel quality disorders include rancidity, immaturity, discolouration (internal or external), mould, germination, insect damage, after roast darkening (ARD) and shoulder damage. It is increasingly recognized that practices both on-farm and in the factory can significantly influence macadamia kernel quality. Producers are the first link in the quality management chain and so have a key contribution to make to the success of the macadamia industry by improving quality management on-farm. However, successful production and marketing of quality macadamia products requires a close partnership between grower and processor. A large research effort has produced much information on producing quality kernel. It is very important that the Australian macadamia industry capitalizes on this research investment by increasing adoption of kernel quality management to maintain its position as a world leader in production of quality macadamias. This review will examine how on-farm and processor practices can safeguard macadamia kernel quality. It will summarize the information available to enable preservation and enhancement of quality and increase of profits.

What is quality?

Defining nut quality is an important starting point for a discussion of quality. Quality has been described as the combination of all the characteristics that give the product value or “a degree of excellence” (Cavaletto, 1981b). Others have reviewed quality standards and methods from around the world for hazelnuts, and their report illustrates the complexity and difficulty of assessing quality of an edible nut (Riedl and Mohr, 1979).

The macadamia industry has developed various indicators of quality. Sampling procedures have been developed to assess quality in macadamia orchards: 1) husk, 2) shell plus kernel (nut-in-shell, NIS) dry weight, 3) kernel recovery (the percentage of kernel to NIS weight) and 4) specific gravity (SG), from which oil content can be estimated (Meyers *et al*., 1999). Some quality characteristics of macadamia kernel are: 1) kernel size and shape, 2) kernel wholeness, 3) oil content, 4) kernel colour and 5) flavour (Cavaletto, 1981). Oil content has been used by the industry as an indicator of quality (Joubert, 1986; Nagao and Hirae, 1992) and today is considered the prime indicator of quality (McConchie *et al.*, 1996). The final phase of macadamia nut development when sugars are converted to oils is critical, because this is when this important aspect of quality is determined (Trochoulias, 1988). Immature kernels are low in oil, and immaturity is a major cause of reject macadamia kernels. The reasons for immature kernels in macadamia are not well understood and further research is needed to clarify the causes.

There are various factors impacting on macadamia kernel quality, both physical and chemical, and some can be controlled or mitigated, such as damage from drying and cracking. Chemical changes can occur because of storage time and/or conditions, impacting on flavour and palatability. Delaying harvest of macadamias, and postharvest handling practices such as dehusking and dropping may affect quality, including the quality of roasted kernels. Other nuts provide some information on quality. Hazelnuts, like macadamias, have a hard shell which must be removed by mechanical means. The drying process necessary to aid cracking also predisposes the delicate tip of the nut to breakage (Riedl and Mohr, 1979). Macadamias are very similar, needing drying to aid cracking and having a pointed, vulnerable end. This is a possible site for damage and chemical and microbial degradation as well as loss of product and visual appeal.

On-farm practices affecting quality

Orchard establishment

The first decision when establishing a macadamia orchard is site selection. This decision is based on local factors such as soil type, drainage, erosion potential, aspect and risk of frost, and these factors will influence production and the sustainability of an operation. The Australian Macadamia Society (AMS) Code of Sound Orchard Practice (COSOP) contains advice for such decisions (O'Hare *et al.*, 2004). However, site can also influence aspects of quality. For example, the fatty acid composition of macadamia can vary between regions, which may change susceptibility to rancidity (Mason, 2003). This is similar to results for hazel-nut (Parcerisa *et al.*, 1994). Another example is that some of the older 'Hawaiian' varieties of macadamia including 246 developed for a tropical climate produce less Grade 1 kernel and have smaller nuts when grown in a sub-tropical region (Allan, 1992). However, newer varieties including 344 and more recent variety 741 performed well in the sub-tropical environment (Allan, 1992). A further influence of site is that macadamia is prone to excessive premature nut drop at daytime temperatures above 30ºC (Stephenson and Gallagher, 1986). This has obvious implications for yield, but also for quality, as there may be an increase in immature nuts at harvest.

Another important decision for orchard establishment is variety (cultivar) selection (O'Hare *et al.*, 1996). An important quality parameter is whole kernel (Stephenson and Gallagher, 2000; Stephenson and Bignell, 2006)). The main factor controlling whole kernel is genetic, i.e., variety (Wallace and Herbert, 1999; Wallace *et al.*, 2001; Wallace and Walton, 2005; Walton and Wallace, 2005b). Some varieties are reported to be more susceptible to nut borer and some more prone to produce stick-tight nuts, both important quality issues (Stephenson and Gallagher, 2000). It has also been suggested that some varieties are more prone to shoulder damage (Wallace and Walton, 2005). Adhesion of the kernel to the white enamelled interior of the shell has been suggested as a factor in shoulder damage (Hartung and Storey, 1939; Cavaletto, 1986), and this may be related to variety. Variety is also important for pollen-parent effects such as yield and whole kernel (Vithanage *et al.*, 2003; Wallace and Herbert, 1999). Fatty acid profiles can vary between varieties, which can affect shelf life (Mason, 2003), an issue that may warrant research on this issue for more cultivars.

Thus it is important to consider effects on quality as well as yield when selecting varieties.

Crop management

Irrigation

The benefit of irrigation of macadamias has been an issue of debate. Trochoulias (1987) found that on the New South Wales north coast there was no benefit from irrigation over a 9 year period. However, Ahrens (1998) and Anon. (2002; 2003) differ and found that irrigation provided significant benefits, especially in a time of drought. Stephenson *et al.* (2003) recommend that water should be applied to alleviate major stress during critical stages of nut development and maturation to maximize kernel recovery, although minor stress at maturation was not harmful, but slightly beneficial. The most critical time for water stress in Australia is from September to January (Stephenson, 2003). An important quality issue is immature kernels, and during severe water stress irrigation may reduce premature abscission and thus quality reduction.

However, there are also dangers from irrigation. Excessive application of water, especially in poorly drained soils, may contribute to the tree health problem called 'macadamia quick decline' (Nishijima *et al.*, 1997). It should be clear that the benefit of irrigation will vary from region to region, depending on reliability and distribution of rainfall. In Hawaii Bittenbender (1995) considered that if annual rainfall is less than 750 mm (30 in) it may be difficult to grow macadamia. That figure would arguably be inadequate in Australia where macadamia growing regions are hotter than Hawaii.

Canopy management

Macadamia grows well when planted at moderate density, e.g., 350 trees/ha (McFadyen and McConchie, 2005). Efficient light interception is vital for optimal production (Huett and Smith, 2005). To manage shading in mature orchards some canopy management is desirable. Macadamia bears on 2 year or older wood, therefore pruning will slightly reduce the bearing area of low density, mature trees, but if done at the right time of year will increase the vigour and production at the bottom of trees (Trouchoulias, 2005). Pruning young trees will delay maturity and excessive pruning will adversely affect yields. Canopy can be managed by mechanical pruning and possibly eventual removal of some trees to reduce shading and overcrowding (Trouchoulias, 2005). Hedging is a more cost-effective option than tree removal for maintaining open space for orchard management (McFadyen and McConchie, 2005). No canopy management programme brings a significant risk of economic loss, and hedging is considered the best canopy management option (McFadyen and McConchie, 2005). Early and frequent interventions are important strategies in canopy management to minimize losses and avoid the necessity of eventual severe canopy management measures (Huett and Smith, 2005).

Nutrition

Nutrition of macadamias is a broad topic because of the wide variety of soils used for cultivation. Because of this fertilizer regimes will vary widely, but optimal nutrition is essential to maintain quality. In this review only general principles will be considered. Essential categories to consider are soil ameliorants, nitrogen (N), phosphorus (P), potassium (K) and trace elements (Freimond, 1998b). Macadamias cannot tolerate poor nutrition, and the first effect is lowered production followed by decline in the general condition of the tree with fewer and sparser leaves, and eventually dieback of branches (van Niekerk, 2002). A general principle is to replace all nutrients removed. Soil analysis and leaf nutrient analysis are important tools for the producer aiding the optimal nutritional management of an orchard (Stephenson, 2004; Huett and Vimpany, 2005).

For N, small but frequent applications are recommended (Stephenson and Gallagher, 1989). Concern is expressed recently that application rates of N remain high despite indications that optimum yields and quality are obtained at a lower rate (Kuperus and Abercrombie, 2000; Stephenson *et al.*, 2000). Excess use of N may be a topic affecting quality that justifies further research. Lime is indicated as an amendment with repeated N applications to maintain quality (Stephenson *et al.*, 2002).

Phosphorus is the major energy source in a plant as a constituent of many enzymes and adequate P increases the uptake of calcium and magnesium (Trochoulias, 1988). However, P is extremely reactive with soils, rapidly becoming less soluble and less available, rendering surface application very inefficient (Vimpany, 1995). Thus P application remains problematic, as much surface-applied P may be wasted. Trochoulias (1988) expressed the need to investigate better methods of application or placement of P. Excess P is toxic to macadamia so care must be taken not to exceed plant needs (van Niekerk, 2002).

Potassium is a soluble ion and is supplemented regularly to maintain optimal levels. K is known as 'the element of quality', and deficiencies result in lower quality. Macadamia kernels contain more K than any other element. An important point is that high rates of application of K require supplementation with magnesium (van Niekerk, 2002).

Lime should be used cautiously because it modifies pH. Macadamias prefer a fairly low pH compared with other subtropical tree crops (Stephenson *et al.*, 1992; Freimond, 1998a). Calcium in lime is not very mobile, and applying lime to the surface without tilling may lock up the micronutrients iron, managanese, zinc, copper and boron in a narrow surface band of high pH (Freimond, 1998a). This may be particularly important for macadamia, as grafted trees have an extensive near-surface root system (Firth *et al.*, 2003). Trace elements, required in very small quantities, are very important and are usually supplied by foliar applications (Trochoulias, 1988; van Niekerk, 2002).

Pests and disease

Pests and disease will be discussed mainly for their involvement with a particular issue, immature kernel. Immature kernel is one of the main causes of reject macadamia kernel. Fruit spotting bug (FSB, *Amblypelta spp.*) is a sucking bug that inflicts major damage on a range of horticultural crops including macadamia. A complication of control measures for FSB is that increasing chemical control methods will adversely impact biologically based IPM strategies based around the parasitic wasp *Trichogrammatoidea cryptophlebieae* for control of another pest, macadamia nutborer (Waite, 2003). One of the effects of FSB on macadamia is premature abscission of nuts, though the extent of this loss is hard to quantify (Waite, 1998). In this way FSB contributes to immature kernel. The macadamia nut borer, *Cryptophlebia spp.* can also cause premature nut drop (Jones and Tome, 1992). Another source of immature kernel is premature nut drop caused by infection of the husk by husk spot, *Pseudocercospera macadamiae* (Drenth, 2003). Kernel quality is drastically affected by the low oil content of immature kernels, and sorting diseased nuts and kernel is costly (Drenth, 2005). Husk can also suffer from husk rot which is associated with, though not necessarily caused by, a *Phomopsis* and *Colletotrichum* complex (Drew, 2004). Husk rot is often associated with nutborer damage (Mayers, 1992). The result of both husk infections can be premature nut drop, contributing to immature kernel. Balanced control of these pests and diseases is important for minimising immature kernel and maintaining kernel quality. An intelligent approach is required through IPM to keep the components in balance.

Preharvest management

Preharvest cleanup and maturity monitoring

Cleaning up the orchard floor is an important preharvest operation based on orchard hygeine (van Niekerk, 2003), and is recommended in COSOP (O'Hare *et al.*, 2004). All unsound, old or immature nuts should be removed or finely chopped before mature nuts drop. While this is an important sanitation measure to reduce resevoirs of husk spot the, removal of immature nuts resulting from premature abscission is a bonus. This greatly reduces the economic losses later down the handling chain due to high rejections for immaturity. It is far more cost-effective to reduce immature nuts at the preharvest stage. Regular checking of the maturity of fallen nut is essential as tree nuts reach full size, and any nuts of doubtful maturity should be consigned separately to the processor (Loebel, 1988). All equipment such as harvesters, augers and dehuskers should be cleared of old nuts before the commencement of a new harvest as these could be a source of contamination by aged kernel (O'Hare *et al.*, 2000).

Harvest aids: shaking and ethephon

One of the difficulties of macadamia harvest is that some varieties have very extended abscission periods. In addition, not all varieties mature at the same time (Trueman *et al.*, 2002). These factors increase costs by necessitating several sweeps of the orchard for complete harvest. There is also evidence that nuts harvested late in the season may have reduced shelf life (McConchie, 2005a). Nuts lying on the ground for extended periods have been shown to have reduced shelf life (Salter *et al.*, 2005) as do nuts remaining on the tree for long periods (Jones, 1939; Penter *et al.*, 2002). The number of harvest rounds can be reduced and late-falling nuts ('sticktights') removed by accelerating abscission by means of tree shaking or use of the chemical ethephon (Trueman *et al.*, 2002). This would reduce quality loss by reducing number of harvest rounds, less time lying on the ground (Wallace and Walton, 2005) and lower quality late harvested nuts (Salter *et al.*, 2005).

Shaking trees is an effective method of accelerating macadamia nut drop and is not damaging when latest methods and modern equipment are used (Trueman *et al.*, 2002; Salter, 2005). The most effective method of accelerating nut drop is to 'loosen' nuts by applying ethephon after commencement of natural abscission and then shake trees. This method did not reduce nut quality (Trueman *et al.*, 2002). However, the most practical strategy is the use of ethephon alone. Care must be taken to use only correct application rates as macadamias are sensitive to ethephon and excessive leaf drop may result, especially for certain varieties. The long-term effect on yield of the use of ethephon remains unclear with variable yields in the 2 years following the work of Trueman *et al.* (2002). However, Stephenson and Gallagher (1987) found ethephon did not affect yield of 'Own Choice' variety. The use of ethephon remains a feasible harvest option although there may be a risk of yield decline (Trueman, 2003; McConchie, 2005a), an aspect requiring further research.

Appropriate methods will vary for each orchard and guidelines must be followed carefully as incorrect use can have dramatic results, e.g., substantial leaf drop. More details of usage are becoming available (Gillett, 2005; Gain, 2005). Those using ethephon must have handling, drying and storage facilities able to cope with large volumes of nuts (Burton and Jones, 2003).

Harvest management

Harvest frequency and efficiency

Macadamia nuts in Australia are harvested from the ground following abscission. During the harvesting season, harvesting rounds may be delayed for a number of reasons: the rapidity of nut abscission, access to harvesting equipment, availability of storage on farm, the ability of processors to receive product and weather conditions (Hamilton and Storey, 1956; Grimwood, 1971). In addition, the timing of harvest rounds is often a function of nut density on the ground for economic reasons (Liang *et al.*, 1996). Spoilage of nuts on the ground is affected by both soil MC and time on the ground (Liang *et al.*, 1996). Leaving nuts on the ground for four weeks did not affect recovery of processable kernel or eating quality, however, longer periods reduced quality mainly with respect to the processed recovery from nuts exposed to sunlight (Mason and Wells, 1984). The warmth of sunlight may enhance germination processes, thus causing deterioration in quality of nuts in sunlight (Bungay, 2003b). Shelf life determined by chemical analysis was not assessed in the study of Mason and Wells (1984). Nuts are only considered resistant to rancidity on-farm at 7-10% MC (Mason *et al.*, 2000a), so nuts on the ground may be at risk.

In another study, delaying harvest for only 3 weeks significantly reduced whole kernel, and increased shoulder damage and weight of pieces (Table 1.1; Wallace and Walton, 2005; Walton and Wallace, 2005a). Slow drying on the ground may reduce whole kernel (Wallace and Walton, 2003). In addition, delayed harvest nuts had significant After Roast Darkening (ARD) when roasted (Wallace and Walton, 2005; Walton and Wallace, 2005a). This result after only 3 weeks is of concern when COSOP allows for harvest rounds of 4 weeks (O'Hare *et al.*, 2004). Bungay (2003b) goes further and recommends that nuts be on the ground no longer than 1 week. The work of Mason *et al.* (1998) showed that shelf life was reduced in NIS stored at high MC at temperatures such as experienced on the ground, indicating the risk of quality loss for nuts on the ground for several weeks.

Quality is adversely affected by delays in harvesting rounds because of chemical and physiological changes, microbial infection and germination occurring in nuts while they are on the ground at high MC (Cavaletto, 1983; Wallace and Walton, 2005). Nuts from different harvest rounds definitely should not be mixed. This is particularly important for the first and second rounds when the first round may contain a higher proportion of low quality nuts (O'Hare *et al.*, 2004). The findings of Wallace and Walton (2005a) show that harvest rounds should be as frequent as possible. Losses of quality in terms of reduced whole kernel, increased shoulder damage and pieces and increased dark kernels result from delays in harvest (Table 1.1). The Australian industry is beginning to harvest nuts more frequently and it is reported that in 2004 this has improved quality to more than offset the increased harvest costs (Heap, 2004).

Table 1.1. Loss of kernel quality during harvest delays of three and five weeks (Source: Wallace and Walton, 2005)

	Experiment	Control (no delay)	3 wk delay	5 wk delay

Whole kernel (% wt)	One	49.0	43.0	
	Two	52.0	40.0	38.0
Shoulder damage (%)	One	44.0	78.0	
	Two	12.0	21.0	24.0
Weight of pieces (%)	One	5.5	9.0	
	Two	3.5	6.0	7.0
Dark kernels (%)	One	5.0	46.0	
	Two	3.0	27.0	33.0

Another harvest issue is efficiency of harvest. Missing some nuts will obviously result in more low quality kernel in subsequent harvest rounds and some operators make a second pass with the harvester to pick up nuts missed in the first pass. However, harvesting is more efficient overall when only one pass is made and the whole orchard is harvested more frequently (Bell, 2002). The number of nuts missed at harvest could by minimized by use of efficient machinery and careful maintenance of that equipment. Suitable preparation of the orchard surface to maximize pickup in the first pass is essential (O'Hare *et al.*, 2004).

Batch harvesting

Hybrid and *M. integrifolia* macadamias should be consigned to processors in separate batches (O'Hare *et al.*, 2000). This is because hybrid cultivars of *Macadamia integrifolia* and *M. tetraphylla* are viewed as being different in terms of roasting colour (Lemmer *et al*., 1998). The South African industry has always harvested, dried, processed and packed nuts of hybrid cultivars completely separately from *M. integrifolia* cultivars (Bungay, 2003b) and known hybrid cultivars are packed separately for overseas roasters (Lemmer *et al*., 1998). In addition, where quantities are sufficient pure varieties should also be consigned in batches to minimize processing difficulties caused by varietal differences.

Macadamia processors in Australia roast macadamias to a very low level of colour because processors fear that batches of mixed cultivars may roast unevenly (Burton, pers. comm.). While these concerns may be justified, other causes of roasting variability are delaying harvest and dropping nuts (Wallace and Walton, 2005). Increasing harvesting frequency and improving handling techniques may improve overall quality enough to enable darker roasts to be successfully achieved in the Australian industry

Dehusking

The fibrous husk of freshly harvested macadamia fruit constitutes 40-45% weight of the fruit (Cavaletto, 1983). The first step in processing is the removal of husk, which is normally accomplished on-farm by mechanical dehuskers although some nut in-husk (NIH) may be transported to a processor and dehusked there. It is vital that dehusking takes place immediately following harvest as respiration of wet NIH will cause heating and deterioration such as rancidity (Hobson, 1991). It is industry best practice to dehusk within 24 hours of harvest to avoid serious loss of quality due to heating of bulk NIH from respiration (Mason *et al.*, 1998; O'Hare *et al.*, 2004).

A variety of machines have been developed for dehusking. Nuts usually fall from the tree at around 25% MC (Weinert, 1993), and at dehusking are typically at 20-23% MC (Wallace and Walton, 2005). It has been widely assumed that nuts at high moisture content (MC) are relatively immune from damage (Pearce, pers. comm.). Dehusking machines have the potential to cause damage to kernels. In a recent study dehusking at field MC with 2 mechanical dehuskers caused significant shoulder damage (Wallace and Walton, 2005). In addition, dehusking at lower MC (around 10%) after nuts had been on the ground for some time resulted in significant loss of whole kernel (Wallace and Walton, 2005). The most common practice is to dehusk only in the shed, typically with a Shaw type dehusker. However, some operators dehusk in the field at harvest with a harvester-mounted dehusker, typically of the Admac® type. This practice normally necessitates a second dehusking in the shed. This means that field-dehusked nuts are subjected to additional mechanical stress, which may have quality implications. In one experiment Wallace and Walton (2005) found that the Admac dehusker caused more shoulder damage, but in a further study both the Shaw and Admac machines caused significant shoulder damage (Wallace and Walton, 2005). The efficiencies gained from field dehusking should be carefully weighed against possible quality loss from subjecting nuts to an extra dehusking.

Dehusking can cause quality loss. Careful attention should be paid to maintenance and adjustment of dehusking equipment. There is also a need for research into an improved dehusker. The most common dehusker today is old technology. At this stage of farm operations dehusked nuts may be transported to a processor without drying.

Sorting and resorting

Following dehusking, nuts must be carefully inspected to remove foreign matter and unsound nuts. Thorough on-farm sorting is essential to remove small, damaged and unsound kernel very early in the postharvest chain. Size is very important as nuts smaller than 18 mm are more likely to be immature (Bungay, 2003b). The production efficiency of the industry is compromised as long as unsound kernel continues to reach the processor (Mason *et al*, 1996). Relying on visual belt sorting alone may result in many unsound kernels, including mouldy product, passing into the processing line. It appears that more objective, SG based systems such as water and air sorting are most practical and cost-effective.

Water and air sorting

Some producers use water flotation on-farm to remove immature nuts (Bungay, 2004). This is a very cost-effective process for the industry as it is very inefficient to handle and transport nuts to a processor only to have the kernels rejected in the factory for immaturity or other types of unsoundness. Wet NIS will sink in fresh water while unsound product floats and can be removed. The Southern African Macadamia Growers Association (SAMAC) supports and encourages the use of flotation sorting of NIS, claiming it increases profitability by up to 13% (Bungay, 2003b). On current evidence, water sorting based on sinking of NIS at >1.02 SG works well if NIS is at 4.5-15% MC. However, segregation of sound and unsound nuts by SG is influenced by variety and time of harvest as well as MC (Mason *et al*, 1996). Size grading before flotation will remove many immature nuts >1.02 SG as undersize (Mason *et al*, 1996). More research may be needed into the accuracy of water sorting of NIS for varieties other than 246 and 660, those used by Mason *et al.* (1996).

If on-farm flotation is used strict hygiene must be observed to avoid contamination by pathogens such as *Salmonella* (Dommet *et al*., 2000; O'Hare *et al.*, 2004). Also, water sorting leaves nuts very wet, and this excess free water must be removed before nuts are moved to storage. NIS must not be visually wet when entering storage (Bungay, 2003b).

Another sorting method based on SG is the use of air (suction) adjusted to remove undesirable nuts and foreign matter (Mason *et al.*, 1996; Bungay, 2003b). For this system NIS must be size graded and MC reduced to <15% before sorting (Mason *et al.*, 1996). To avoid unnecessary losses of sound kernel while eliminating the majority of unsound, regular sampling and kernel assessment of NIS on-farm during sorting is essential (O'Hare *et al.*, 2004).

Dropping nuts

Following dehusking, every sorting operation involves moving and dropping NIS. The effect of physical damage due to handling has been a concern for many workers on many crops including peanut (Turner *et al*., 1967), navy beans (Hoki and Picket, 1973; Bartsch *et al*., 1986), pea bean (Perry and Hall, 1966), and various common seed grains (Bilanski, 1966). Where there are many handling operations the increase in damage caused by individual handling operations may be small and difficult to measure (Perry and Hall, 1966).

Dropping macadamias causes damage and loss of quality (Wallace and Walton, 2005). In general, damage from impacts increases as MC decreases for many seeds, and this applies to macadamia (Wallace and Walton, 2005). However, although macadamias are more subject to damage at low MC, e.g. 3%, they can also be damaged by dropping at intermediate and high MC, e.g., 20%. NIS dropped at 20% MC produced dark kernels at roasting (Table 1.2; Wallace and Walton, 2005). There is also some evidence that different cultivars vary in susceptibility to damage (Wallace and Walton, 2005). Dropping damage to high MC NIS is a particularly important finding for handling of nuts on-farm, as they are at high MC for most of the handling operations on-farm.

Dropping NIS at 3% MC significantly increased shoulder damage from 14% for the control to 24% when dropped, and at intermediate MC (9%) shoulder damage increased from 17% for the control to 30% for the dropped treatment. In these experiments (Wallace and Walton, 2005) NIS was dropped four times from a height of two m onto NIS. Dropping at both 3% and 20% MC produced significant dark kernels at roasting (Wallace and Walton, 2005). Table 1.2 shows the potential for loss of quality on-farm as revealed in loss of roasting quality. To minimize dropping damage, resorting should be kept to the minimum needed to optimise quality.

Table 1.2. The effect on roasting colour of dropping NIS four times from a height of 2 m onto a bed of NIS. Shaded results are for dropped treatments.

Cultivar 741 Dropped at 20% MC 2003		
Colour	**Kernels (%) from undropped controls**	**Kernels (%) from NIS dropped at 20% MC**
Very light	20.0	8.0
Light	57.0	51.0
Dark	19.0	38.0
Very dark (reject)	4.0	3.0
Cultivar 741 Dropped at 3% NIS MC 2003		
Colour	**Kernels (%) from undropped controls**	**Kernels (%) from NIS dropped at 3% MC**
Very light	15.0	0
Light	49.0	15.6
Dark	32.0	36.7
Very dark (reject)	4.0	47.8

In addition, the height of drops and receiving surfaces should be considered (Wallace and Walton, 2005). The AMS C0SOP recommends drop heights not exceed 2 m, a standard that is difficult to attain, but the message is to minimize drop heights. The work by Wallace and Walton (2005) involved drop heights of 2 m, so it is conceivable that at greater drop heights more damage would occur. Typical drop heights on farms are 3-4 m or higher in some cases (McConachie, pers. comm.). NIS may be dropped up to six times while on the farm during various operations, including dropping into the truck which transports nuts to a processor (McConachie, pers. comm.). A specific example comes from an on-farm study of a commercial operation by Wallace and Walton (2005) where there were five drops before consignment.

The receiving surface is also important. NIS may be dropped onto a surface of metal plate or NIS depending on how full the receiving container is at the time of dropping. Wallace *et al.* (2001) found that nuts dropped onto a steel surface at 13% MC suffered more shoulder damage than those dropped onto NIS. Impacts can be reduced by installing 'easy let-downs' in macadamia silos on-farm, design features which allow nuts to roll down a series of ramps or drop in stages rather than just in a single drop (Bungay, 2003b; 2004). Another impact reducing technology is special tough, resilient polymer surface coatings now available. These surfaces can be applied to all processing equipment and have potential to reduce impacts to NIS, as well as reduce wear and tear on equipment and reduce the high noise levels associated with macadamia processing. Uptake of impact reduction measures has been slow to date (Bungay, 2004; O'Hare, pers. comm.). Considering that recent research has confirmed the damage to kernel caused by impacts to NIS, research to determine the benefits of such coatings should be considered. The effect of impact damage on shelf life has not been studied. The release of oil from cells damaged by dropping may predispose to the development of rancidity.

Slow uptake of these potentially beneficial technologies raises the issue of application of research by producers. There may be reluctance on the part of some producers to spend money implementing measures to maintain quality when they do not perceive that they receive compensation for their expenditure in the form of higher prices for quality. Maintaining quality should benefit all in the industry. There is an urgent need for the industry to move to a more genuine 'payment for quality' system as an incentive to reap the benefits of research (Bungay, 2004). Quality issues need to be addressed all along the postharvest chain and are not the sole responsibility of either grower or processor.

NIS may be transported to a processor at this stage. However, the scale and production volume of the Australian macadamia industry probably makes on-farm drying and some on-farm storage essential for most growers. Lack of suitable on-farm storage may result in serious quality loss in the event of delayed despatch to processors at peak harvest.

Storage of NIS

There is an increasing need for storage of macadamia NIS on-farm because of increasing scale of farming operations and to provide safe storage during periods of congestion at processors. There are 3 considerations for storage: 1) MC of NIS, 2) storage temperature and 3) storage duration. These conditions are important for determining the quality of kernel produced. Raw kernel from NIS stored under certain conditions may suffer no apparent loss in quality, and deterioration may only become evident in the roasted kernel (Mason *et al.*, 1998). A summary of how storage conditions affect quality of raw and roasted kernel is presented in Table 1.3, and actual losses which may be experienced are presented in Table 1.4. Quality loss was reflected in reduced times to roast to a set colour standard (Table 1.4; Mason *et al.*, 1998). Decrease in quality of roasted kernel was also accompanied by a significant deterioration in sensory attributes (Mason *et al.*, 1998).

Table 1.3. Effect of moisture content, temperature and storage duration on quality of raw and roasted kernel from stored macadamia NIS (compiled from Mason *et al.*, 1998). Shaded areas show where significant results occurred.

NIS Moisture Content (%)	Temperature (ºC)	Storage Duration (months)	Quality loss in Raw Kernel (%)	Quality loss in Roasted Kernel (%)
≤ 7.5	5	12	**No**	**No**
10.0	5	4	**No**	**No**
7.5	25	2	**No**	**Yes**
10.0	25	1	**Yes**	**Yes**
12.5+	5	4	**Yes**	**Yes**

12.5+	25	1	**Yes**	**Yes**
12.5+	25 (ambient)	1	**No**	**Yes**
3.5	40	1	**Yes**	**Yes**
10	40	1	**Yes**	**Yes**

Table 1.4. Roasting times and reject kernels (%) for NIS stored under different MC and temperature regimes (compiled from Mason *et al.*, 1998). Shaded areas show where critical changes in roasting times and kernel rejects occurred. Shorter roasting times indicate reduced quality.

NIS Moisture Content (%)	Temperature (ºC)	Storage Duration (months)	Roasting Time (min)	Mean Kernel Rejects
3.5	Control	Nil	10.5	2.6
10	25	1	11.0	7.5
		2	10.2	6.4
		4	7.6	7.8
		8	6.9	6.6
12.5	25	1	11.2	18.4
		2	8.1	31.2
		4	6.3	48.7
15	25	0.5	10.8	8.3
		1	11.1	15.6
		2	11.2	22.7
		3	6.7	33.4

The optimum procedure for on-farm storage to preserve quality is to rapidly dry NIS to a MC of 7.5-10% (Kowitz and Mason, 2001), then consign nuts to a factory as soon as possible. Storing NIS on-farm at high MC leads to rapid loss of quality. Storing NIS of 12.5% and 15% MC at 25ºC, and other NIS of 15% at 5ºC resulted in brown spotting of kernels at roasting (Kowitz and Mason, 2003). These spotted kernels must be rejected. An on-farm study of a commercial operation found unsound kernel increased rapidly with storage time and number of drops over a period of two weeks (Wallace and Walton, 2005) (Figure 1). In this study where ambient air only was used for drying MC was reduced from 23% at dehusking to only 16.5% after two weeks. NIS should be stored on-farm no longer than one month. At the factory nuts should be dried to 3.5% (1.5% kernel MC) as soon as possible after consignment (Mason *et al.*, 1998). NIS should not be dried on-farm to less than 7.5% as damage during transport may occur at lower MC (Mason, 2000a). As an alternative, NIS at 7.5% MC may be stored for up to 12 months provided the temperature is maintained at 5ºC (Mason *et al.*, 1998).

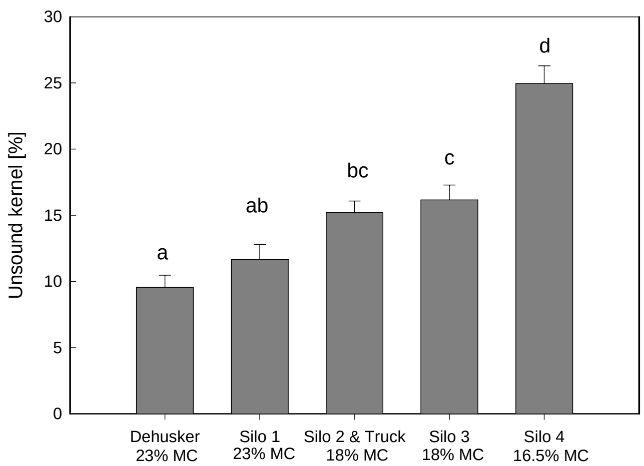

Fig. 1. Unsound kernel weight of macadamia kernels at various on-farm postharvest stages over a period of two weeks. Means and standard errors are presented; means with different letters are significantly different (Duncan's, $P<0.05$) (Source: Wallace and Walton, 2005).

Another storage issue is aeration of storage containers to remove the vital heat of respiration. Respiration of stored NIS at 23% MC can raise temperatures 0.5ºC per day within the mass of NIS (Mason *et al.*, 1998). Therefore constant aeration is essential until the MC has been reduced to at least 12%. As well as excessive temperature causing quality loss, nuts while respiring are using up energy, resulting in mass and quality (oil) loss (Bungay, 2001). In this respect the relative humidity (RH) of the air input must be lower than that within the NIS mass or no drying will occur and nuts can even be re-wet if RH of the input air is too high (Mason *et al.*, 1998). To summarize, deterioration of stored kernel increases with increasing MC and temperature. Loss of quality is not always apparent in raw kernel and may show up only in roasted kernel.

Drying NIS

Drying is one of the most important steps, perhaps the most important step (Weinert, 1993) in the macadamia processing chain for determining the quality of saleable product. Correct MC is important for food products for microbial stability, texture and shelf life (Labuza and Contreras-Medellin, 1981; Bungay, 1995; Kowitz and Mason, 2003). The aim must be to have a drying regime that permits the highest moisture removal rate and energy efficiency within operational restraints, including quality of product (Davidson *et al.*, 2000). For macadamias, the drying process is necessary to prevent microbial infection, facilitate cracking and roasting, improve flavour and texture characteristics and to stabilize the chemical components of the kernel to maximise shelf life (Kowitz and Mason, 2003). Despite this there is limited information on drying conditions for macadamias as reflected in the relatively small number of papers in published literature (Mason and Van Blarcom, 1993). Quality loss from incorrect drying methodology may only be obvious when kernels are roasted (Kowitz and Mason, 2003).

Drying should not be seen as a simple operation, as the macadamia nut consists of a living embryo surrounded by an extremely hard, dense, stone-like shell. The shell must first be dried before water from the kernel can exit the seed. Excessive speed of drying predisposes it to internal browning (Prichavudhi and Yamomoto, 1965), probably from cell damage caused by pressure building within the kernel (Bungay, 2003b). Drying high MC NIS at initial temperatures of 45ºC and 50ºC causes brown centering at roasting (Kowitz and Mason, 2003). Thus there are firm grounds for the AMS COSOP recommendation that NIS be dried initially at no higher than 30ºC or more than 5ºC above ambient temperature (O'Hare *et al.*, 2004).

MC is a critical factor influencing macadamia stability (Cavaletto *et al.*, 1966) and drying determines storability, palatability and roasting qualities of kernels (Cavaletto, 1983). At harvest, macadamias can have a MC as high as 30%, and it is essential to reduce this to a level at which hydrolytic activity and mould development are prevented. Temperature and RH conditions during drying are critical to maintain quality, and unsuitable control of drying can seriously reduce quality, as shown in Table 1.5. MC should be reduced to 7.5-10% within 2 weeks of harvest to maintain quality (O'Hare *et al.*, 2004; Kowitz and Mason, 2001). Bungay (2004) is more demanding recommending that nuts be dried to 10% MC in only 7 days. However, drying must be accomplished in ways that do not compromise other quality parameters. NIS should not be dried to low MC such as 3.5% on-farm for the following reasons: 1) quality can be severely reduced if drying temperatures are not strictly controlled and 2) handling and transportation of NIS at low MC can result in physical damage to kernel (Mason, 2000a). Growers may not have the equipment to maintain control over drying and this can result in abnormal kernel browning during roasting (Kowitz and Mason, 2003). Over-drying nuts also poses dangers as once the kernel MC of each nut has been reduced there is less evaporative cooling, and overheating of the kernel can occur (Bungay, 2003b).

If nuts are held on-farm, drying should be commenced immediately. However, many farms do not have suitable equipment to achieve MC of 7.5% (Mason, 2000a). An example is a study by Wallace and Walton (2005), where nuts on-farm in a commercial macadamia operation remained at 16.5% MC after 2 weeks in silos with only ambient air for drying. Drying with air over 70% RH poses risk of losses from mould and kernel discolouration except at temperatures below 15ºC (Table 1.4). Prolonged exposure of NIS at high MC to air with a high RH can cause kernel to brown excessively all over or develop brown spotting on the upper surface at roasting (Kowitz and Mason, 2003). If drying cannot be achieved with ambient air dehumidified air should be used. Control of the RH of air entering the nut mass is of primary importance in achieving even and effective drying throughout the nut mass. Using only ambient air provides little control over the drying process, particularly where cool, wet conditions prevail. An aeration controller based on RH provides more control over drying and dehumidified air or supplementary heat may be needed to achieve more rapid and more even drying (Kowitz and Mason, 2003).

If a producer cannot dry nuts on-farm to 7.5-8% MC in 2 weeks they should be dispatched to a processor with all urgency. Investment in suitable drying equipment on-farm could be one of the most cost-effective means of improving macadamia quality. Several drying regimes have been used for macadamias (Table 1.6).

Table 1.5. Kernel quality losses (%) from incorrect drying conditions for NIS 0n-farm (Source: Kowitz *et al.*, 2001). Shaded areas show where commercially important losses occurred.

Drying air conditions		Quality loss	
Temperature (ºC)	**Relative humidity (%)**	**Mouldy**	**Discoloured**
15	50	0.1	0.0
	70	0.1	0.1
	90	0.2	4.6
20	50	0.0	0.1
	70	0.3	0.0
	90	2.1	5.2
25	50	0.0	0.0
	70	0.4	0.0
	90	3.6	5.9
30	45	0.0	0.0
	35	0.1	0.1
	25	0.1	0.0
	25	0.1	0.0
	25	0.0	0.1

Table 1.6. Various drying regimes for macadamia nut-in-shell.

Stage 1	Stage 2	Stage 3	Stage 4	Reference
X d @ 38°C [b]	X d @52°C [c]	X d @ 60°C [d]	----	Cavaletto, 1981
4-5d @ambient	2-3d @ 38°C	4-5d @ 50°C	1-2d @ 60°C	Cavaletto, 1983
2d @ 38°C	2d @ 45°C	2d @ 60°C	----	AMS., 2002

5-7 d @ 32°C	1-2 d @ 38°C	1-2 d @ 44°C	Finish @ 50°C	Mason, 1983a
3-4d @ 30°C	2-3d @ 40°C	X d @ 50°C[a]	----	Mason, 1983b, Mason *et al.*,1995
6 d @ 45°C				Trueman, 2003

a Dried at 50°C until kernel MC of 1.0-1.5% achieved.

b Dried at 38°C until kernel MC of 8% is achieved.

c Dried at 52°C until kernel MC of 5-6% achieved.

d Dried at 60°C until kernel MC of 1.0-1.5% achieved.

What is clear from these methods is that there is considerable discrepancy in the necessity for staged temperature increase, the timing of stages and the temperatures employed. Some of the regimes above are for laboratory conditions, and may not be applicable to bulk lots of nuts. Drying appears to be a topic for which consensus on temperatures and timing has not been reached. Clarification of the optimum drying regime is probably required.

Design of on-farm drying facilities

Design of an on-farm drying system is one of the most critical elements of a producer's infrastructure and large operations are particularly vulnerable to large losses in quality (Gordijn and Potgieter, 2003). It is beyond the scope of this review to give details of drier design, but some principles are presented below. The most effective and efficient system for both drying and storage combines both heated or dehumidified air with a RH based aeration controller, remembering that on-farm the same silo is usually used for storage while nuts are drying (Kowitz and Mason, 2001). As discussed under storage, it is essential that the air used for drying is of RH lower than in the nut bed or nuts will not dry, and will even rewet if RH of air used is higher than in the nut bed. Moltzau and Ripperton (1939) showed that a RH of 60% or more resulted in macadamias rewetting. A RH based aeration controller is a minimum requirement for all on-farm drying and storage facilities (Kowitz and Mason, 2001). This controller will prevent nuts dried below 10% MC from re-wetting in periods of wet weather. A rule to guide the design of a drying facility is that is should be capable of removing 2% of NIS moisture per day, a requirement that usually rules out ambient air-only systems (Bungay, 2003a). A very important issue is whether to dry NIS in a silo or in a recirculation bin. True silos appear to have few advantages and many disadvantages for drying, compared with a recirculation bin (Bungay, 2003a).

There are dangers with using heated air. Uncontrolled heating of high MC nuts can cause off flavours, pre-germination changes, reduction of shelf life, cracking of shells and brown centred kernels (McConachie, 1994). The drying temperatures should never exceed 30ºC when NIS is above 15% MC to prevent: 1) over-drying of NIS at the bottom of the drying vessel closest to the air source, 2) kernel becoming brittle from drying too rapidly and 3) brown centring in kernels after roasting (Prichavudhi and Yamomoto, 1965; Kowitz and Mason, 2001). A thermostat to monitor incoming air and emergency shut-off and alarm systems are essential. Monitoring of the air at both inlet and outlet is required. The importance of monitoring systems for on-farm drying cannot be overemphasised. Professional advice should be sought to achieve best possible quality, according to the producers scale, needs, finances and resources. The report of Kowitz and Mason (2001) and the book by Bungay (2003b) are useful resources.

To prevent over-drying at the air intake the air temperature should not, as a rule of thumb, exceed 30ºC (Kowitz and Mason, 2001), although the safe temperature depends on the RH of the air (Bungay, 2003a). Bed depth of a silo should be a maximum of 1 m (Kowitz and Mason, 2001). Technically, a silo is a storage facility with a height of 3 m or more (Bungay, 2004). It should be noted that this temperature is lower than the 38ºC suggested earlier by Hamilton *et al.* (1980), and Cavaletto (1980, 1981). Where bed depth is greater than 1 m, lower temperatures of 20-25 ºC must be used to prevent over drying of NIS at the bottom of the silo. Bungay (2003b) states that a maximum bed depth of 2.4 m is allowable using ambient air, but that 2 m is preferable. The greater the bed depth, the lower the temperatures that must be used (Kowitz and Mason, 2001). Over-drying at the silo base also involves rewetting further up the container, with consequent problems (Bungay, 2003a). Many silos currently in use exceed 1m in bed depth, perhaps as a consequence of adapting silos designed for other crops such as grain (Bungay, 2004). This is an issue that needs to be urgently addressed by the Australian industry, and may be an area where rapid and significant gains can be made in quality. What is critical is the bed depth of nuts. Bed depths greater than 1 m decrease the drying rate, increase the capacity of the fan required, increase the temperature gradient across the nut bed and increase the risk of uneven drying (Kowitz and Mason, 2001). Many Australian drying facilities would not pass the bed depth test. The temperature of drying on-farm should never exceed 40 ºC (Kowitz and Mason, 2001). High temperatures may damage cells in the kernel by developing a miniature ‘pressure cooker’ in each individual nut, even for short periods (Bungay, 2001). Such cell damage may enable leakage of oil from cells especially as temperatures rise late in the drying cycle and oil viscosity decreases (Bungay, 2001, 2003). These factors may contribute to the ‘oily’ appearance of many kernels after drying. Uneven drying will lead to uneven quality later in the chain, especially at roasting. A series of low-volume batch-drying bins is preferable to one large silo of equal volume. Large structures should only be used for storage awaiting consignment once satisfactory MC had been achieved Kowitz and Mason, 2001).

Dispatch

On some farms NIS is transported to a processor after dehusking while other operators partially dry nuts before consignment. It is important to transport nuts as soon as possible, especially if nuts are not dried on-farm. It is undesirable to transport nuts at <7.5% MC because of the increased risk of impact damage at lower MC (Mason, 2000a). Cavaletto (1986) even suggests that transport at >10% MC may result in bruising damage. This may be a matter of concern for nuts transported long distances, such as from North Queensland and Bundaberg. However, there is a lack of clarity over the best MC for transport (Mason, 2000a). Transported nuts can be subjected to severe impacts when dropping into a truck on-farm as dropping heights into a truck can be as high as 6m (McConachie, pers. comm.). Damage may also occur when dropping into the receiving facility at the processor. Studies of transport effects would need to control for the effects of dropping on transported nuts, and it is unclear if this has been done in the past. Drop heights and receiving surfaces are important issues discussed above. At 15% MC, drop height should not exceed 3 m, and at 10% MC, should not exceed 2 m (Simpson, 1992). It is very obvious that these standards are violated during many farm procedures and most dispatch operations. Vibrations and bumps during transport are considered to increase loss of whole kernel and to damage kernel (Simpson, 1992; Mason, 2000a). However, these claims appear to be without hard evidence. In addition, Cavaletto (1986) states that transport produces dust in NIS from the milling action of shells on kernels during transport. Heating from the sun should be avoided during transport, consequently Bungay

(2003b) recommends not transporting during the heat of the day and covering loads with a white tarpaulin.

Processor practices affecting quality

There is limited information available on some processing practices because of closely guarded commercial interest. However, many of the principles for maintaining quality that apply on-farm have validity in the processing environment. Processing has been reviewed by Weinert (1993) and Mason and McConachie (1994).

Dropping damage and processing

NIS is subjected to numerous drops in the factory between the receiving and drying facilities. There are further drops moving to a storage facility, depending on factory operations. The effect of dropping is dependant on four factors, MC of the nuts, drop number, drop height and receiving surface and these are discussed above. Multiple drops of four and six times from a height of one metre have been found to increase shoulder damage (Wallace *et al.*, 2001). Wallace and Walton (2005) found that four drops from 2 m onto NIS at both 3% and 9% MC increased shoulder damage and that dropping at high or low MC can cause loss of roasting quality. NIS may be subject to up to 15 drops at heights of from 0.3m to 4m in a factory before cracking (McConachie, pers. comm., 2002). In total, NIS may be subjected to as many as 22 drops between harvest and cracking (McConachie, pers. comm., 2002). Numerous drops as NIS from low heights cause damage to macadamia (Wallace *et al.*, 2001; Wallace and Walton, 2005). It is likely that the studies of Wallace *et al.*, (2001) and Wallace and Walton (2005) are conservative in the amount of dropping applied, and that the effects of actual industry dropping are greater.

Once the protective shell has been removed kernel is directly exposed to the damaging effects of dropping and may be more prone to damage (Smit, 1996), although there is little information on this subject. This may account for much of the accumulation of kernel dust found in bulk packs of factory kernel (Wallace *et al.*, 2001), similar to the ‘milling’ described by Cavaletto (1986) for transported nuts.

Hard dropping surfaces such as steel have been shown to reduce kernel quality (Wallace *et al.*, 2001). Polymer surface coatings are such as “Rhino Linings®” are available to reduce the effect of impacts but the degree of uptake of this new technology in the processing sector is unknown. Processors have the opportunity to lead the way in implementing this innovation in quality control. The effect of impacts caused by dropping shelled kernel in a processor setting has not been quantified. Wallace and Walton (2005), using electron microscopy, showed that the cuticle of kernel from nuts dropped as NIS showed visible damage. This would probably also be the case for kernel dropped after shelling, and is an aspect of dropping that merits further research.

Sorting and cleaning NIS at the processor

It is economically advantageous that as much unsound kernel as possible should be removed as NIS before it gets into the processing line. Water flotation can be used on-farm to sort NIS early in the chain, however, water is considered unreliable and carries a high risk of microbial cross-contamination (Mason *et al.*, 1996). A method of air-sorting located on-farm or at the processor to remove unsound nuts based on SG has been successfully tested (Mason *et al.*, 1996). This system is combined with a NIS cleaning and sanitising system at the processor (Mason *et al.*, 1996). Locating both facilities at the processor is more efficient in terms of number of units needed, and would offer the greatest advantages, although the cost would be borne by processors (Mason *et al.*, 1996).

Drying NIS for processing

Drying, sometimes also termed curing (Bungay, 1995; 2001) has been described as the most critical step in macadamia processing (Weinert, 1993). Many of the details of their drying methods are kept confidential by processors (Grimwood, 1971; Weinert, 1993).

All NIS received by processors must immediately be dried to 3.5% NIS MC (1.5% kernel MC) to prevent flavour deterioration, harden the shell for cracking, and also to loosen the kernel-shell attachment by shrinking the kernels (Weinert, 1993). Bungay (2003b) claims that whole kernel decreases during storage. He suggests holding NIS at 5% MC at the correct temperature until drying to 3.5% just before cracking to reduce loss of wholes. If at arrival the nuts already have been dried to 7.5-10% MC they can be safely stored for up to 12 months as long as the storage temperature is maintained at 5ºC (Mason *et al.*, 1998). This cold storage provides an important option for processors to accept NIS from growers in peak times and maintain kernel quality instead of kernel deteriorating in inadequate on-farm storage when processing capacity is strained during harvest peaks. Upon removal from cold storage NIS must be immediately dried to cracking MC to prevent condensation and rewetting of the cold nuts (Bungay, 2003a).

The principles of drying NIS on-farm discussed above also apply in a factory setting (Bungay, 1995, 2001, 2003b; Kowitz and Mason, 2001). In general, the higher the MC of NIS at the beginning of drying, and the larger the drying facility, the lower must be the commencing temperature of drying. The drying operation should be planned to minimize movements, drops and drop heights as these all contribute to loss of quality as discussed above. Where possible, batch processing of nuts should be implemented, particularly keeping hybrid varieties separate from pure integrifolia lines. However, this may not be practicable with small lots. The advantages of batch processing will be most evident when nuts are roasted, as hybrids may have different roasting characteristics to integrifolia varieties (Lee, 1998). However, batch processing may have other quality control advantages when nuts from different farms, districts and even regions are kept separate. Drier design is an important consideration for processors and principles are discussed above (Kowitz and Mason, 2001; Bungay 2003).

Rehydration

Macadamia NIS dried to 3.5% MC will rehydrate at ambient RH (Palipane and Driscoll, 1992; Bungay, 2003b). This means that great care must be taken with stored NIS and kernel to ensure storage containers are sealed. This is especially important if NIS is stored at higher temperatures, for example, NIS stored at 25 ºC must have MC no more than 3.5% to maintain quality (Mason *et al.*, 1998).

Storage of NIS in the factory

Following drying to 3.5% NIS MC at the factory NIS may need to be stored awaiting further processing. NIS can be safely stored for 12 months: 1) at 25ºC when dried to 3.5% MC or 2) at 5 ºC when dried to 10% MC. These and other principles and guidelines are discussed above in relation to on-farm storage (Mason *et al.*, 1998). This gives processors great flexibility if they have access to cold storage facilities and some processors are moving to more cold storage (Underhill, pers. comm.). It may be to the industry’s advantage to enable producers who do not have drying and storage facilities capable of reducing MC to 7.5-10% in no more than 2 weeks to transport their crop to a processor immediately following dehusking. The cost of cold storage may be less than the losses to the industry from poor on-farm drying and storage.

Cracking NIS

Decortication, commonly called cracking, is an unavoidable but very difficult operation due to the strength of the macadamia shell (Grimwood, 1971; Chun-Hui and Yiu-Wing, 1994/95), equal in tension to that of reinforced concrete (Jennings and Macmillan, 1986). The most commonly used method for cracking is compression, a method that yields an appreciable amount of partially cracked nuts and broken kernels (Liang, 1977; Mason and McConachie, 1994). Applying excessive force at cracking drives shell fragments into the kernel, causing damage (Liang *et al.*, 1988). Liang *et al.* (1988) assessed notching shells and freezing NIS to aid cracking. Notching the shells before cracking increased whole kernel % from 28% to 42% while half kernels remained unchanged (Liang *et al.*, 1988). This suggests that increased whole kernel came from reduced pieces when shells were notched before cracking. Freezing for 8 h at -18ºC alone increased whole kernel from 38% to 83%, while half kernels decreased from 46% to 7% (Liang *et al.*, 1988). While freezing did not reduce quality the kernels were not roasted, so a question remains over the effect of freezing on roasting quality. Notching reduced the force required for cracking, while notching and freezing combined reduced uncracked nuts from 14% to 2%. The authors considered the investment in these methods economic at the time of publication (Liang *et al.*, 1988). Weinert (1993) reviews different cracker types.

Some workers recommend grading nuts into sizes to improve cracking efficiency (Grimwood, 1971; Liang, 1980; Cavaletto, 1983). Liang (1977) identified most losses at cracking were in chips too small to recover, kernels discarded in the bulk of shells, and mouldy and discoloured kernels. The first loss highlights the importance of cracker design. This remains a very challenging problem due to the remarkably tough macadamia seed coat. There remains a great need for better crackers and designers are still wrestling with this problem (Jones, 2004). The second problem, loss of kernel, emphasises the need for improved separation methods (Liang *et al.*, 1977). Brine separation was found to improve kernel separation from broken shells (Liang *et al.*, 1977) and this method will be discussed below. The problem of mouldy kernels can be solved by more frequent harvest (Mason and Wells, 1984; Weinert, 1993). One of the great problems when cracking macadamias is differences in strength of the nuts in different orientations (Fig.2). If hilum of the nut is considered the north pole and the micropyle the south pole the nut is weakest at the equator and is most easily cracked by compressing at the hilum and micropyle (Braga *et al.*, 1999). To minimize uncracked nuts, commercial crackers must apply maximum force, that is, the force needed to crack in the strongest orientation, in the plane of the ‘equator’ 90º from the suture. Consequently, greater force is applied than needed to fracture shells in the ideal orientation. The ideal cracking orientation would be very difficult to achieve in bulk nuts.

Moisture content of nuts is very important at cracking. A balance must be struck because if the nuts are very dry they crack easily but the kernel is more subject to shattering (Liang, 1977). Higher MC nuts suffer less kernel damage but are harder to crack, resulting in more uncracked nuts (Liang, 1977). Moltzau and Ripperton (1939) recommended cracking nuts at 3.5% NIS MC, then drying kernels to 1.5% after cracking. However, it is important to note that NIS equilibrated to 3.5% MC already has kernel MC of 1.5% MC (Bungay, 2003b). Golden Macadamias in South Africa crack NIS at 4.5% MC (Anon., 2006). Cavaletto (1983) recommended cracking at 3.5-5% MC to obtain more whole kernel. However, this has not been adopted in Australia because it is felt that double handling required to complete drying of kernels after cracking and loss of kernel adhering to shells at cracking make this an unviable option (Mason and McConachie, 1994). Flash drying of shells just prior to cracking to render them drier than kernels for ease of cracking without making kernels brittle greatly increased whole kernel (Tang *et al.*, 1982). However, Weinert (1993) questions the practicality of processing large quantities this way.

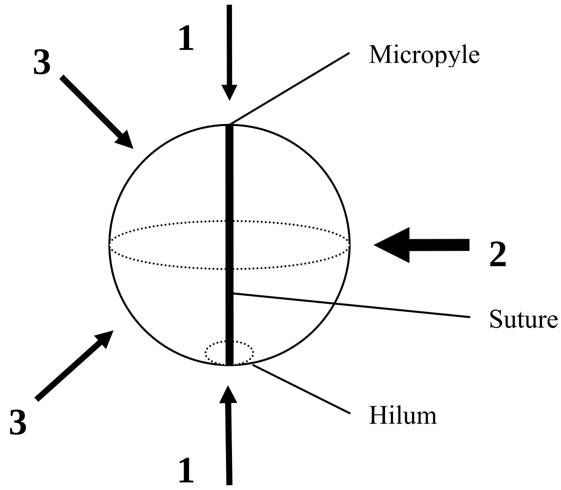

Fig. 2. Schematic drawing of macadamia nut showing strongest and weakest orientations under compression. Arrows show direction of compression: 1 = weakest orientation for cracking, requiring least force (ideal position); 2 = strongest orientation at equator (dotted line), maximum force required for cracking; 3 = intermediate position for cracking force. (Based on information in Braga *et al.*, 1999).

Separation of shell from kernel

Separation of shell and shell fragments from kernel is a difficult operation. At this stage the exposed kernel is a high value produce and is very vulnerable to damage from handling equipment. The traditional approach is to use screens, air separators, electronic colour sorters and hand separation (Mason and McConachie, 1994; Smit, 1996). Most processors in Australia use various combinations of these methods (Mason and McConachie, 1994). Another approach is to use flotation separation (Liang, 1977; Weinert, 1993; Mason, 2000a), which is based on the oil content of the kernels making them lighter than water. Oil content is considered to be a broad indicator of macadamia quality (Mason and Wills, 1983). The degree of separation is regulated by adjusting the SG of the grading solution, e.g., by using different brine solutions (Mason and McConachie, 1994). There is some possible overlapping of shell separation and sorting if flotation separation is used.

Sorting kernel

Water and air sorting

The quality of macadamia nuts in a factory can be highly variable. Mason (2000a) lists several possible reasons:

- Different cultivars are harvested together
- Cultivars reach maturity at different times
- Harvesting intervals vary
- On-farm storage and drying programmes vary

It would be desirable to exercise more quality control before this point, e.g., by more grading on-farm. Some work has been done on sorting nuts prior to processing by water grading but this is currently only used to remove immature nuts (McConchie *et al.*, 1996). An alternative is to use flotation (wet grading) to grade kernels after cracking. This was first proposed by Moltzau and Ripperton (1939), and is based on the premise that higher oil content denotes better eating quality. The South African industry uses flotation to grade kernels into:

- Grade 1: SG < 1. The highest eating quality, oil content > 72%
- Grade 2: SG 1.00-1.02. Lower quality, but acceptable for processing, oil content 67-72%
- Grade 3: SG > 1.02. Unsuitable for processing, excepts perhaps for oil extraction (Mason, 2000a).

At present the Australian industry uses only dry sorting by colour sorters and visual inspection, so that it is difficult to eliminate immature kernels. Dry sorting cannot reliably produce the Grade 1 kernels just described (Mason, 2000a). A recent test in Australia found that 2 different sources of commercial kernels contained 10% Grade 2 and Grade 3 kernels, and 1.9% and 5.9% reject kernels respectively (Mason, 2000a). Australian processors are reluctant to move to flotation grading (Mason, 2000b) even though this has the potential to improve the quality of premium kernel, particularly by eliminating immature kernels, difficult to grade out manually.

However, there are advantages and disadvantages of both systems (Mason, 2000a). Flotation produces a high eating quality, cleaner product, with less damage from equipment (Mason, 2000a, 2000b). However, kernels must be re-dried, and there may be risks of reduced shelf-life and flavour alteration (Weinert, 1994; Mason, 2000a). In a later report on flotation for grading of whole kernels and pieces, Ross *et al.* (2003a, 2003b) found no loss of shelf life for all wet grading solutions used, though brine and ethanol solutions altered kernel flavour. While the brine imparted an acceptable flavour ethanol was considered to reduce palatability (Ross *et al.*, 2003a). With proper safeguards, use of water and brine for grading is recommended, but ethanol is unacceptable (Mason, 2000b; Ross *et al.*, 2003a, 2003b). However, Weinert (1994) considers it is not advisable to use the flotation method to divide a total harvest into grades as it may not produce results consistent with analysed oil content. This may be due to whole kernels which float, but +sink when halved. Chemical analysis provides the most reliable results (Weinert, 1994). This means that water sorting may be a more reliable guide for quality of wholes than halves and raises serious doubts about the accuracy of water sorting for kernels.

Microbial contamination from wet grading

There is a risk of microbial contamination from wet grading (Luttig *et al.*, 1998). Producing safe food has become the biggest issue facing Australian horticulture (Beattie, 2000). The presence of both *E. coli* and *Salmonella* has been demonstrated on macadamia NIS on-farm, but the risk of them arriving at a processor is rated low (Dommet *et al.*, 2002). Nevertheless, both *E. coli* and *Salmonella* have been detected in kernel batches in recent years (Dommet *et al.*, 2000). It is essential that if wet grading is used the utmost care is taken to implement correct procedures. For example, proper treatment of kernel after grading and strict adherence to procedures such as regular changing of solutions to remove any risk from microbial contamination are mandatory

Instrumental sorting by NIR

Near infrared (NIR) spectroscopy technology is widely used for oil and MC determination in the oilseed and grains industries and has also been used to detect fungal contamination and insect damage in some grains (Guthrie *et al.*, 2004). NIR has been trialled to test macadamia kernels for oil content, MC, insect damage, rancidity, discolouration, mould growth, germination and decomposition. This technology showed good potential but required further research to examine the robustness of predictive models (Guthrie *et al.*, 2003, 2004). At present there are no practical instrumental methods for sorting macadamia kernel.

Storage of kernel

Many of the principles of storage of NIS discussed above apply equally well to storage of kernel. The final MC of kernel after processing should be 1.5% or lower (Cavaletto, 1981). Both the Australian Macadamia Society and the South African Macadamia Growers Association recommend that both raw and roasted kernel should be stored at low MC, no more than 1.5% (SAMAC, 1998; AMS, 2001). This is necessary to not only reduce the risk of rancidity developing (Mason *et al.*, 2004), but also to prevent kernels losing their characteristic 'crunch' (AMS, 1994). This loss of texture is because macadamia kernels rehydrate readily under ambient conditions (Palipane and Driscoll, 1992). These recommendations are based in part on studies by Cavaletto *et al.* (1966) and Dela Cruz *et al.* (1966). Temperature of storage is also important as quality assessed by a tasting panel decreased with increasing temperature and MC, and kernels stored at room temperature tend to rapidly develop rancidity (Cavaletto *et al.*, 1966). A storage temperature of 0ºC is recommended for kernels at higher MC such as 2.3% or 4.3% MC (Cavaletto *et al.*, 1966). For greatest stability, kernels should be dried to 1% MC and stored at 18 ºC (Kaijser *et al.*, 2000).

Quality packaging of kernels is vital to ensure shelf life is not reduced. Unlike other edible nuts, macadamia kernel requires a storage environment which is very low in both moisture and oxygen (< 2% residual oxygen; AMS, 1994). These standards are best achieved by a combination of gas flushing and partial vacuum prior to hermetically sealing in suitable containers (AMS, 1994). The correct containers are hermetically sealed metal cans or glass jars, or high barrier flexible packaging materials with the correct gas transmission properties (Cavaletto and Yamomoto, 1971; Bowden and Reeves, 1987). The quality of flexible packaging material used will in part determine the shelf life. Mixing macadamia kernel with other products such as nuts, dried fruit etc is not recommended because of differences in MC and different flavours and odours that may adversely affect macadamia kernel quality (AMS, 1994).

Roasting

Roasting of macadamia kernels is widely practiced and Mason *et al.* (1995) believed that most macadamias are sold at the retail level in the roasted form. Roasting of macadamias has been reviewed by Weinert (1993). Some workers consider that roasting improves shelf life in foods due to the fact that it reduces the binding sites for water in the kernel (Martinez-Navarrete and Chiralt, 1996). Roasting is considered to enhance stability and improve palatibility of macadamias (Leverington, 1971). However, some have found that roasted kernels have reduced shelf life (Isaacs *et al.*, 1991; Lemmer and Kruger, 2000). Roasting of macadamia commenced in Hawaii (Moltzau and Ripperton, 1939). The fledgling Australian industry at first adopted Hawaiian roasting practice until studies such as those of Leverington and Winterton (1963) and Winterton (1966) modified procedures. Most kernels initially were roasted in oil, but Leverington and Winterton (1963) developed a dry air roasting regime.

There are a number of factors that are known to influence the quality of roasted macadamias, such as temperature and duration of roasting, and MC of kernels at roasting. It is essential that kernels are below 1.5% MC at roasting to avoid excessive browning (Prichavudhi and Yamamoto, 1965). Going further, Dela Cruz *et al*. (1966) state that kernels should be at no more than 1.1% MC at roasting for maximum sensory and chemical quality. MC at the time of roasting is also important in determining the final colour. Kernels with MC higher than 2% do not have crisp texture, brown too rapidly and do not have good shelf life (Cavaletto, 1983). Kernels should also have high oil content, as indicated by SG of less than one, as there is an inverse relationship between oil content and sugar content. High reducing sugar content leads to dark kernels at roasting (Cavaletto, 1983). The time/temperature relationship is proposed as the most important factor in the prevention of rancidity in roasted nuts (Leverington, 1962). Too high a temperature will not cook the kernels through to the centre by the time a desirable colour is obtained (Leverington, 1962). When this happens, the binding sites for water in the centre of the kernels are not reduced effectively by roasting (Martinez-Navarrete and Chiralt, 1996).

Segregation at roasting

The genotype may also have an influence on the quality of roasted macadamia. Some workers have recommended that *M. integrifolia* and *M. tetraphylla* kernels should be separated before roasting because of different roasting characteristics and resultant variable quality of roasted product (Grimwood, 1971). It has further been recommended that cultivars which are hybrids of *M. integrifolia* and *M. tetraphylla* also be roasted separately and that standards for *M. integrifolia* be applied to its cultivars and those for *M. tetraphylla* be applied to hybrids (Lee, 1998). Despite this, the influence of hybridization on kernel roasting quality is not always clear (Lemmer *et al.*, 1998). Some cultivars considered *M. integrifolia* have produced variable browning results when roasted (Lemmer *et al.,* 1998). Examples of the confusing situation are that known hybrids produced superb quality and high uniformity when roasted at the correct temperature and time, while HAES 741 and HAES 791 differed from HAES 508, HAES 246 and HAES 788 in respect to the roasting time to desirable colour (Lemmer *et al.,* 1998). Cultivar HAES 788, classified as *M. integrifolia*, exhibited roasting characteristics of both groups (Lemmer *et al.,* 1998). Difficulties such as this suggest the desirability of segregating cultivars for roasting, and having defined standards for each cultivar. There is also a need for flexibility when roasting, and varying time of roasting as necessary to achieve the desired colour. Such difficulties may explain the Australian industry's reluctance to roast to a distinct colour (Burton, pers. comm.).

Oil roasting of macadamias

In Hawaiian industry most roasted macadamias were roasted in oil (Grimwood, 1971). One problem with oil roasting can be that degradation of roasting oil due to heating can lead to peroxidant contamination of kernels (Winterton, 1966; Grimwood, 1971). This can be counteracted to some extent by treating roasted kernels with antioxidants (Cavaletto and Yamamoto, 1971). This practice was not considered necessary for kernels roasted correctly (Winterton, 1966). Another problem with oil roasting is that kernels can lose substantial quantities of endogenous oils to the frying oil (Cavaletto and Yamamoto, 1971). However, an advantage of oil roasting is that a more even colour of product is obtained (Grimwood, 1971). Various methods have been reported for oil roasting macadamias (Table 1.7). When oil roasting, temperatures between 115ºC and 125ºC achieve better control of colour-time relationships than a temperature of 135ºC (Mason *et al.,* 1995). Roasting at 135ºC produced inferior flavour compared with roasting at 115 to 125ºC (Mason *et al.,* 1995). Oil roasting improves shelf life more than dry roasting, probably because it is more effective at de-activating the enzymes responsible for browning reactions (Lemmer and Kruger, 2000).

Air roasting of macadamias

Most roasted macadamias produced in Australia are air-roasted (Burton, pers. comm.). Various air-roasting regimes have been reported for roasting macadamia kernel in air (Table 1.8). Macadamia processors in Australia tend to use low temperatures when roasting to minimize the risk of dark kernels caused partly by kernels being of mixed cultivars (Burton, pers. comm.). The roasting regimes presented in Table 1.7 and Table 1.8 were those used by experimenters under laboratory conditions. For processors, batch sizes and the scale of roasting equipment are very different, and equipment used also varies. An example of dry roasting methods used by a processor are presented in Table 1.9.

Table 1.7. Roasting regimes for roasting macadamias in vegetable oils

Cultivar or species	Oil type	Temper-ature (°C)	Duration (min)	Author
M. integrifolia	Unknown	127	25	Winterton, 1966
HAES 246	Coconut	127	15	Cavaletto & Yamamoto, 1971
M. integrifolia	Coconut	135 127	12-15 12	Grimwood, 1971
HAES 508	Coconut	127	15	Prichavudhi & Yamamoto, 1965
HV A4, HV A16, HAES 344,	Coconut	125	#	Isaacs *et al*., 1991

HAES 741, HAES 800, H2				
HV A4, HV A16, HAES 741, HAES 800, HAES 246, HAES 344	Coconut	125	10-15 #	Fedric, 1997
Hybrids♦	Coconut	127	12	Lemmer *et al.*, 1998
HAES 246, HAES 508	Coconut	115 125 135	19-35 # 10-14 # 4 #	Mason *et al.*, 1995
Hybrids Various*	Coconut	121 128	#	Lemmer and Kruger, 2000

To desired colour standard ♦ Nelmak 1, Nelmak 2, Nelmak 26, Beaumont (695)

* HAES cultivars 294, 344, 660, 695, 741, 788, 789, 791, 800, 814, 816, 863

Table 1.8. Roasting regimes used for roasting macadamias in air

In-shell or shelled	Cultivar or species	Temperature (ºC)	Duration (min)	Author
Shelled	*M. integrifolia* *M. tetraphylla*	135 127	25	Leverington & Winterton, 1963
Shelled	*M. integrifolia* *M. tetraphylla*	163-190	12-15	Grimwood, 1971
In-shell	Yonik	110	60-75	Rosenthal *et al.*, 1984
In-shell	Beaumont (695)	102	70-75	Basker and Kadman, 1986b
Shelled	Yonik	104	16	Basker and Kadman, 1986a
Shelled	Hybrids*	127	12	Lemmer *et al.*,

	791, 741, 788, 508, 246	127	25	1998

*Nelmak 1, Nelmak 2, Nelmak 26, Beaumont (695)

Table 1.9. Example of a roasting regime for a batch roaster used by an anonymous commercial macadamia processor

Roast colour	Nut style	Temperature (°C)	Duration (min)
Light	Large, style 0-4	125	26
	Small, 5 - fine	130	40
Medium	Large, style 0-4	130	50 (25x2)*
	Small, 5 - fine	135	50 (25x2)*
Dark	Small, 5 – fine#	138	40

* Trays mixed after 25 min

Roasted for biscuits, confectionery

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Chapter 4

Identification of critical quality management points in the macadamia production and processing cycle

Kevin Quinlan and Neil Treverrow

Summary

A quality chain for macadamia production and processing was developed to identify critical points that would significantly affect macadamia kernel quality. This quality chain was developed by the project team and an industry steering group. The quality chain was used as the basis for determining the focus of the 'Adopting quality management systems project'. The steering group decided that the project should focus on factors affecting quality that could be changed in the short-term, including; harvesting and drying and storage practices.

Introduction

Macadamia kernel quality may be influenced at many stages throughout production and processing. The quality chain for macadamia production was produced as the first step in identifying the areas that have the greatest impact on the quality of macadamia kernel. This chain forms the basis of the further research and analysis that was undertaken as part of this project.

Materials and Methods

The project team met to develop a draft of the quality chain and identify the factors at each step that impact upon the kernel quality in Australian macadamia orchards.
A steering group of leading growers and processor representatives was assembled to further examine the draft quality chain developed by the project team. This further analysis included determining how significantly these factors affected quality, and the period of time over which these factors could be changed (ie short, medium and long term).

Results and Discussion

The quality chain as defined by the project team and steering group is shown in Appendix 1 of this chapter. This quality chain formed the basis of the areas that were to be surveyed to gather economic and grower attitudes, practices and aspirations information.

Harvest management was identified as a critical area for investigation and has been an area highlighted previously (Mason and Wells, 1984; Wallace and Walton, 2005; Walton and Wallace, 2005; Liang, 1996; Bungay, 2003; O'Hare *et al.,* 2004). The effect of harvest management was seen as critical to the whole quality chain, as it is the first step in the chain that was identified as being highly significant and something growers could change over the short term. More economic information on the costs and effects of harvesting on quality are needed to help growers improve their practices. Sorting and the drying and storage processes, whether they be performed on-farm or in the factory, were identified as critical and important areas to investigate further because they can affect quality rapidly and cause considerable losses. Insect and disease management were not considered as important because there are generally good management systems in place.

The project team decided that the focus of the project would be on the factors which were considered to most significantly impact quality and which could be influenced over the short term. Long term changes were not examined in depth or considered as priorities for this project because the group believed that they could not be, or were unlikely to be changed by growers.

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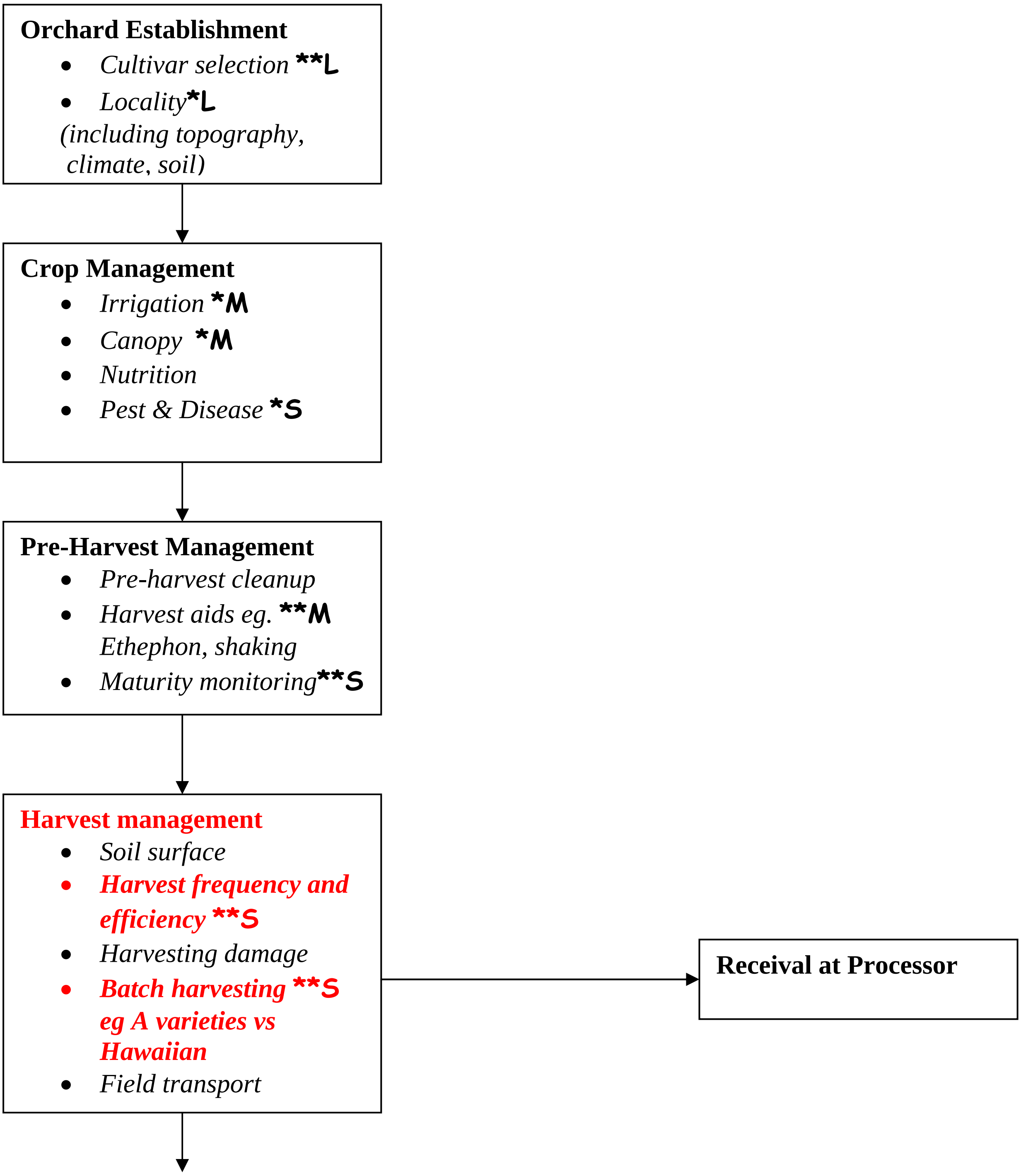
Appendix 1

Quality Management Flow Chart – On Farm

verified by steering group



Significance rating:
*The number of * represents the significance of the trait, with the more the higher its influence*
S, M, L – the length of time that this trait can be influenced over

Quality Management Flow Diagram - On Farm Or At Processor

Note: whether or not these following steps are carried out on farm or at a processor, the same quality management issues are faced and each step occurs in the process.

Dehusking → **Receival at Processor**

- *Machinery damage* **S
- *Moisture content* **S
- *Timing*
- *Shed vs field*

↓

Sorting & Resorting → **Receival at Processor**

- *Wetting up by water sorting*
- *Drop heights* **S
- *Efficiency of different systems* **S
- *Moisture content & Cultivar effects* **S

  - Economic impact of the efficiency of the sorting system
  - Do you do a re-sort or not?

↓

Storage NIS ** → **Receival at Processor**

- *Design*
- *Temperature*
- *Timing*
- *Moisture content*
- *Maturity*

↓

Drying (7-10% NIS MC) ** → **Receival at Processor**

- *Design*
- *Timing*
- *Temperature*
- *Heating*
- *Maturity*
- *Drop height and number*

↓

Dispatch → **Receival at Processor**

- *Transport management*
- *Moisture content* **S
- *Drop height and number* **L

Quality Management Flow Diagram - Processing

Drying to 3.5% mc NISS**

- *Drop number and height*
- *Timing and temperature*
- *Batch processing*
- *Design*
- *Heating*
- *Maturity*

↓

Storage @ 3.5% mc NISS**

- *Timing and temperature*
- *Variations in mc*
- *Design*
- *Drop number and height*
- *Batch processing*
- *Heating*
- *Maturity*

- o Factory storage of NIS (6% or 3% mc in cool store)
- o The bigger issue is how do processors store NIS when received

↓

Cracking **

- *Cracker type*
- *Moisture content*
- *Cultivar*

- o Hand vs machine
- o What are people achieving in terms of factory loss
- o What moisture content is being used

↓

Separation of shell from kernel **

- *Handling damage by equipment*
- *Flotation sorting (cleaner prod. Less damage)*
- *Separation halves from wholes*

↓

Sorting Kernel **

- *Efficacy of different systems:*
- *Optically*
- *Visually*
- *Mechanically (size sort)*
- *Chemically (NIR)*
- *Physically (SG separation)*

↓

Storage of kernel @ 1.5% mc **

- *Moisture content*
- *Packaging*
- *Vacuum/gas flush*
- *temperature*

↓

Roasting

- *Batch roasting by variety*
- *System eg oil vs air*
- *Timing and temperature*

- What is the cost of removing impacted shell?
  eg. Laser vs human
- What is the economic benefit of grading by visual vs other methods

Chapter 5

Survey of grower practices

Kevin Quinlan, Neil Treverrow, Paul O'Hare, Geoff Slaughter

Summary

A survey of grower practices, attitudes and aspirations in relation to quality management was carried out. The results were varied. In general the messages from research findings on quality management have been heard by growers, but in many cases have not been adopted. Most growers aspire to improve their harvest frequency and reduce the amount of time they store NIS on farm recognising that these practices affect nut quality, but there were restraints of some form on them achieving the desired outcome.

A major impediment to more frequent harvesting is the belief by many growers that more frequent harvesting is not cost effective, or growers are unsure if it will deliver better returns. To improve adoption of increased harvesting frequency the economic impacts need to be documented; this issue is dealt with further in Chapter 5.

Introduction

A survey of macadamia producers' attitudes, awareness and practices in relation to quality was carried out. The aims of this survey were:

- Evaluate the awareness of macadamia producers of quality management issues.
- Survey grower practices that affect quality management.
- Gain an understanding of the knowledge, attitudes and aspirations of producers with respect to farming practices that affect quality.
- Gain information on the attitudes of producers towards quality management issues.

Materials and Methods

The survey was designed using Bennett's Hierarchy (Bennett, 1975). Not all elements of the hierarchy were used, being modified to focus on benchmarking, grower aspirations and gaining producer attitudes to farm practices and their impact upon quality. This survey also provides a benchmark of responses for future work on quality management. A copy of the survey can be found in Appendix 1 of this chapter.

Bennett's hierarchy can be used for planning projects and assessing performance. In this instance it was used to benchmark quality management. Bennett's hierarchy measures outputs at seven different levels:

1. Resources
2. Activities
3. Participants
4. Reactions of participants
5. Knowledge, attitude, skills and aspirations of participants
6. Practice change
7. Social, economic and environmental outcomes

The major focus of the survey was on level 5, often referred to as the KASA (Knowledge, attitude, skills and aspirations) section. The survey was designed by the project team: Neil Treverrow, Kevin Quinlan, Paul O'Hare, Geoff Slaughter, Helen Wallace and Richard Mason.

A tick box format was adopted to minimise the time required to complete the survey and thereby increase the chances of a satisfactory response rate. Reply paid envelopes were used, as these have been found to increase the response rate.

For each question; the percentage of all respondents choosing each option was calculated. For certain questions, the responses were also examined after partitioning on the basis of farm size, locality, percentage of trees bearing and grower experience. The following categories were determined:

• Size	<2000 trees, 2001 – 6500 trees and >6500 trees.
• Locality	NSW and QLD responses
• Percentage of bearing trees	<90% and > 90% bearing
• Years experience	<5, 5 to 10 and >10 years

These classes were chosen to ensure a minimum of about 30 entries per class, except for locality, where only 2 classes could be made.

Graphics of the grower responses were produced, in some cases including further partitioning, and these were analysed visually.

Results and Discussion

Response rate

A total of 144 responses to the survey were received, the majority of which were fully completed. Based on an estimate of grower numbers using the AMS database, an overall response rate of 18 % was achieved, or 20% and 13% response rates for NSW and QLD respectively.

Variations in tree number, percentage of trees bearing and grower experience between orchards in NSW and QLD are presented in Table 1. There was little difference between NSW and QLD in the percentage of trees of bearing age and years of experience, however there was a difference in average tree numbers, due primarily to the responses from a few large growers in Northern NSW.

Table 1. State averages and ranges for responses to the mail out survey.

	State average and range			
	NSW		QLD	
	Mean	Range	Average	Range
Tree number	6082	260-54000	4309	250-25400
% of trees of bearing age	86	30-100	84	33-100
Years of Experience	12	0-31	12	0-30

Table 2 shows the make up of the total sample. The results show that the distribution of respondents is similar to the total macadamia industry demographic and provides confidence that the survey results should be representative of the wider industry. The percentage of respondents based on locality is similar to the figures reported by Jones (2006) but is slightly under represented by growers in QLD. Only a few very large plantations responded but this is probably representative of the industry. The percentage of trees bearing show that the majority of respondents have orchards that are mature, there is also a large percentage of producers who have expanded their operations, demonstrated by the number of farms with only a percentage of trees bearing. The level of experience varies substantially amongst growers.

Table 2. Description of the respondents based on locality, orchard size, proportion of the orchard bearing and grower experience.

Indicator	Category	Percentage of respondents
Locality	Mid North Coast NSW	13
	North Coast NSW	69
	QLD	18
Size, number of trees per orchard	<1000	23
	1001 – 2500	37
	2501 – 5000	32
	8001 – 10000	33
	>10000	13
Percentage of tree bearing	<51%	12
	51 – 75%	15
	76 – 99%	17
	100%	55
Years experience	<6	27
	6 – 10	26
	11 – 15	18
	16 – 20	13
	>20	16

Harvesting, Questions 1 to 6

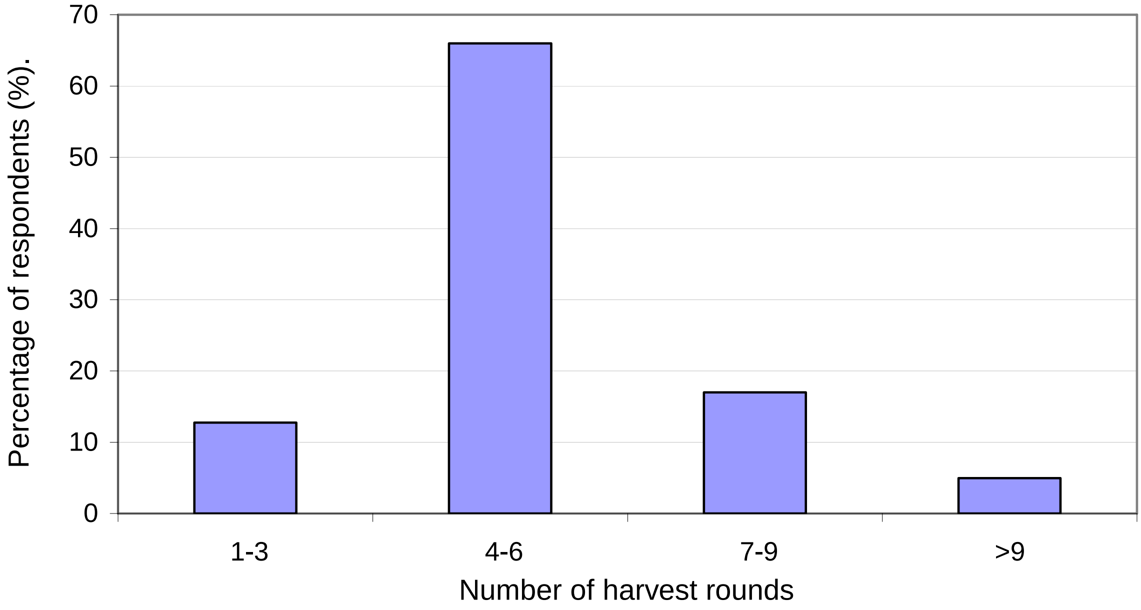


Figure 1. Number of harvest rounds in favourable conditions

About 10% of respondents harvested no more than three times, and less than 80% harvested six times or less during the season (Fig. 1).

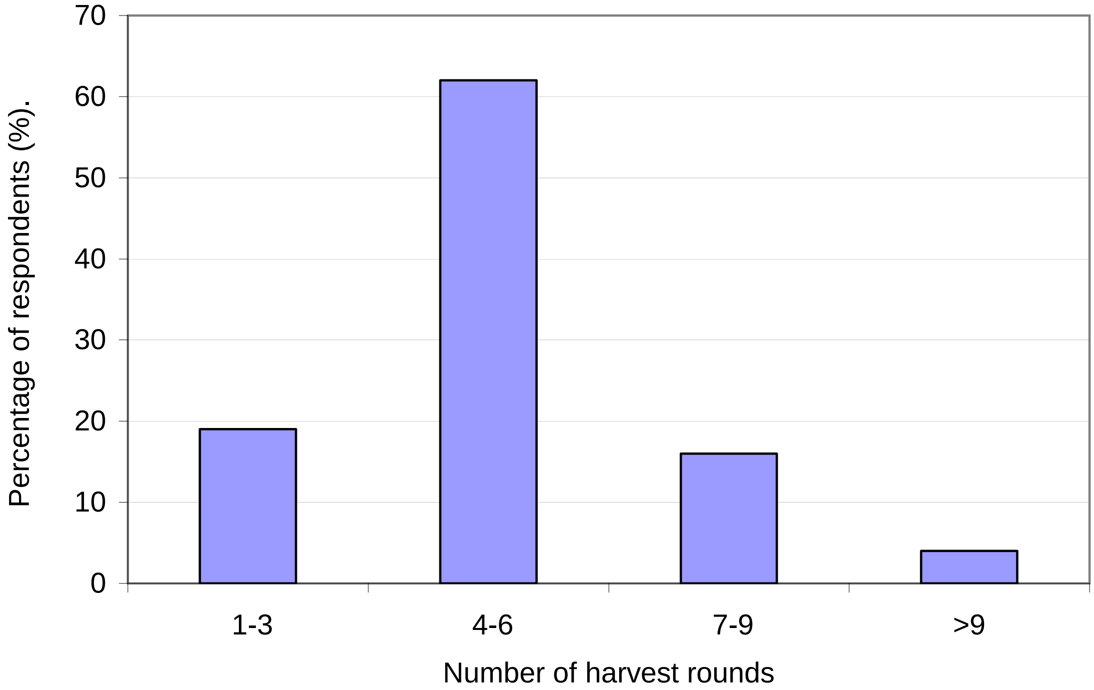


Figure 2. Number of harvest rounds under unfavourable conditions.

The percent of respondents harvesting no more than 3 times in unfavourable conditions (Fig. 2) was twice that in favourable conditions, there was still about 80% that harvested 6 times or less in a season.

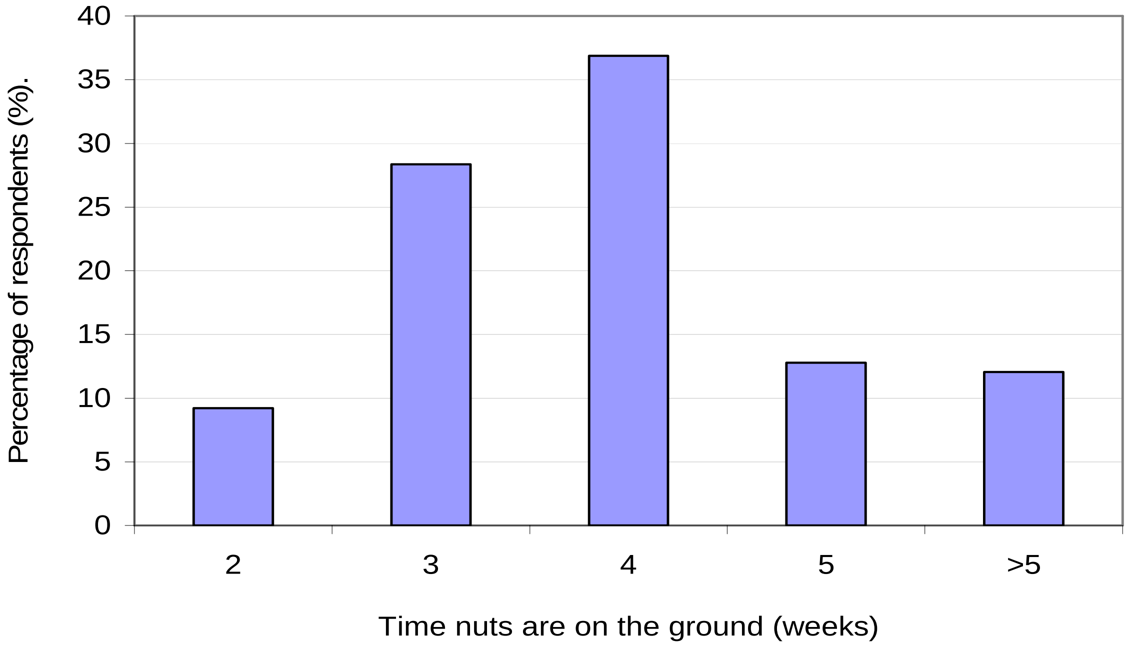


Figure 3. The longest time nuts are on the ground under favourable conditions

Approximately 25% of respondents indicated nuts were on the ground for longer than four weeks and about 10% for longer five weeks under favourable conditions (Fig. 3). On the other hand less than 10% indicate 2 weeks or less under favourable conditions.

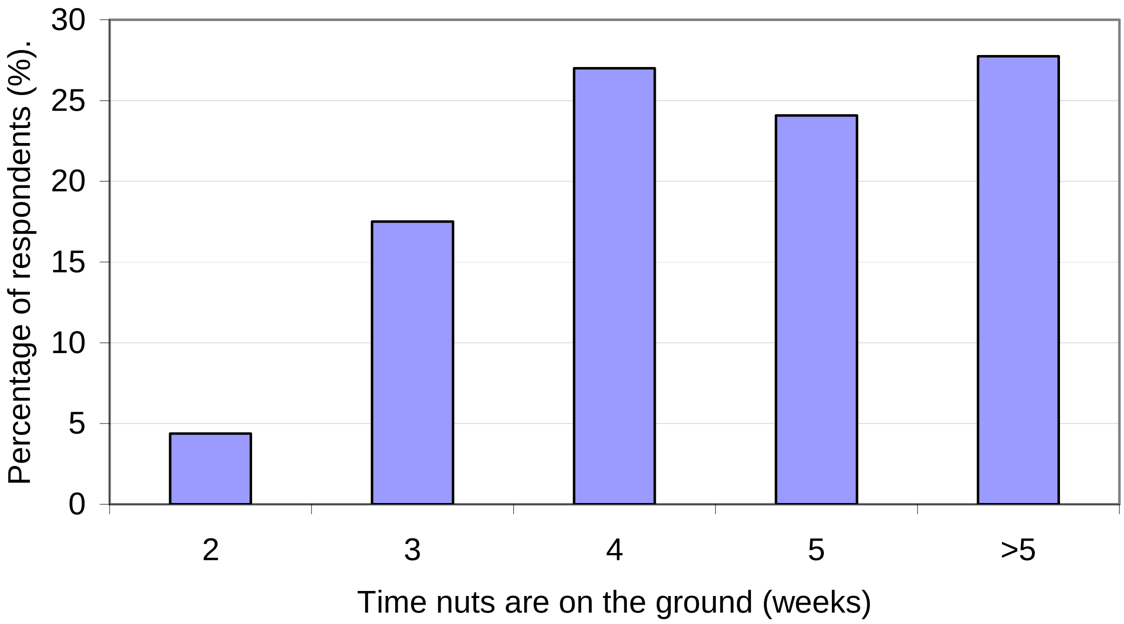


Figure 4. The longest time nuts are on the ground under unfavourable conditions.

Approximately 75% of growers indicated nuts were on the ground for four weeks or longer and almost 30% were on the ground for more than five weeks under unfavourable conditions (Fig. 4). Clearly, when conditions are not favourable, the length of time between harvest rounds increases significantly compared to under favourable conditions. Additionally, the time between rounds is more affected than number of rounds completed (Fig. 1 and 2) by unfavourable conditions. These responses may indicate that growers feel the number of harvests performed each season is more important that the time between harvest rounds. This may also indicate that the duration of the harvesting season increases under unfavourable conditions.

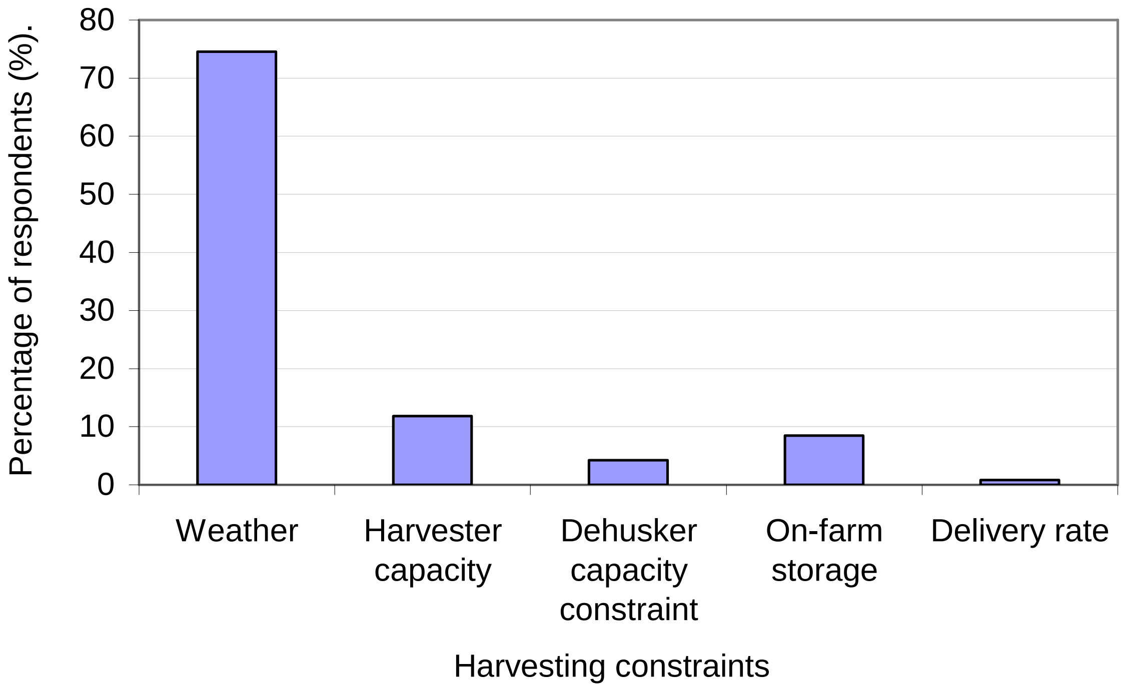


Figure 5. **Main constraints on harvesting frequency.**

The weather was the most important constraint, cited by more than 70% of respondents, while harvester capacity was the next most important constraint (Fig. 5).

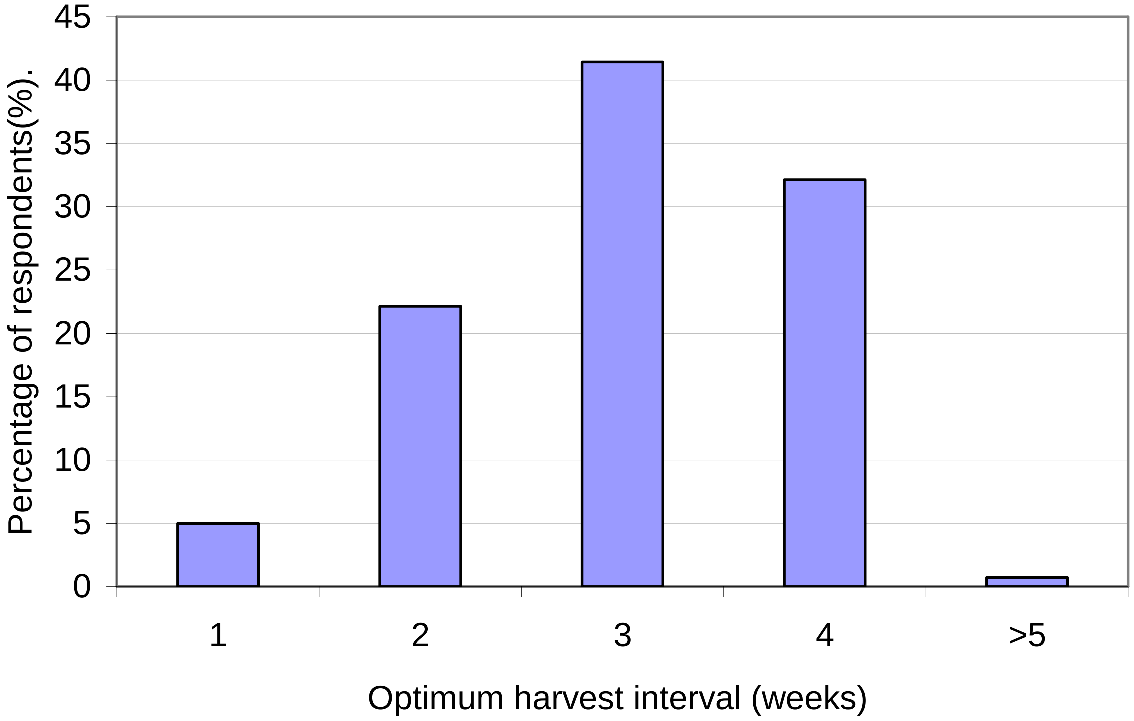


Figure 6. Optimum harvest frequency to maximise quality and profit.

Most respondents indicated harvest frequency should be at least every four weeks, 70% every three weeks and more than a quarter indicated two weeks (Fig. 6). Therefore growers are aware of the research findings that demonstrate quality and hence profit can be maximised by harvesting every four weeks (Mason, 1984; others).

Sorting of nut in shell, questions 7-8

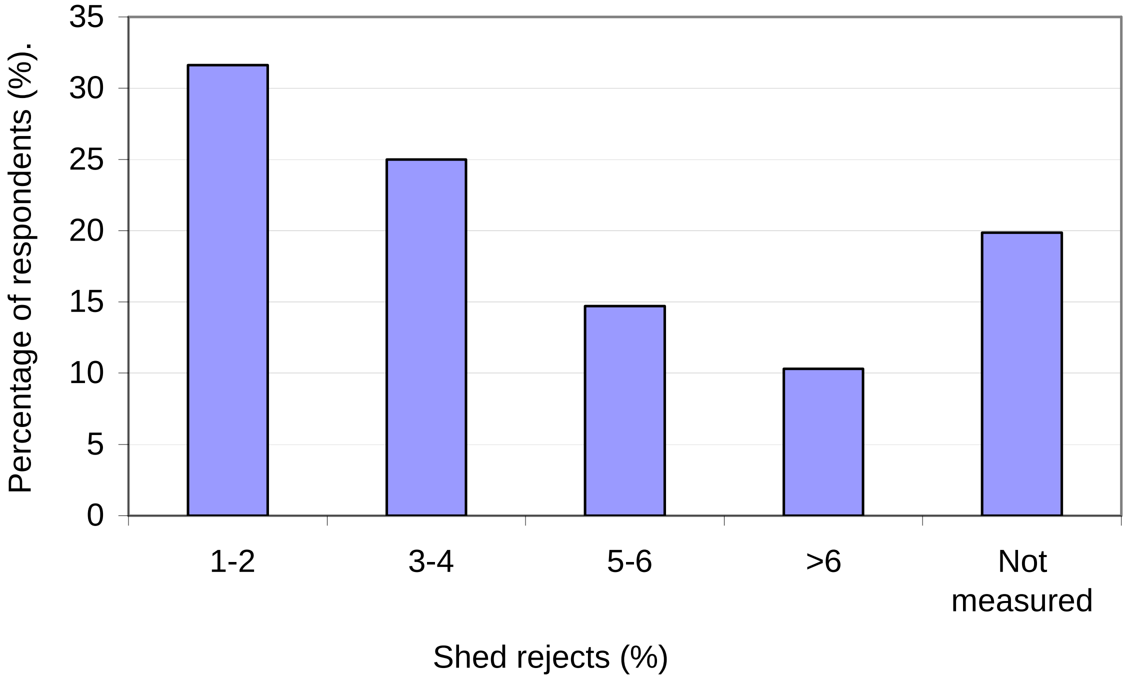


Figure 7. **Levels of NIS typically rejected.**

About a third of respondents indicated they rejected 2 % or less of NIS in the shed and about 55% rejected 4% or less in the shed, on the other hand 20% did not measure shed reject levels (Fig. 7). The average shed reject level was 3 % which is lower than the level of 5.7% reported by O'Hare (2005) for growers in MacMan best practice groups during the 2004 season. The high level of growers that do not measure the amount of NIS rejected (20%) is concerning considering the research and extension work that has been conducted to formulate and implement crop loss protocols (Treverrow, 2002).

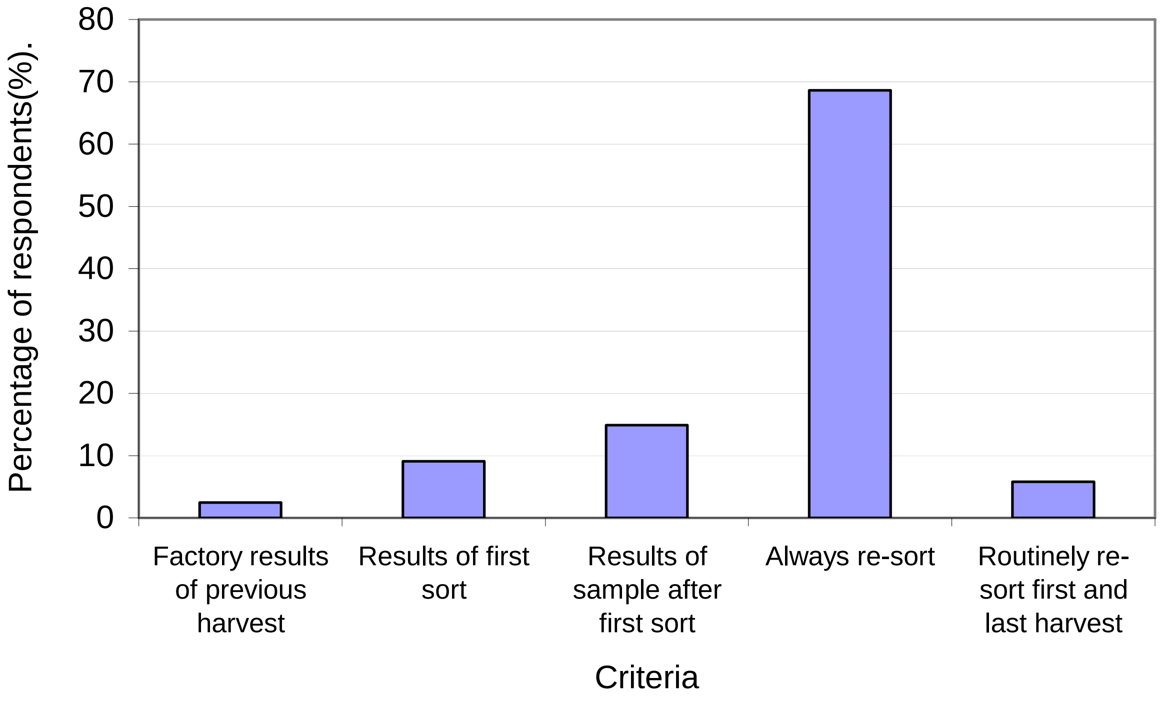


Figure 8. **How re-sort decisions are made.**

About 70% of respondents always re-sorted, while only 15% used a sample of nuts after the first sort, to decide on the need for a re-sort (Fig. 8). This result shows that further work on making growers aware of the value of sampling NIS and basing re-sort decisions on the results of testing needs to be carried out. The industry has tools to determine if re-sorting is necessary (David Bell's Sorting Calculator. Pers.comm), however the adoption has been limited.

On farm storage of nut in shell, Questions 9-12

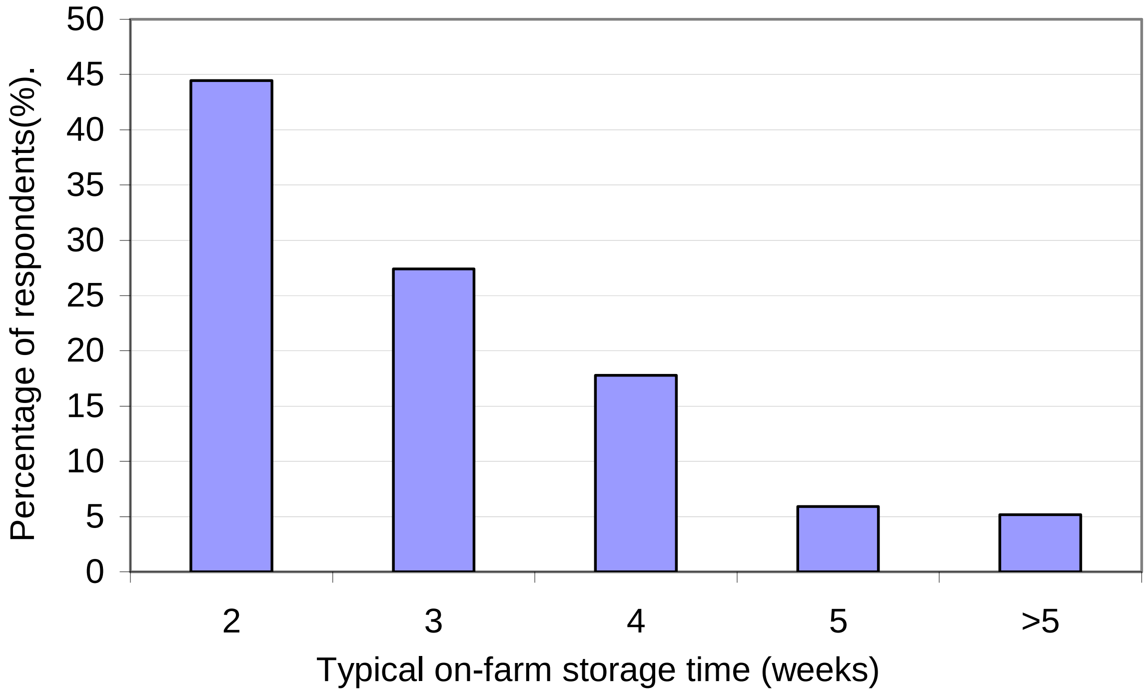


Figure 9. Typical time for on farm storage of NIS

About 55% of respondents indicated nuts were stored on farm for more than 2 weeks, and 10% indicated five weeks or longer (Fig. 9). A key recommendation has been for growers to dry/store NIS for a maximum of two weeks and consign to processors as quickly as possible. A significant proportion of growers are following this recommendation (40%), but there is still a majority (60%) who store on farm longer than recommended.

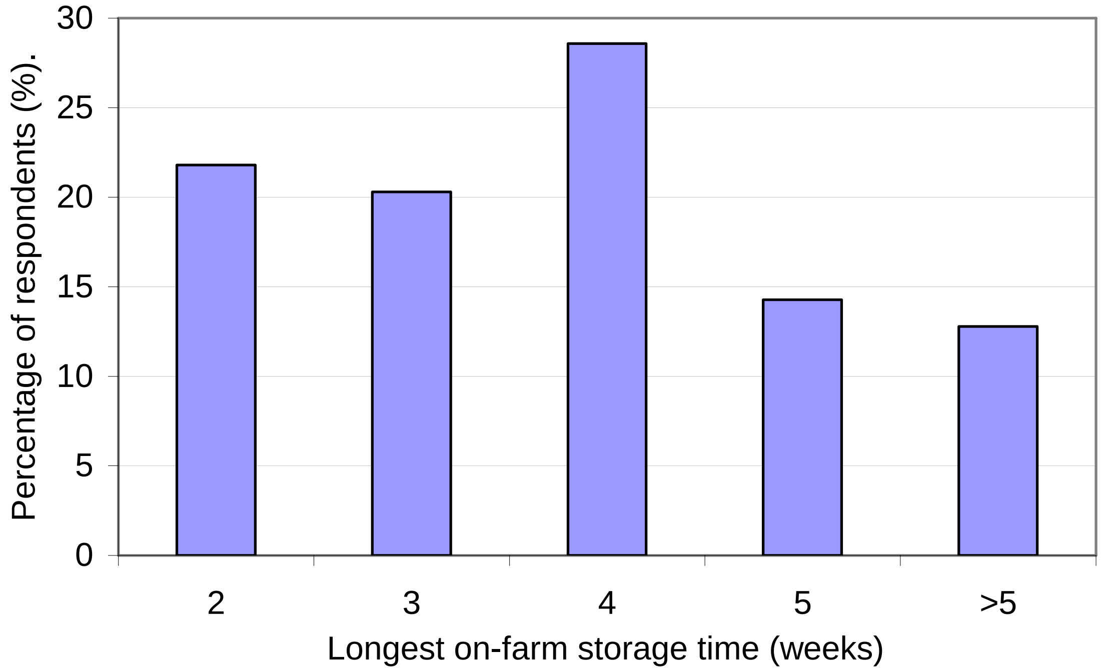


Figure 10. Longest time for on farm storage of NIS.

About 80% of respondents indicated nuts were stored for more than two weeks and about 15% stored for five weeks or more. This shows that the majority of growers experience difficulty in being able to dry and sort NIS within the recommended timeframe of two weeks. Perhaps this is related to environmental conditions. The storage time can also be affected by the capacity of processors to receive nuts during periods of peak supply.

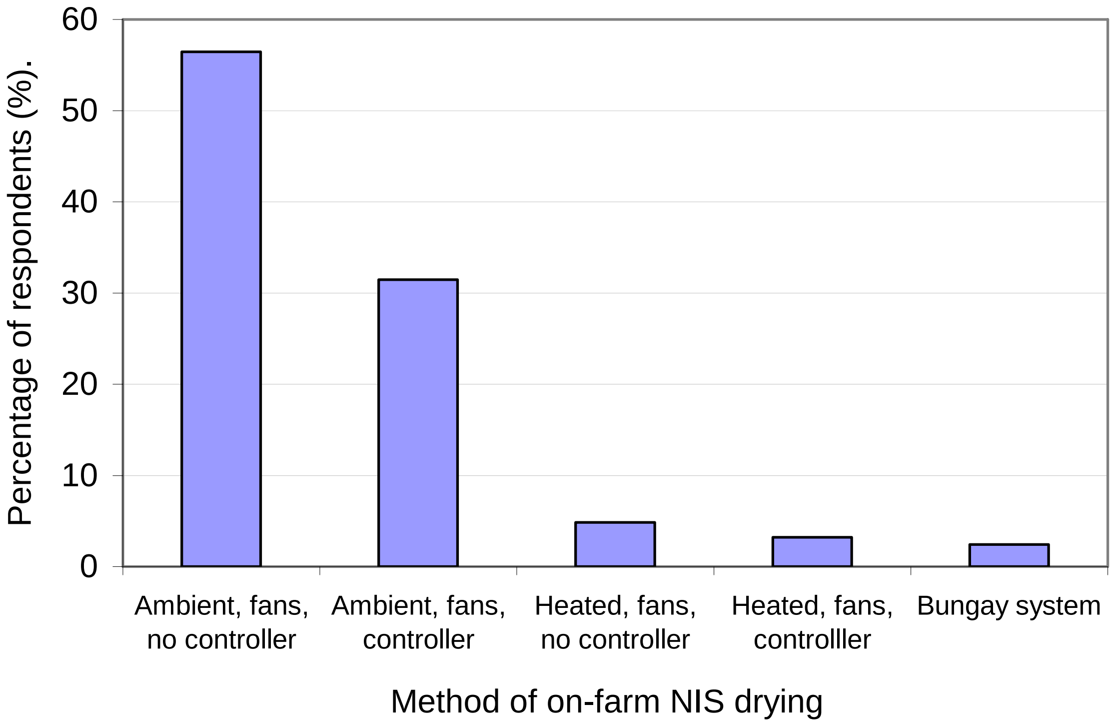


Figure 11. How NIS is dried on farm

The majority of growers dried NIS under ambient conditions (about 90%) and almost two thirds of this is done with systems where the fans have no controller (Fig. 11). The large proportion of respondents using ambient air with no controller to dry NIS (50%) could help to explain why NIS is stored on-farm longer that recommended. The growers using this system may be unable to dry NIS sufficiently within 2 weeks as weather conditions may often be unsuitable; high ambient relative humidity during peak harvest periods. The weather may impede NIS drying as well as harvesting (Fig. 5).

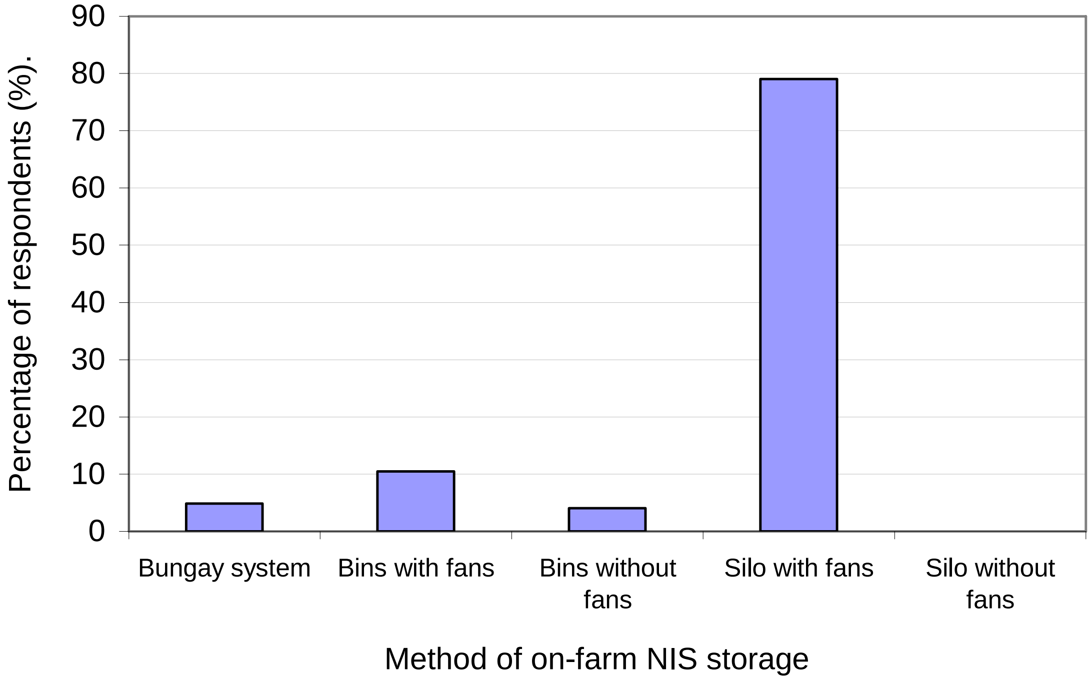


Figure 12. How NIS is stored on farm

About 80% of growers held NIS in silos with fans. The size of silos was not recorded, but from the research work conducted within this project (Chapter 5) it has been found that many people have silos with bed depths over 2.5 metres, which is the recommended maximum height for effective drying (COSOP, 2004). This may also help to explain why nuts are stored on farm for longer than recommended.

Kowitz and Mason (2001) found that NIS can be "stored safely for about 2 weeks at 25°C. If the storage period is likely to be nearer to 4 weeks, the moisture content should be dropped to 7.5%. Similarly, if the storage temperature is likely to exceed 25°C, the moisture content will need to be lower again". Considering the periods NIS are stored on farm (Fig. 9 and 10), the type of drying control system used (Fig. 11), the type of storage used (figure 12) and the average silo bed depth (Chapter 5); many growers are storing NIS on farm for longer than is optimal for preserving quality. Additionally, many of the drying systems used may not be optimal for preserving quality.

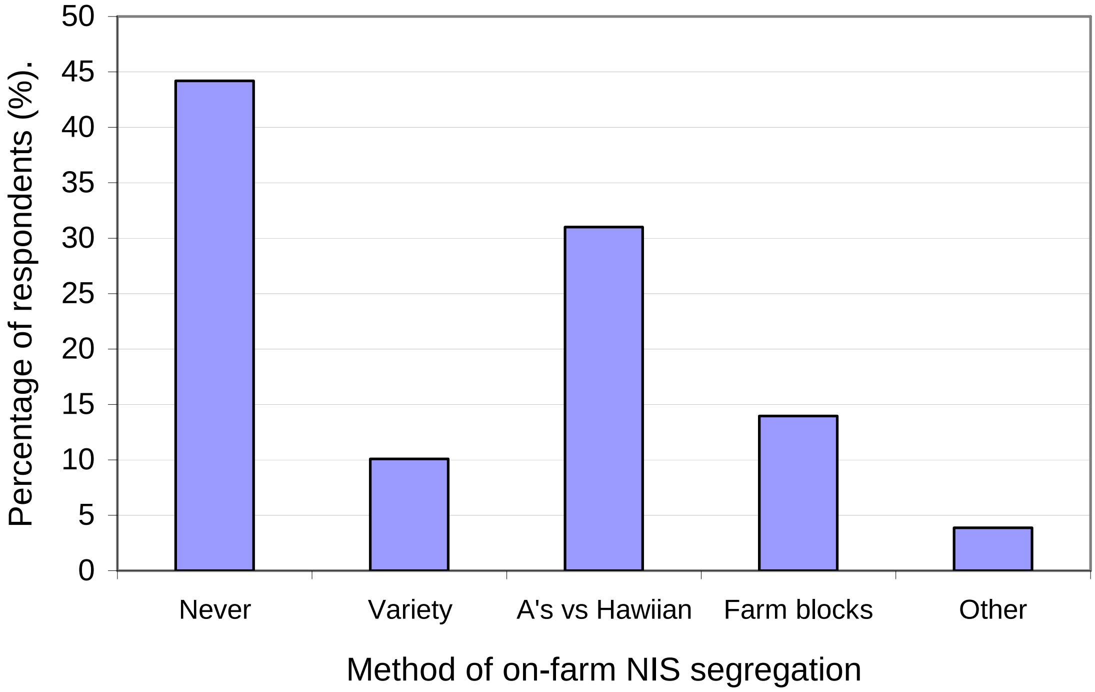


Figure 13. Segregation of NIS in storage

Almost half the respondents never segregated NIS in storage while of those that did; segregating Hawaiian from 'A' series varieties was by far the most common method (Fig. 13). About 10% of growers segregated by individual varieties and about 10% by blocks. It is difficult to know whether growers who never segregate mix Hawaiian and 'A' series varieties, or have only one of either Hawaiian or 'A' series varieties, and so do not segregate. The high percentage of growers who segregate Hawaiian and A series varieties (30%) indicates that the recommendation to keep "like with like" has been adopted by many growers.

Growers' view of optimum total time on farm for NIS, question 14

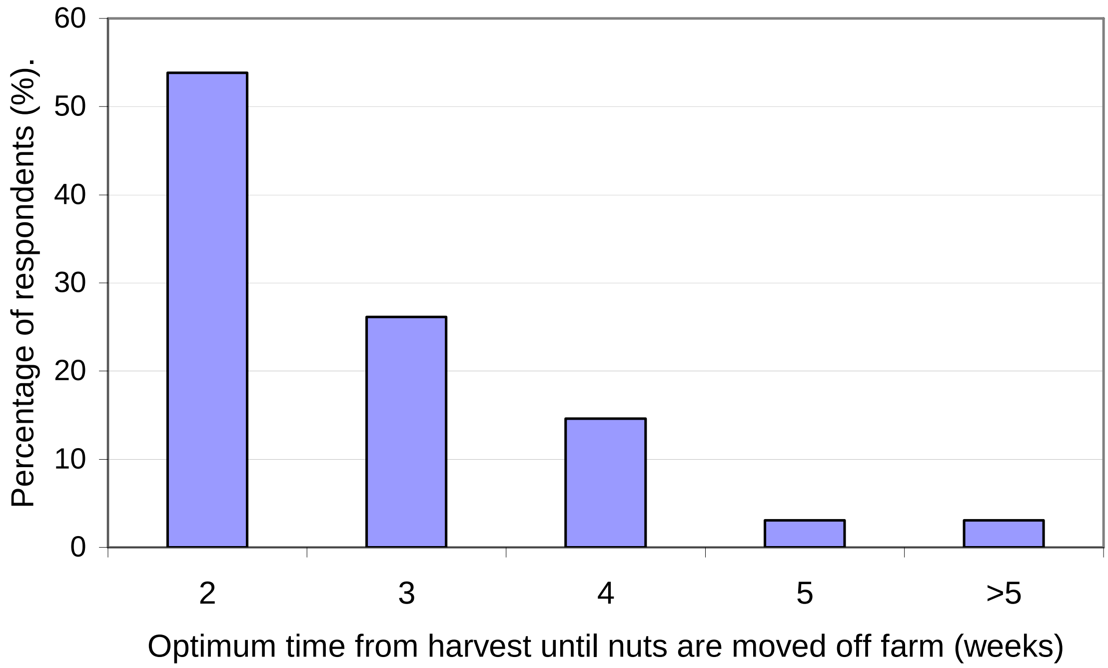


Figure 14. Optimum period of time from harvest until nuts are moved off the farm.

Half the growers felt 2 weeks or less was optimum and 80% felt 3 weeks or less was an optimum period from harvesting to when nuts are moved off-farm (Fig. 14). This highlights that the industries' key message to harvest frequently and store NIS for as short a time as possible has been received and accepted by growers.

Number of nut in shell drops, question 15

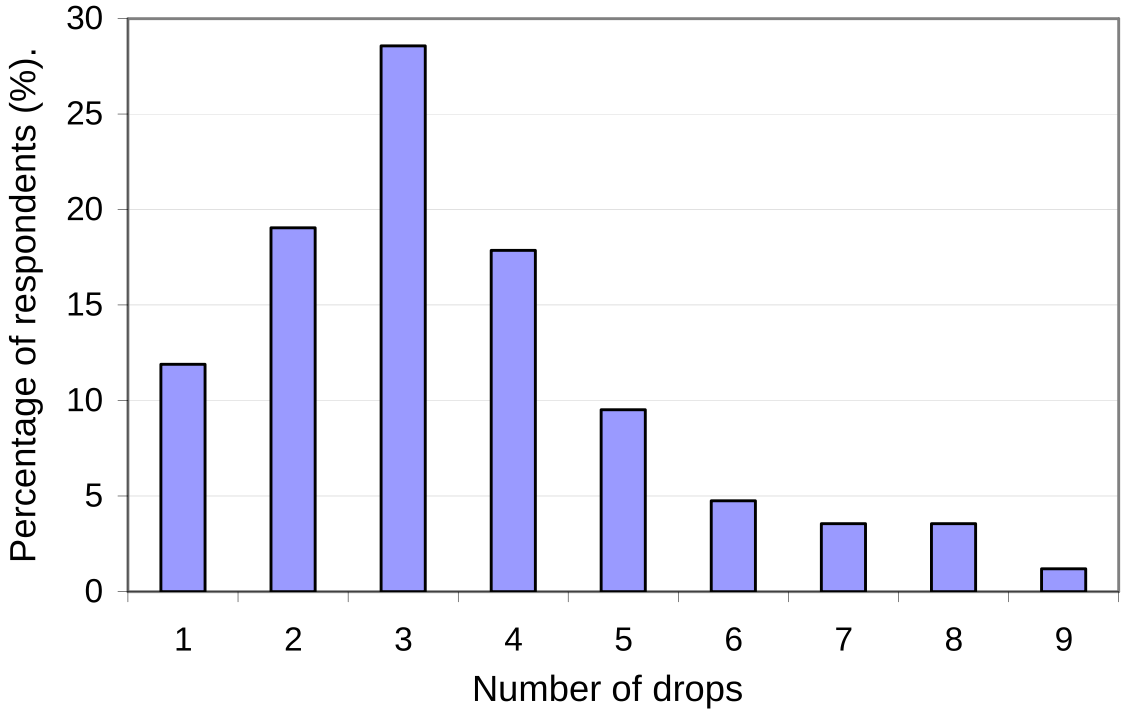


Figure 15. How many drops are estimated from harvest to consignment (15a).

The median number of drops of NIS from harvest to consignment was three (range 0 to 9). This is a fairly low number of drops, considering the height specified in the question was "greater than 30cm". Drops of NIS from heights of greater than 30cm affect kernel quality, especially shoulder damage and ARD (Wallace and Walton, 2005).

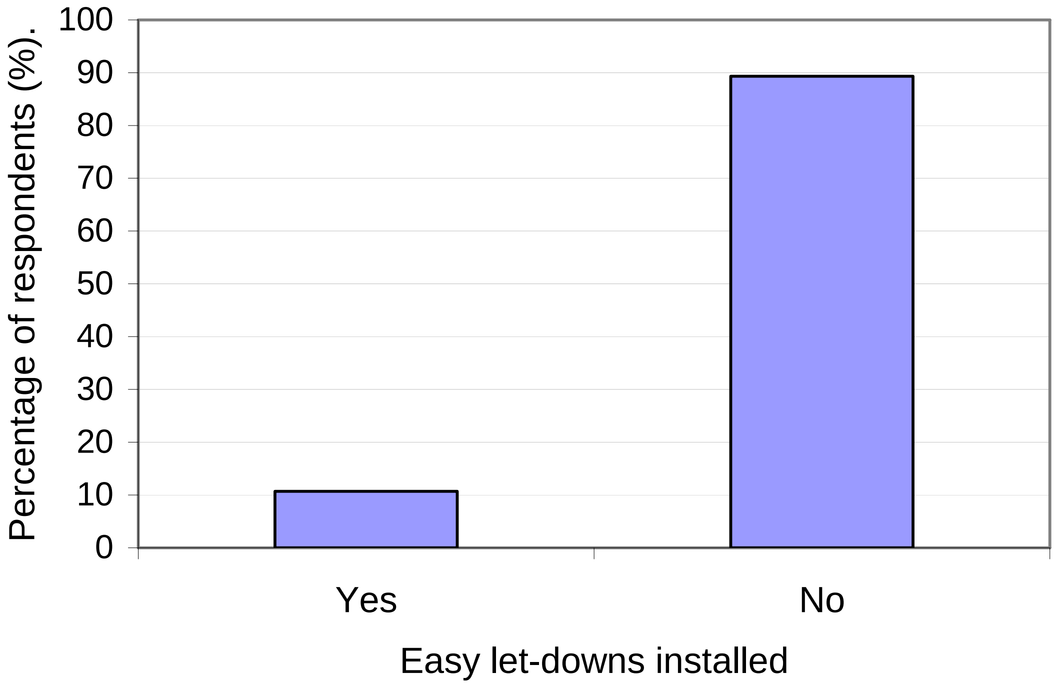


Figure 16. **Installation of easy let-downs in silos**

Approximately 10% of growers have easy let-downs installed in their silos or drying system (Fig. 16). Considering the cost of easy letdowns is small, $200 per silo (Burnett, Pers.comm.), and significant quality benefits have been identified (most to processors), the poor uptake of this technology is concerning.

Grower attitudes, questions 16-25

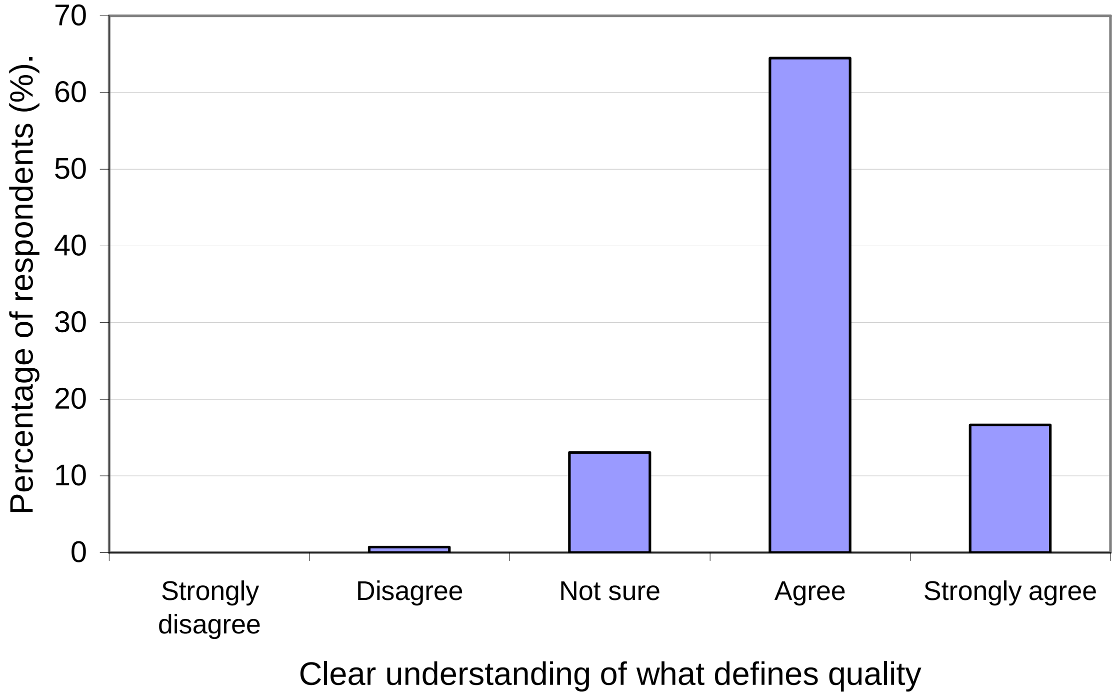


Figure 17. Grower attitudes on their understanding of what defines quality.

Approximately 85% of the respondents believed they have a clear understanding of what defines quality (Fig. 17). That most growers understand what defines quality gives us confidence in analysing their attitudes towards practices that affect crop quality.

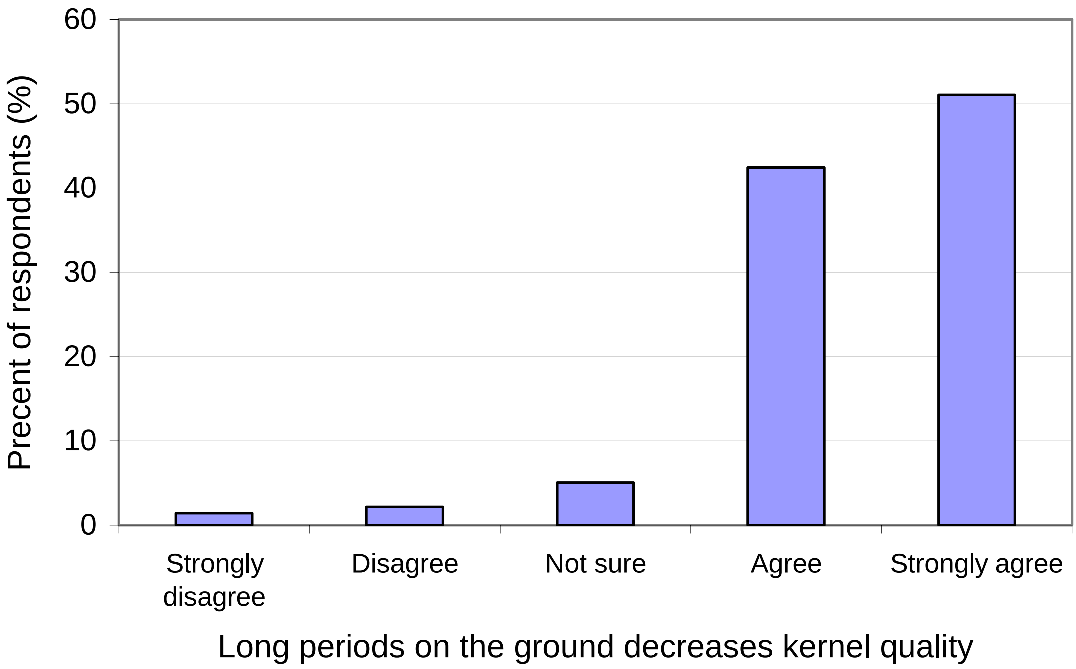


Figure 18. Does leaving nuts on the ground for a long period of time affect quality?

About 95% of growers agreed that nuts left on the ground for long periods of time would be of a reduced quality (Fig. 18). This illustrates that growers have found either through experience or via extension activities that nut quality is reduced by extended periods of on-ground storage.

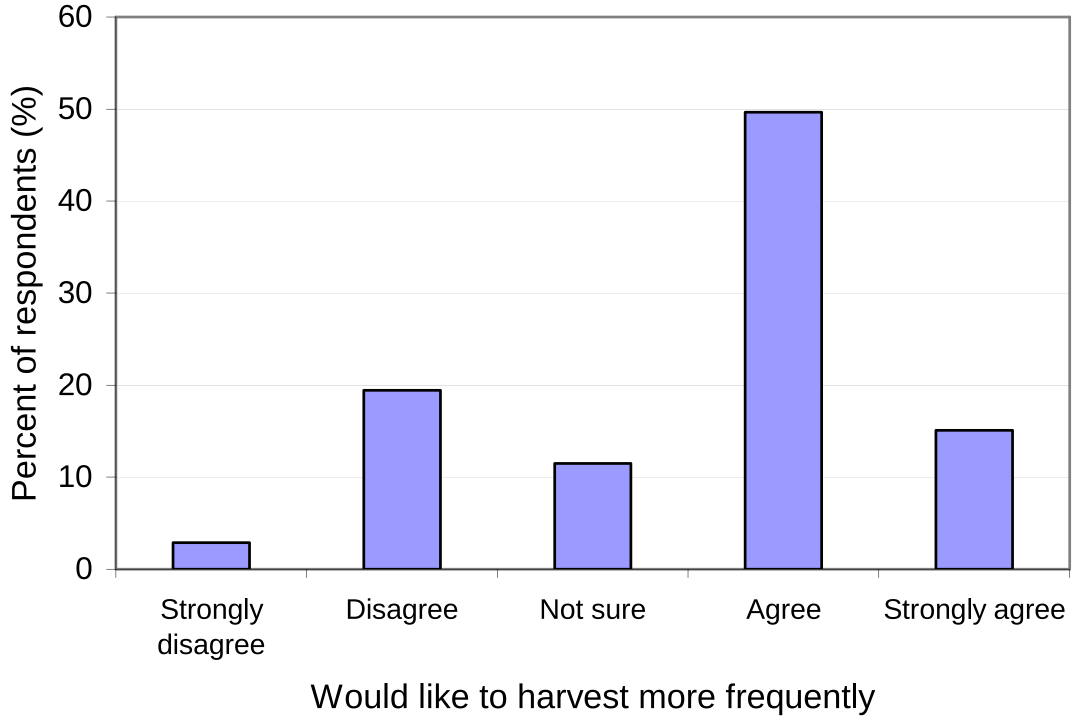


Figure 19. Would growers like to harvest more frequently?

Sixty five percent of growers wished to harvest more frequently, while35% were uncertain or did not wish to harvest more frequently (Fig. 19). This shows that most growers aspire to harvest more frequently, and most growers understand why harvesting more frequently is important (Fig. 17 and 18). This is important because it shows that the recommendation to harvest more frequently has been received and understood by growers, but for varying reasons has not been adopted.

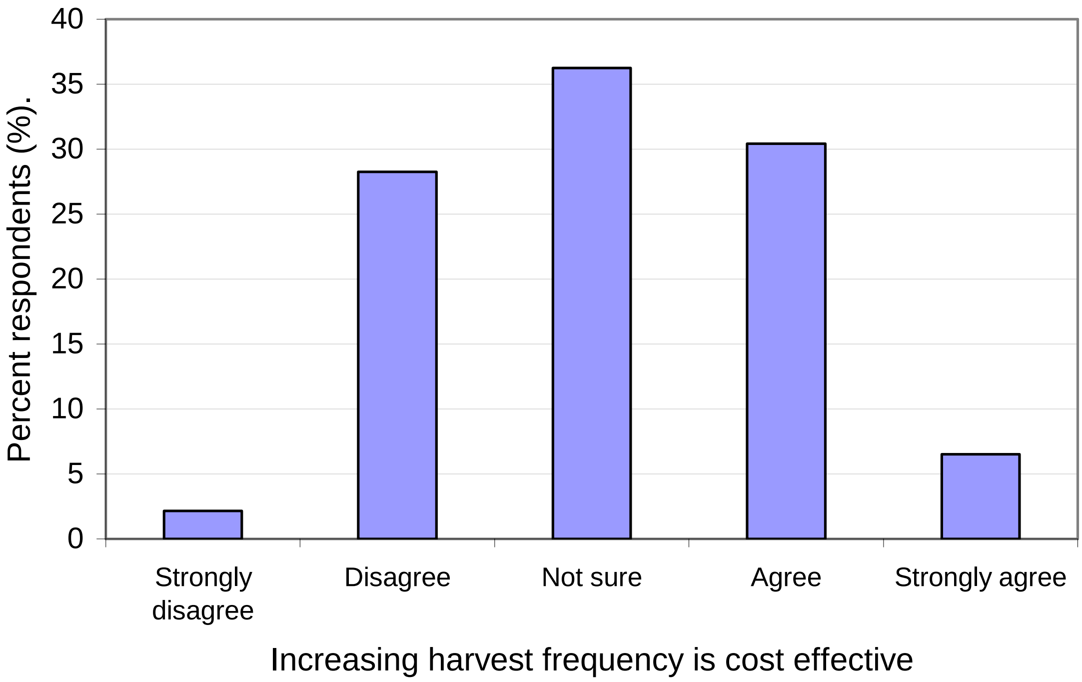


Figure 20. Is increasing harvest frequency cost effective?

There was strong segregation amongst growers about whether increasing harvest frequency is cost effective (Fig. 20); roughly equal numbers (about 30%) agreed or disagreed while slightly more (35%) were unsure. This demonstrates that although many growers believe harvesting more frequently results in improved quality (Fig. 18), they are unsure if there will be extra costs and/or greater return. This further highlights the need for economic information on the costs and benefits of harvest frequency, which is explored in other sections of this report (Chapter 5).

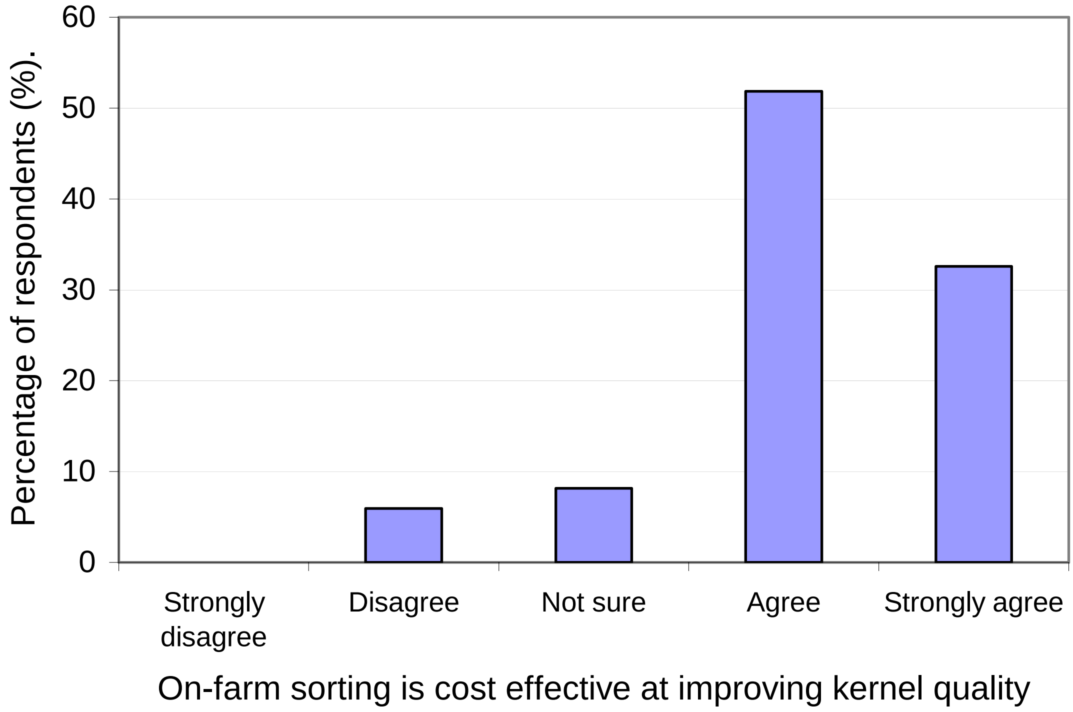


Figure 21. Is on-farm sorting cost effective in improving quality?

About 90% of growers agreed that on-farm sorting is cost effective in improving quality (Fig. 21). It highlights that the current grower attitude is to sort NIS as they believe they can do it cost effectively. It also highlights that they believe they have the skills to sort effectively.

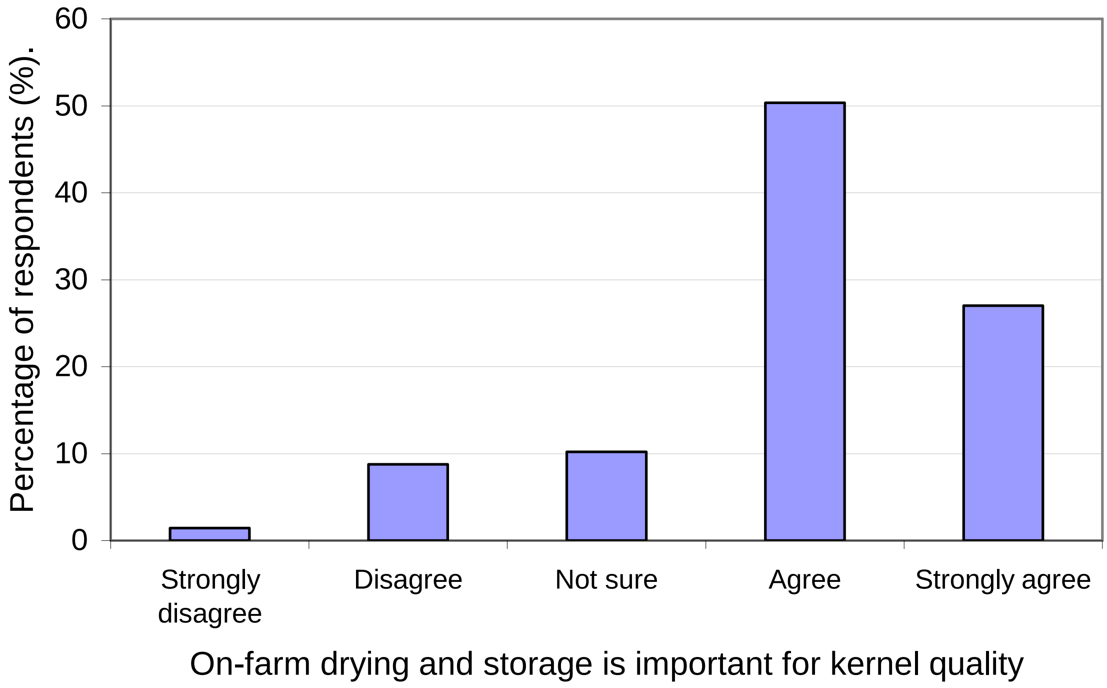


Figure 22. Is on-farm drying and storage important for kernel quality?

About 80% of respondents agree or strongly agree and 10% disagree or strongly disagree that on-farm drying and storage is important for kernel quality (Fig. 22). There is scope to examine the best method for on-farm drying and storing, particularly from an economic perspective.

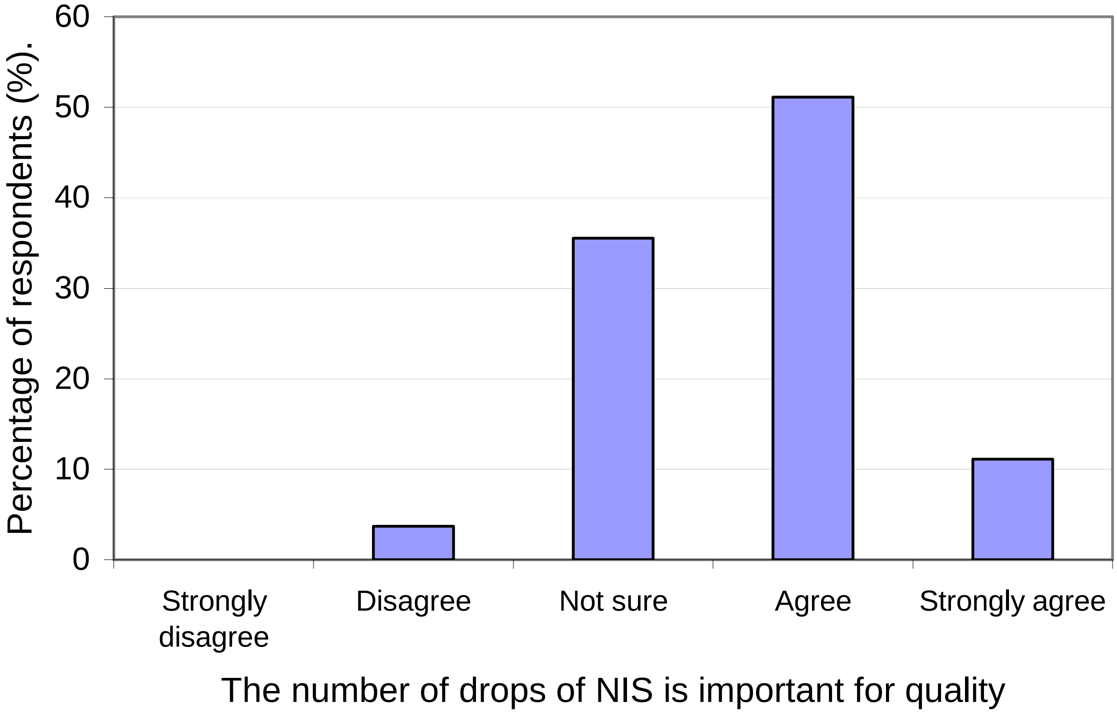


Figure 23. Is the number of drops of NIS is important for quality?

Approximately 60% of growers agreed, whereas only about 5% disagreed that the number of NIS drops affects quality (Fig. 23). This result shows that growers understand the importance of easy letdowns or reducing the numbers of drops but with the low number of these devices fitted to drying systems (figure 16), the value of installing them may not be seen to be economically worthwhile at this stage.

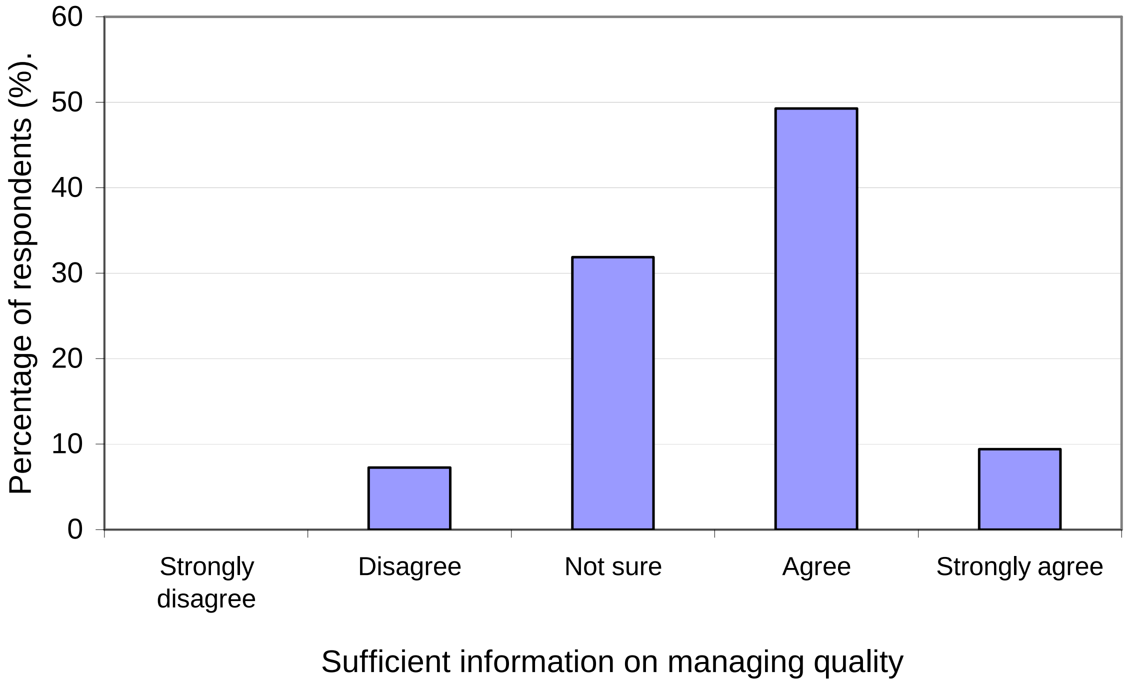


Figure 24. Growers have sufficient information on managing quality.

About 60% of growers agreed, and 40% were uncertain or disagreed, none strongly, that there was sufficient information available to manage quality (Fig, 24). A significant amount of research on quality management of macadamias has been performed, so given that many growers do not believe they have sufficient information to mange quality; more effort needs to be put into the extension of this information.

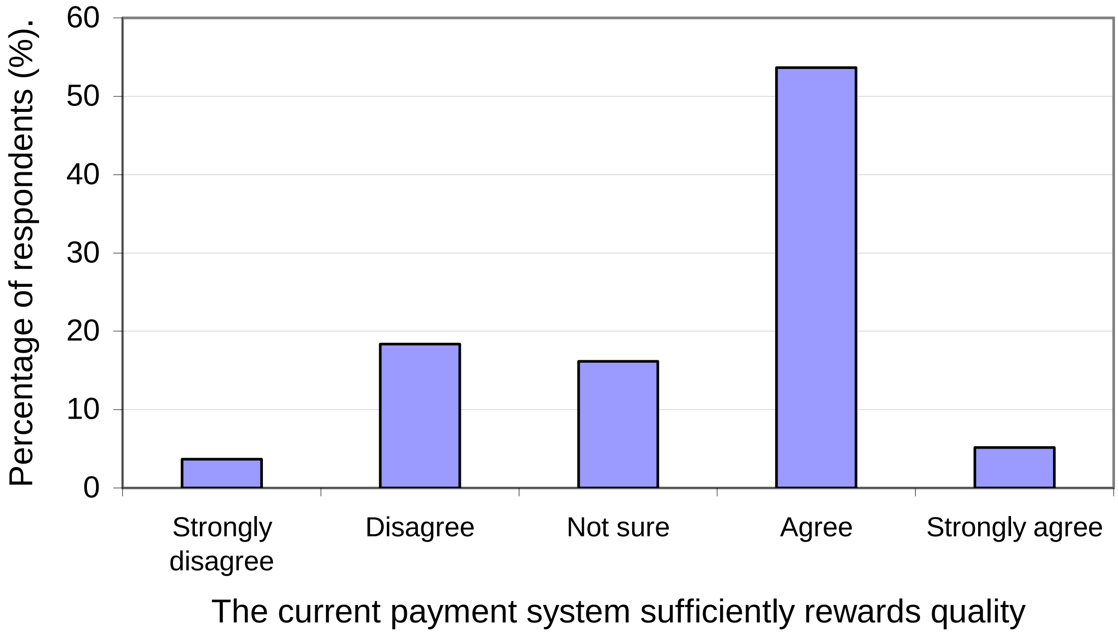


Figure 25. The current payment system sufficiently rewards quality.

About 60% of growers agreed that the current payment system rewards quality sufficiently (Fig. 25). This is positive for the industry because if growers believe the payment system rewards quality they will probably be more likely to attempt to manage it effectively. However, there are currently quality factors such as shelf-life, ARD susceptibility and percentage whole kernels that are not within the payment scheme, but which do add or remove value to the kernel for the processor.

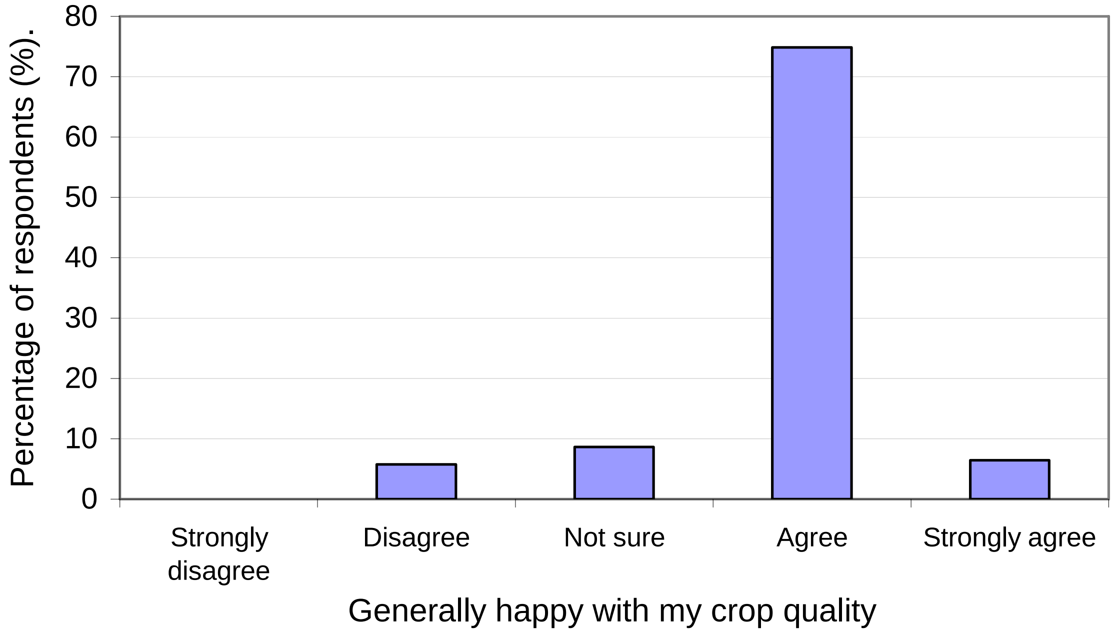


Figure 26. Are growers happy with their crop quality?

More than 90% of growers agreed they were happy with the quality of their crop (Fig. 26). This is somewhat at odds with approximately 40% of growers feeling they did not have adequate information to manage their quality.

On-farm storage time, further analysis

By comparing responses to questions 9, 10 and 14 we can show the relationship between on-farm storage times under typical, and difficult conditions and what growers see as ideal.

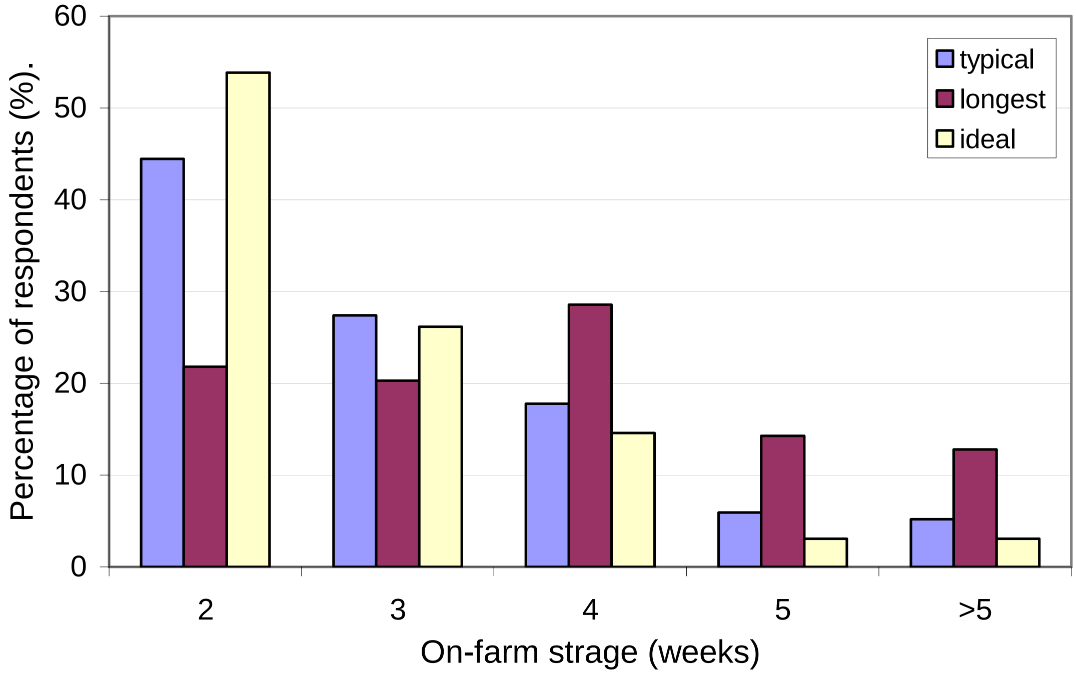


Figure 27. On-farm storage under different conditions

The on-farm storage time under typical conditions was similar but slightly longer than the ideal time, whereas the time under difficult conditions was considerably greater (Fig. 27). For example, half the respondents saw two weeks as the ideal storage time and almost as many (45%) indicated they achieved this under typical conditions, but only 20% achieved this under difficult conditions. The difficult conditions typically also have higher ambient relative humidity. Under difficult conditions 30% indicated that they store for 4 weeks or more, compared with only 10% of respondents indicating more than 4 weeks under typical conditions. Perhaps the drying systems being used are not coping under these difficult conditions.

Total on-farm time

Combining the responses for the longest time nuts are on the ground (question 3 or 4) with time in storage (question 9 or 10), gives the longest total time NIS is on-farm (Fig. 28). For the purpose of this analysis the category of "more than 5 weeks" was given a nominal value of 6 weeks and the category of 2 weeks or less was given a value of 2 weeks.

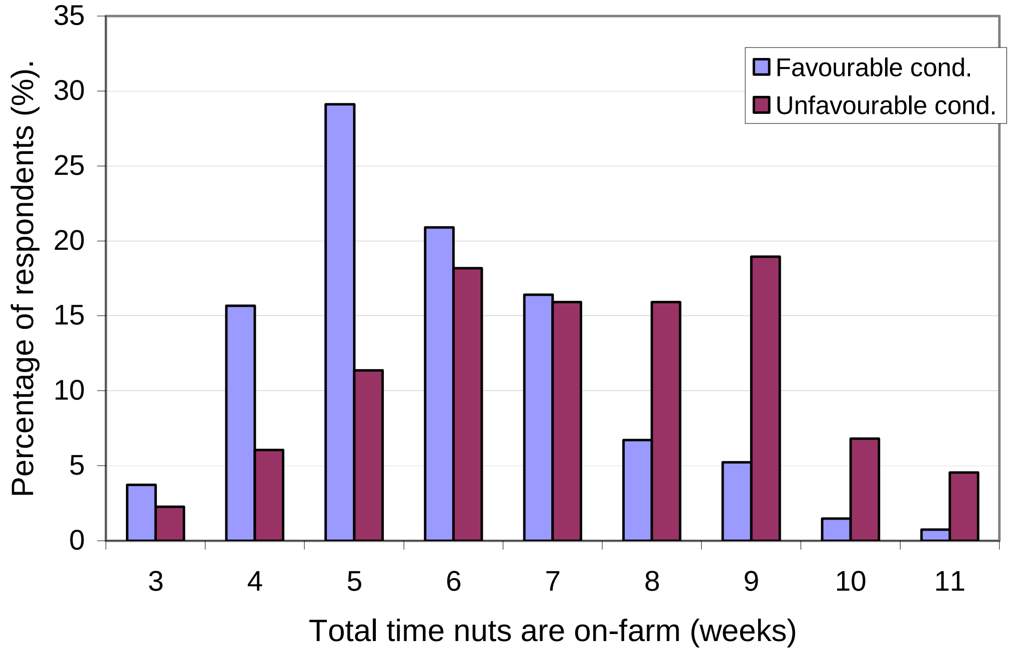


Figure 28. Total on-farm NIS storage time, including on-ground and post-harvest storage.

Under favourable conditions only 4% of nuts were on-farm for 3 weeks or less and only 15% of respondents had nuts on-farm for 4 weeks or less. Half of all respondents indicated maximum total on-farm time was more than 5 weeks under favourable conditions and about half indicated more than 7 weeks under unfavourable conditions. On further analysis, it was found that the total on-farm time was made up of approximately equal proportions of on-ground and post harvest storage time. Most growers always re-sort (Fig. 8), use silos with ambient air and no controllers (Fig. 11 and 12) and weather is the biggest impact upon harvesting. Therefore there is a need to highlight the value of systems that allow growers to dry NIS quickly so the storage time is less than 2 weeks, or for growers to accept an inability to dry the nuts effectively and for them to consign the nuts at moisture contents greater than 10%. The value of frequent harvesting also needs to be highlighted, and both messages conveyed, to give a simple but powerful message.

Harvest frequency aspirations

The relationship between grower harvest frequencies aspirations (question 17) current harvesting frequency (question 1) was examined on an individual grower basis. By grouping growers on the basis of current number of harvest rounds, the percentage of each group who aspired to harvest more frequently was calculated (Figure 29).

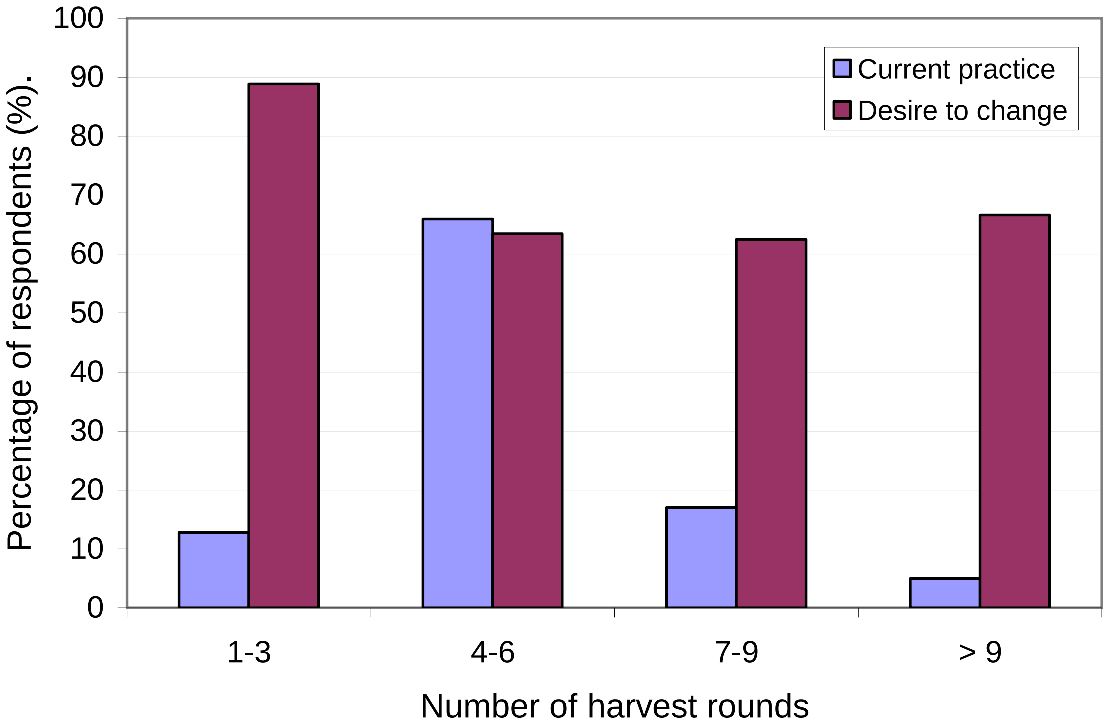


Figure 29. Aspiration to harvest more frequently based on current harvest frequency.

In all groups of current harvesting practice more than half of respondents indicated they wished to harvest more frequently; the level was about 60% in every group except those with only harvested one to three times per year, where almost 90% wanted to harvest more often (Fig. 29). It is important to note that the number of entries was small in some classes.

Recommendations

Based on the findings from this survey, the following recommendations are made:

- The benefits of harvesting more frequently, especially the economic benefits, need to be investigated and demonstrated to growers. The cost/benefit of greater investment in capital equipment to facilitate more frequent harvesting, especially in unfavourable conditions, also needs to be investigated and demonstrated to growers.
- There is a need to improve the use of crop loss monitoring protocols by growers because a high percentage of growers do not measure crop loss on-farm. There is potentially a high level of useable kernel being discarded on-farm. Linked to this is the need to investigate the value of using a simple re-sort decision guide/strategy as many growers always re-sort and this may not be cost effective in all situations.
- The benefits of reducing the on-farm storage time need to be investigated further, as many growers are exceeding the recommended time for on-farm storage. There is also a need to revise COSOP to have the maximum on-farm storage time for NIS at 10% MC reduced from 4 weeks to 2 weeks, to reflect the findings from research work. Linked to this will be the need to investigate the options available to reduce on-farm storage time and highlight the value of each system in achieving this outcome.
- The economic value of having easy-letdowns in silos needs to be investigated and demonstrated to growers and processors, especially for quality parameters for which growers are not paid. Research has demonstrated the quality advantages of using easy let downs but few growers are using them; therefore there is a need to improve the adoption of this technology. There may be an opportunity to get manufacturers to make them standard in new silos or other drying systems.
- There is a clear need to have more resource information on quality management available to growers, because a high percentage believes they do not have adequate information.

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Appendix 1. Survey for quality management in macadamias.

The project:

Attached is a survey form seeking information and ideas from growers to inform our project, MC03008: Adoption of Quality Management Systems in Macadamia.

This project is using existing research findings and industry best practices information, to develop a comprehensive quality management system for the quality chain in the Australian macadamia industry.

Most importantly the project is analysing the economic component of quality management programs in order to ensure there are clear economic drivers for growers to adopt quality management. Some of our team have already been busy, with the help of growers, collecting on farm economic data.

In this survey we are hoping you will tell us about conditions on farm now, a little of how you would like them to be, and what your views on a few of the fundamental quality issues are.

The survey:

The survey is designed to be quick and easy, with a "tick the box" format that takes **no more than ten minutes** to complete. Free -Post envelopes are enclosed for your convenience.

Your collective responses are very valuable for the project team and for the industry as a whole; to make sure we have a real life picture of what is happening on farm and what your opinions are concerning quality management.

To keep the call on your time to ten minutes, we have only used a "tick the box" format. However any comments you would like to add will be valued so please feel free to include a page or two if you are inclined. We will collate any comments and make sure they are captured in our final report.

Confidentiality:

Providing your name is entirely optional: All returned surveys will be kept in strict confidence.

Fabulous prizes:

Just joking, we cannot offer any prizes for the best entries, but please take the time to do the survey anyway, your information is important for us and for the industry.

Our thanks in anticipation,

Project team.

Neil Treverrow, Kevin Quinlan: NSW DPI. Paul O'Hare: QLD DPI&F. Richard Mason, Geoff Slaughter: University of Queensland, Helen Wallace: University of the Sunshine Coast

This project has been funded by Horticulture Australia Ltd and grower levies with support from the AMS.

Survey for MC03008- Adoption of Quality Management Systems :To complete, please tick the boxes for your responses					
Name: (Optional)					
Orchard Postcode	**Farm size (Ha, or tree number)**			**Ha**	**Tree #**
Age of trees (range)	**% of trees of bearing age**			**Years as a grower**	
Harvesting					
How many harvest rounds do you do **in a favourable season?**	1-3	4-6	7-9	More than 9	
How many harvest rounds do you do **in a wet or difficult season?**	1-3	4-6	7-9	More than 9	
What is the longest time nuts are on the ground **in a favourable season?**	2 weeks or less	3 weeks	4 weeks	5 weeks	More than 5
What is the longest time nuts are on the ground **in a wet or difficult season?**	2 weeks or less	3 weeks	4 weeks	5 weeks	More than 5
What are the main constraints on harvesting frequency?	Weather	Harvester capacity	Dehusker capacity	On farm storage	delivery to processor
With no constraints, what do you think is the optimum harvest frequency to maximise quality and profit?	1 week	2 weeks	3 weeks	4 weeks	5 or more weeks
Sorting					
What levels of NIS do you typically reject (includes nuts sent for oil?	1 -2%	3-4%	5- 6 %	More than 6%	Not measured
If you resort how do you make your decision?	Factory results from previous harvest	Results of first sort	Nut sample after first sort	Always resort	Routinely resort first and last harvest

On farm storage					
What is the **typical** time for NIS storage on farm?	2 weeks or less	3 weeks	4 weeks	5 weeks	More than 5
What is the **longest** time from NIS storage on farm?	2 weeks or less	3 weeks	4 weeks	5 weeks	More than 5
How do you dry NIS on farm?	Ambient with fan, no controller	Ambient with fan, with controller	Heated with fan, no controller	heated with fan, with controller	Bungay style system
How do you store NIS on farm?	Bungay style system	Bins with fans	Bins without fans	Silo with fans, no heating	Silo without fans, no heating
Please see over page					
After harvest, do you segregate NIS in storage?	Never	By variety	A's from Hawaiian	By blocks	Other
What do you think is the optimum time to get nuts from pick up to off the farm, to maximise quality and profit?	2 weeks	3 weeks	4 weeks	5 weeks	6 or more weeks
Nut drops on farm					
How many drops for nuts (say more than 30 cm) are there from pick up to consignment?	Do you have let-downs in your silos Yes No				
Kernel quality : your views:					
Long periods for nuts on the ground reduces kernel quality	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
I would like to harvest more frequently	Strongly disagree	Disagree	Not sure	Agree	Strongly agree

Increasing the frequency of harvesting is cost effective	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
On farm sorting is cost effective in improving kernel quality	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
On farm drying and storage is important for kernel quality	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
The number of drops of NIS on farm is important for kernel quality	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
I have a clear understanding of what defines quality	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
I have sufficient information on managing kernel quality issues	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
I believe the current payment system rewards quality sufficiently	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
I am generally happy with the quality of my crop	Strongly disagree	Disagree	Not sure	Agree	Strongly agree

Thanks for your time, it is very much appreciated. Please feel free to add any comments with your return

Chapter 6

The economic effects of farming practices on macadamia quality

Kevin Quinlan, Geoff Slaughter, Paul O'Hare

Summary

The economic effects of on-farm practices on nut in shell (NIS) and kernel quality were investigated. A sample of 40 farms representing a cross section of the Australian industry was used. Only 19 of the 40 farms had detailed shed reject information, which limited the sample size for some of the analysis, even though significant relationships were found, the results should be treated with caution due to the small sample size.

There was no correlation between on-farm reject categories and factory reject categories, but some on-farm practices significantly affected factory reject levels. The most significant impacts of management on quality are:

a. Harvest frequency has a strong relationship to the quality of NIS. Frequent harvest intervals (less than or equal to every four weeks on average) gave a mean sound kernel recovery (SKR) of 34.2%, whereas harvesting intervals longer than every four weeks, gave an average SKR of 31.6%. This difference of 2.6 % SKR, using current payment scales (10c more per kg NIS for each 1% increase in SKR), results in a difference of $260 per tonne NIS. On a 40 tonne NIS farm, this equates to $10,400 in additional revenue.
b. Frequent harvesting also reduces shed rejects. Frequent harvest intervals (less than or equal to every 4 weeks on average) resulted in shed reject levels of 4.6% of the harvested yield, whereas harvest intervals longer than every four weeks resulted in shed reject levels of 8.3%. For a 40 tonne NIS farm, this is an extra 1.5 tonne of NIS delivered to the factory.
c. Smaller silos (less than or equal to 20 tonnes) were found to reduce unsound kernel recovery (UKR) levels on average by 0.34%, compared with larger silos (greater than 20 tonnes). The main effect is on reducing internal discolouration of kernel (brown centres) and this has been identified as a serious problem by the industry. This reduction, using current payment scales

(10c more per kg NIS for each 1% increase in SKR), results in a difference of $34 per tonne of NIS delivered to the factory. Smaller silos also reduce the moisture content of NIS delivered to the factory, which may affect external discolouration of the kernel.

Introduction

There are many factors that influence the uptake of research by growers. Considerable work that has been carried out to identify practices that affect macadamia kernel quality or the causes of reduced quality, however many of these findings have not been adopted by growers. One reason for this is that even though a quality benefit has been demonstrated, the grower may not believe a significant economic benefit will follow directly to them, for example; many growers do not believe increasing harvest frequency is cost effective (Chapter 5). In this chapter, the economic implications and benefits of various operations were examined using on-farm data. We found real farm data supports the research findings and the benefits to growers were quantified in economic terms, in an attempt to improve adoption of on-farm practices. We recommend that the results be used to develop an extension and adoption strategy to improve the uptake of research information.

Materials and Methods

A sample of 40 macadamia farms was chosen to collect information from, relating to the different practices carried out on-farm, the economic value of these different practices, the quality results achieved and other necessary information. A copy of the data collection template is included in Appendix 1. The data required for analysis was determined by using the results obtained from the industry based steering group in the identification of the quality management chain and in consultation with the project team. In order to maximise efficiencies, the data collection process was combined with that of the project 'On-farm economic analysis of the macadamia industry' (MC03023).

Data was collected from 2004 to May 2006, with all information collected on a quarterly basis. This was to coincide with taxation reporting for business activity statements (BAS) so the requirements for extra reporting by growers was kept to a minimum. Two financial years of data have been collected, covering the financial years 2002/2003 to 2004/2005 to give a robust sample. A series of years was also chosen to remove seasonal effects and to help isolate the farm practices that were actually affecting quality, not by chance.

Once data collection was complete, all information was checked for validity and entered into a database. Different statistical analysis has been performed upon the data to determine areas of greatest impact upon quality. The following is an outline of the major types of analysis used:

Stepwise regression - A multiple regression model uses more than one explanatory independent variable to explain the variation in the dependant variable. For example how much variation in the percentage of factory UKR can be explained by insect damage, external discoloration and so on. Stepwise regression is a technique for screening the variables to be included in a multiple regression model. In this research we use forward stepwise regression which starts with no model variables. At each step it incrementally adds the most statistically significant variable (the one with the highest F statistic or lowest p-value) until there are none left. The F statistic shows the level of contribution of a given independent variable to the variation in the dependant variable. Alternatively the p-value shows the level of significance of that contribution. To be 95% confident that there is a significant contribution the p-value must be less than 5%, that is, $P < 0.05$. An important assumption behind the method is that some input variables in multiple regression do not have an important explanatory effect on the dependant variable. If this assumption is true, then it is a convenient simplification to keep only the statistically significant variables in the model. Therefore, stepwise regression analysis only includes independent variables that have a significant influence on the dependant variable.

Correlation - A statistical technique which can show the strength of the relationship between two variables. A correlation coefficient is a quantitative assessment of the strength of relationship between two variables. In stepwise regression analysis we used Pearson's sample correlation analysis to select the independent variables to be included in the model. Because stepwise regression assumes that each independent variable is linearly related to the dependant variable. Pearson's sample correlation coefficient measures the strength of the linear relationship between two variables. Therefore it is most applicable in selecting independent variables for the regression analysis. Spearman's Rank correlation coefficient can be used to ascertain both linear and non-linear relationships between two variables. As such it does not assume that the two variables have a linear relationship. Therefore by using a combination Spearman's rank correlation in addition to Pearson's sample correlation we can not only ascertain the strength of the linear relationships between two variables but also the strength of the non-linear relationships between those variables. This improves the understanding of the relationships that exist within the data.

Independent t-tests - The independent t-test is used to test for a difference between two independent groups on the means of a continuous variable. For example, it was used to test for a significant difference in SKR between average harvest intervals less than or equal to four weeks and those greater than four weeks.

Description of the data

Due to confidentiality reasons, all results are reported as averages or medians so as to protect the privacy of individual growers. Table 1 shows a summary of the farm descriptive values for the sample size. There was a wide range of sizes, locations, tree ages and yield within the sample size and the averages and median is extremely close. This meant that there is an even distribution of farm variables used, making the use of averages rigorous.

Table1. Descriptive statistics for the 40 the farms surveyed.

	Years of management experience	Tree area	Number of trees	Planting density	Mean tree age	Slope	Mean rainfall (mm)	Mean NIS per hectare (tonnes)	Mean SKR (%)	Mean UKR (%)
Mean	12	32.95	9192	288	14	Gentle (4-8%)	1424	2.52	32.77	2.27
Median	13	31.60	8009	283	14	Gentle (4-8%)	1409	2.53	32.17	1.88
Min	1	2.76	1200	160	0	Flat (0-3%)	750	0.12	24.43	0.60
Max	25	112.00	35000	487	32	Steep (>15%)	2125	5.02	43.50	9.20

Initially, correlations were performed for all variables to determine if possible relationships existed. These correlations were then analysed further to determine if the relationship was valid or due to chance. Each significant correlation was scrutinised by the project team to determine if the result was a possible cause and effect relationship or just likely due to chance.

After consultation with the project steering committee and the project team, it was decided to focus upon those variables that macadamia producers could change in the short to medium term. This meant that the effect of varieties on kernel quality were not analysed in any detail because it is difficult for growers to manipulate variety selection after the orchard has been planted. Additionally, there was insufficient data available to look at the effect of variety, as many growers did not segregate varieties.

Results and Discussion

Factors affecting sound kernel production per hectare

Table 2 shows that average yield of sound kernel per hectare is significantly correlated at the 5 percent level with per hectare expenditure on crop protection and crop nutrition. We do not suggest that purely increasing fertiliser and pesticide spray inputs will improve yields, but it does suggest that active management and strategic expenditure in these areas has a positive impact on sound kernel yields. To ensure that this relationship was not merely a function of orchard age, the same correlation was performed after splitting farms into different age categories. The same correlation was not evident, showing that it was not purely due to the age of the trees and the natural increase in production expected over time. The point of diminishing returns is where the increased expenditure for an input becomes greater than the increase in value of the outputs, in this case sound kernel per hectare. In terms of farm management, growers will only receive an economic benefit if they have not reached the point of diminishing returns for a particular input, for example pest management and crop nutrition; however the point of diminishing returns is not clear from this analysis.

Planting density and sound kernel production were correlated (Table 2, P = 0.08); higher density orchards produced more sound kernel per hectare. This finding is supported by that of Stephenson *et al* (2006) who reported the rate of yield increase in maturing orchards and the maximum yield was greater in higher density orchards. It must be noted that the highest density in the sample was 487 trees per hectare (7 x 3m). The production from higher density orchards needs to be collected and analysed to determine if this relationship holds true for all densities.

Profit per hectare increased with sound kernel production per hectare (Table 2, P = 0.00), which demonstrates that the biggest driver to profitability of a macadamia operation is the sound kernel yield. This means that costs for producing more kernel per hectare may rise, but will be small in comparison to the extra returns. Results from the 'on-farm economic analysis' project show a similar trend; costs for all farms staying relatively stable over time. The yield of kernel per hectare therefore drives the profit margin, with the more kernel produced, the more profit per hectare (O'Hare, pers comms 2006).

Sound kernel production significantly increased with tree age, this correlation was used to validate the data set (Table 2, P = 0.00). This trend is comparable to that found by McFadyen (2004), who reported that productivity increased as canopy volume and light interception increased up to approximately 45 000 m^3 per hectare and 97% respectively, a similar trend is shown in the macadamia growers guide (2005).

Table 2. Sound kernel per hectare is significantly affected by crop protection inputs per hectare, crop nutrition inputs per hectare, planting density and tree age. Additionally, as sound kernel production per hectare increases, so does profit.

		Sound Kernel per Hectare
Crop Protection per Hectare	Spearman's rho	0.36*
	Sig. (2-tailed)	0.02
	N	40
Crop Nutrition per Hectare	Spearman's rho	0.32*
	Sig. (2-tailed)	0.04
	N	40
Profit per Hectare	Spearman's rho	0.69**
	Sig. (2-tailed)	0.00
	N	40
Planting Density per Hectare	Spearman's rho	0.28^
	Sig. (2-tailed)	0.08
	N	40
Average Tree Age	Spearman's rho	0.57**
	Sig. (2-tailed)	0.00

	N	40

*** Significant at the 0.01 level; * Significant at the 0.05 level; ^Significant at the 0.1 level.*

Harvest Intervals

The total percentage of crop removed as on-farm rejects increased with the length of harvest interval (Table 3, P = 0.04). This has major impacts upon a farm business; greater levels of shed rejects decrease shed sorting efficiency and decrease the amount of crop available to be sold, thereby reducing profit.

On-farm germination rejects also increased with harvest interval (Table 3, P = 0.03). This relationship was also demonstrated by Mason and Wells (1984), it is believed that a combination of sunlight on the nuts of high moisture content leads to germination, which increases with the length of time nuts are on the ground. By reducing the length of time between harvests, the amount of germination can be reduced, especially in warm and humid conditions.

Longer harvest intervals lead to a higher level of factory mould (Table 3, P = 0.03). As there is no correlation between shed reject levels for discolouration/mould and factory mould levels it would indicate that either the mould that is found in the factory is not detected during on-farm sorting and/or the longer harvest intervals pre-dispose nuts to deterioration that is occurring during on-farm storage. This relationship needs further investigation so that management systems can be designed that address this issue.

The significant correlation between the average annual rainfall and the harvest intervals (Table 3, P = 0.048) demonstrates that the environment significantly impacts harvesting practices. The results of the grower practices and attitudes survey (Chapter 5) also indicated that harvesting is affected by the weather. Higher rainfall growing regions are likely to have delayed harvesting due to wet weather.

Factory internal discolouration significantly increased with harvest interval (Table 3, P = 0.01). Since internal discolouration is difficult (if not impossible) to remove during shed sorting, by decreasing harvest intervals this problem can be reduced. There is also work by Walton and Wallace (2005a) that shows that longer harvest intervals increase after roast darkening (ARD) susceptibility.

Table 3. On-farm germination, the total percentage of the crop removed as on-farm rejects, factory mould rejects and internal discoloration rejects increased with increasing harvest intervals. Additionally, increasing rainfall increased the harvesting interval.

		Harvest Interval
Farm Sorting Germination	Spearman's rho	0.49*
	Sig. (2-tailed)	0.03
	N	19
Factory Sorting Mould	Spearman's rho	0.35*
	Sig. (2-tailed)	0.03
	N	40
Factory Sorting Internal Discolouration	Spearman's rho	0.42**
	Sig. (2-tailed)	0.01
	N	40
Average Farm Rainfall	Spearman's rho	0.314*
	Sig. (2-tailed)	0.048
	N	40
Total Percentage of crop sorted out as on-farm rejects	Spearman's rho	0.48*
	Sig. (2-tailed)	0.04
	N	18

*** Significant at the 0.01 level; * Significant at the 0.05 level; ^Significant at the 0.1 level.*

Moisture content affects germination

Rejects due to germination at the factory increased with consignment moisture content (Table 4, P = 0.00). As germination requires moisture and warm temperatures, any nut that has been stored on-farm with higher moisture content is predisposed to germination. Kowitz and Mason (2001) found that NIS at between 10 and 15% should only be stored for up to two weeks at 25°C. The results of the grower practices and attitudes survey (Chapter 5) indicate that on-farm storage often exceeds this time frame, and so leads to the problem of reduced quality, especially higher levels of germination in factory analysis.

Table 4. Factory germination and moisture content correlation

		Consignment Moisture Content
Factory Average Germination	Spearman's rho	0.50**
	Sig. (2-tailed)	0.00
	N	37

*** Significant at the 0.01 level; * Significant at the 0.05 level; ^Significant at the 0.1 level.*

On-farm (Shed) rejects analysis

Figure 1 shows the percentage of total shed rejects found by growers. The largest category, called "external discolouration" is actually a combination of mould and discolouration because it is often difficult to separate the two categories without cracking nuts open. It is difficult to say whether mould or discolouration is the higher of the two, in any case, considerable quantities of NIS are lost to these two problems.

Immaturity accounts for approximately 15% of all shed rejects. This level of immaturity in the rejects does not account for the portion of the crop that is immature and removed during pre-harvest cleanup, which could make it a considerably higher proportion of rejects. Insect damage is approximately 12% of all rejects, showing that it is also a major contributor to on-farm rejects.

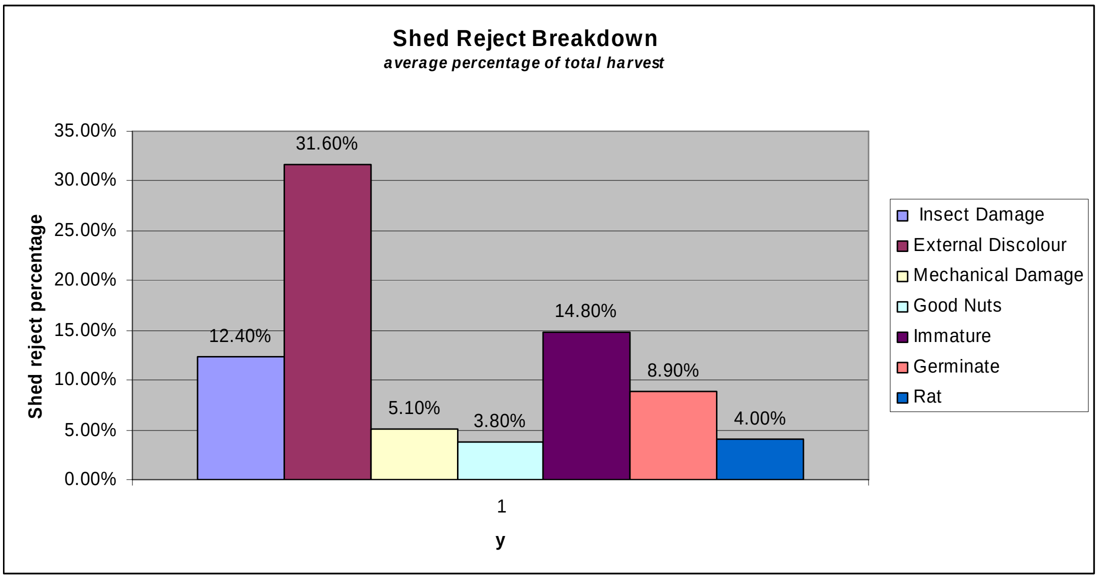

Figure 1. The mean proportion of each defect category comprising on-farm rejects.

Note: Percentages are based on averages and as such do not add up 100%.

To determine the proportion of the variation in on-farm rejects accounted for by different reject categories, the different reject categories were added sequentially to statistical models explaining the total shed rejects (stepwise regression), the change in the proportion of variation explained by the addition of each reject category is the proportion of the variation explained by that reject category (Table 5, Fig. 2). External discolouration, immaturity, insect damage, germination and good nuts rejected explained 97.4% of the variation in the amount of nuts rejected on-farm. External discolouration explained the most variation (46.6%), which means that it is the reject category that has the most variation between farms. Whereas mechanical damage is the fifth highest reject category (Fig. 1) but accounts for the least amount of the variation of shed rejects (Fig. 2). This means that most farms throw out a similar percentage of mechanical damage (ie. it is a constant reject level on all farms).

Table 5: The proportion of the variation in on-farm rejects explained by the addition of each reject category to the regression models, analysed using stepwise regression.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
a	0.682	0.466	0.430	0.10776	0.466	13.069	1	15	0.003
b	0.798	0.636	0.584	0.09206	0.170	6.554	1	14	0.023
c	0.887	0.788	0.739	0.07299	0.152	9.272	1	13	0.009
d	0.951	0.904	0.872	0.05103	0.117	14.591	1	12	0.002
e	0.987	0.974	0.963	0.02753	0.070	30.250	1	11	0.000
f	0.997	0.994	0.990	0.01433	0.019	30.585	1	10	0.000
g	1.000	1.000	1.000	0.00000	0.006	.	1	9	.

a Predictors: (Constant), external discolouration.
b Predictors: (Constant), external discolouration, Immaturity.
c Predictors: (Constant), external discolouration, immaturity, insect damage.
d Predictors: (Constant), external discolouration, immaturity, insect damage, germination.
e Predictors: (Constant), external discolouration, immaturity, insect damage, germination, good nuts.
f Predictors: (Constant), external discolouration, immaturity, insect damage, germination, good nuts, rat damage.
g Predictors: (Constant), external discolouration, immaturity, insect damage, germination, good nuts, rat damage, mechanical damage.

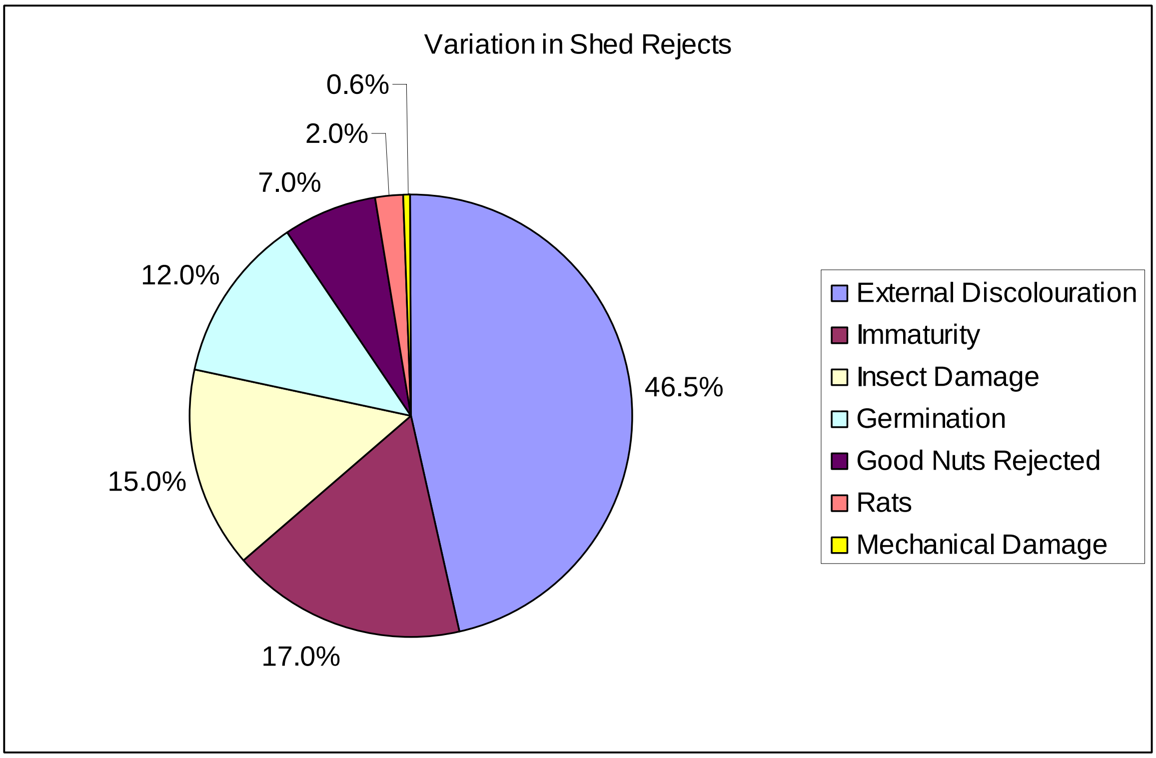

Figure 2: Summary of the influence of factors that explain the variation in shed rejects.

Relationships between farming practices and on-farm rejects

The relationship between farming practices and the five categories that explained the most variation in on-farm rejects were investigated using correlation (Table 6). There was no relationship observed between any of the measured on-farm practices and discoloration or immaturity.

Insect damage has strong positive correlation with tree area (0.589) and tree numbers (0.505), which indicates that larger farms are likely to have more insect damage. These two factors can explain 40% of the variation in insect damage.

Germination is positively correlated with harvest interval (0.524), separation of variety (0.483) and time on farm (0.475), but is negatively correlated with harvest rounds (-0.561), the use of in-field dehuskers (-0.553) and planting density (-0.477). These six factors can explain 75.2% of the variation in germination. The most significant result from this analysis is that more nuts are rejected on-farm due to germination as the time nuts remain on-farm increases. It is important to understand why in-field dehuskers lead to less on-farm rejects due to germination.

The number of good nuts rejected increased significantly with the number of harvest rounds (0.565) but decreased with the time on-farm (-0.499). These two factors can explain 47.4% of the variation in good nuts rejected. As the amount of good nuts being rejected is one of the smallest categories (7.35%) of on-farm rejection, the significance of this correlation is relatively small and because we do not understand why this is occurring it is possible this correlation is merely by chance.

Table 6: Correlation between the five on-farm reject categories and farming practices.

Discolouration	Immature	Insect	Germination	Good nuts
No significant correlation with any production operation	No significant correlation with any production operation	Tree area (0.589) Tree number (0.505)	Harvest rounds (-0.561) Harvest interval (0.524) Harvest dehusker (-0.553) Separation of variety (0.483) Time on farm (0.475) Planting density (-0.477)	Harvest pass (0.565) Time on farm (- 0.499)

Using the factors which show significant correlation with the individual categories of on farm rejection, we can explain 73.5% of the variability in the total on-farm rejection (Table 7), however, individually, none of the on-farm factors significantly affect total on-farm rejects. Again, given the small sample size, we should treat these results with caution.

Table 7: Significance of farm practices to total on-farm reject levels.

On-farm factors	The % change in on farm rejection caused by a per unit change of on-farm factor	Importance of each factors to on farm rejection	Level of significance	Lower bound 95%	Upper Bound 95%
Tree area	0.00162%	1.047	0.507	-0.004	0.007
Tree numbers	- 0.00001%	-1.798	0.253	0.000	0.000
Harvest passes	-0.01305%	-0.595	0.077	-0.028	0.002
Harvest rounds	-0.03430%	-1.649	0.122	-0.080	0.011
Harvest interval	-0.02830%	-1.447	0.206	-0.076	0.019
Harvester dehusker	-0.13400%	-1.728	0.106	-0.304	0.036
Separation of varieties	-0.05321%	-0.618	0.260	-0.155	0.048
Time on farm	-0.00267%	-0.649	0.114	-0.006	0.001
Planting density	0.00019%	0.310	0.458	0.000	0.001

Factory Reject Analysis

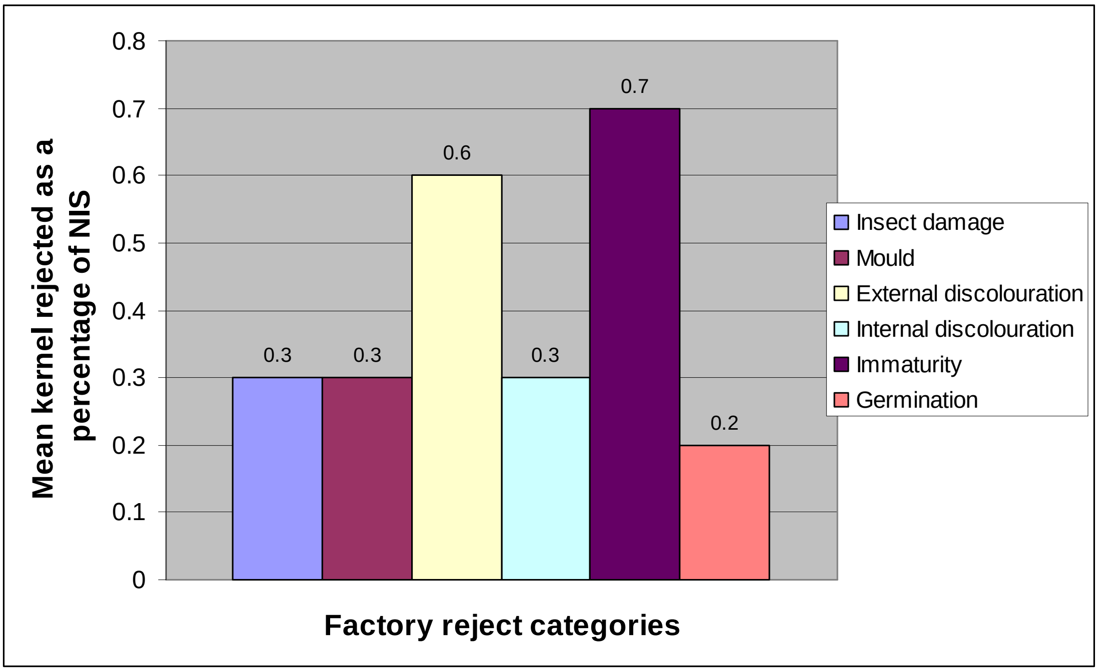

Figure 3. Mean factory kernel rejects as a percentage of NIS

The greatest amount of kernel rejected at the factory was due to immaturity (0.7%), followed by external discolouration (0.6%), then insect damage (0.3%), mould (0.3%), internal discolouration (0.3%) and germination (0.2%) (Fig. 3).

Factory reject categories were regressed against total factory rejects (stepwise regression) to determine the amount of the variation in total factory rejects the individual categories were responsible for. Ninety seven percent of the variability of factory UKR can be explained by immaturity, external discolouration, internal discolouration and mould (Table 10, Fig. 4). If we examine just immaturity, it accounts for 72% of the total variation. It must be remembered that this is just the variation, with some growers having very low levels while others have very high levels. Immaturity is caused by a lack of oil accumulation in a macadamia kernel, apart from premature nut abscission due to mechanical forces, pests and diseases, the physiological reasons for immaturity are largely unknown.

Table 10: The proportion of the variation in factory rejects explained by the addition of each reject category to the regression models, analysed using stepwise regression.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
a	0.847	0.717	0.710	0.00769746
b	0.911	0.829	0.820	0.00605671

c	0.963	0.927	0.921	0.00402542
d	0.984	0.968	0.964	0.00271770
e	0.994	0.989	0.987	0.00161058
f	1.000	1.000	1.000	0.00000000

a Predictors: (Constant), immaturity
b Predictors: (Constant), immaturity, external discolouration
c Predictors: (Constant), immaturity, external discolouration, internal discolouration
d Predictors: (Constant), immaturity, external discolouration, internal discolouration, mould
e Predictors: (Constant), immaturity, external discolouration, internal discolouration, mould, insect damage
f Predictors: (Constant), immaturity, external discolouration, internal discolouration, mould, insect damage, germination

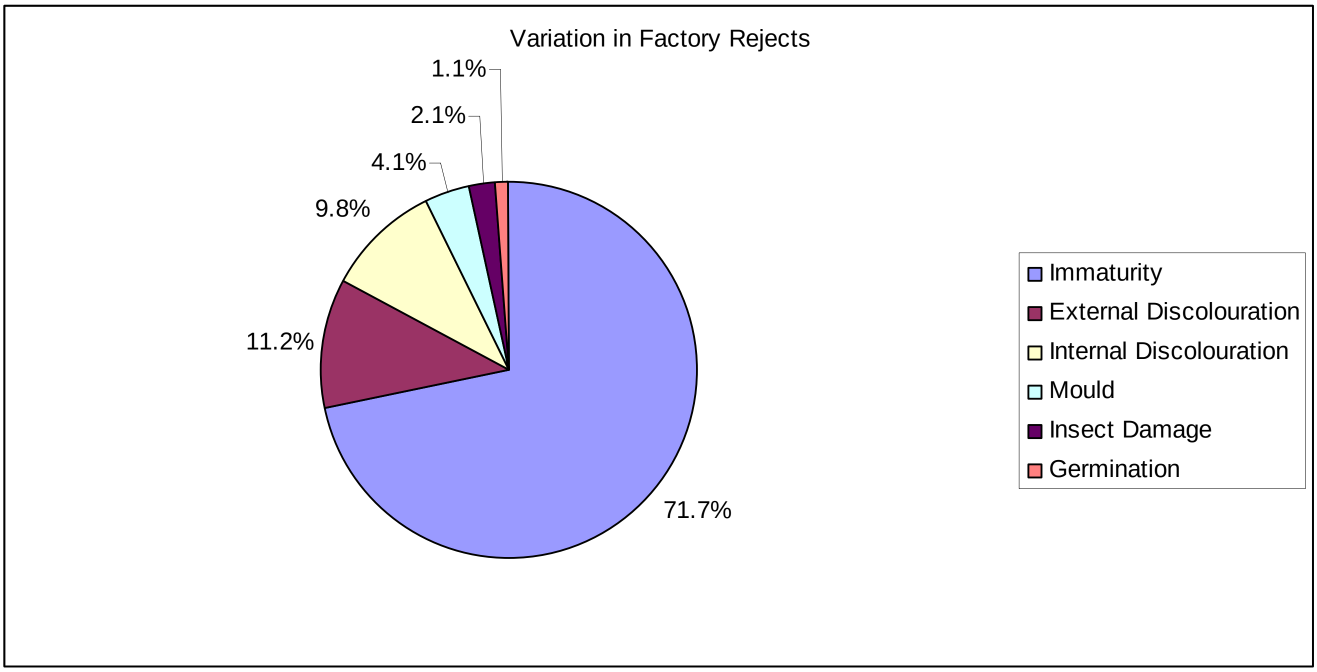

Figure 4. The proportion of the variation in factory rejects explained by each reject category.

The standardised regression coefficients (Table 11) demonstrate the effect a one unit change in the independent variable will have on the dependent variable, in this case factory rejects. The standardised regression coefficient for external discolouration is greater than that for immaturity, 1.419 and 0.836 respectively, which means that increasing external discolouration by one unit will increase the total factory rejects more than by increasing immaturity by the same amount, even though immaturity is a greater mean proportion of total factory rejects than external discolouration. In fact the standardised regression coefficient for immaturity is the lowest of any of the variables in the linear model (Table 11). External discolouration, internal discolouration and mould are probably correlated to some degree because they can be induced by similar factors, such as poor harvesting and post-harvest practices, so if one increases it is likely the others will also increase, having a greater impact on total factory rejects than an increase in only immaturity.

The causes of discolouration are not well understood. Kowitz and Mason (2003) found that humidity of air during storage had a significant impact upon the levels of discolouration. It has been reported by many growers in personal correspondence that the length of time on the ground also impacts upon discolouration problems. The effect of moisture content, temperature and length of time on ground and in storage would also affect the levels of mould.

Internal discolouration, often called “brown centres” also contributed to factory rejects. In summary findings from MacMan best practice groups, it has been found that internal discolouration is becoming a more significant issue. The causes of internal discolouration are not fully understood; Fullerton (2005) found that the setup of his dehusker was a major factor in reducing brown centres; it may also be related to drying temperatures and an interaction between NIS moisture content and drying temperature. Further research is required to determine the causes of brown centres.

Table 11. Analysis of factory USK levels.

		Unstandardised regression coefficients		Standardised regression coefficients	T	Sig.
Model		B	Std. Error	Beta		
a	(Constant)	0.0036	0.001		4.544	.000*
	Immaturity	0.8360	0.085	0.420	9.841	.000*
	External discolouration	1.4190	0.151	0.398	9.388	.000*
	Internal discolouration	0.9110	0.096	0.304	9.534	.000*
	Mould	1.0580	0.160	0.219	6.632	.000*

a Dependent Variable: Total rejects (UKR)

Relationships between farming practices and factory rejects

The major factory reject categories were then examined for correlations against on farm operations (Table 12). There was no correlation between immaturity levels and on farm operations, other factors such as the environment or cultivar may lead to variation in the observed levels of immaturity.

Table 12: The relationship between four factory reject categories and farming practices

Immaturity	External Discolouration	Internal discolouration	Mould
no significant correlation with any production operation	Water sorting (r = -0.373) AV moisture content (r = 0.352) (these two variables can explain 25% of the variation of discolouration. If immaturity included it can explain up to 62%. (the correlation between immaturity and discolouration is r = 0.68)	Tree age (r = 0.390) Harvest wheel size (r = 0.425) KGS dehusked per hour (r= 0.478) Size silo (r=0.397) These four variables can explain 60% of variation in internal discolouration.	Harvest round (r= -0.337) Wheel size (r= 0.390) These two variables can explain 17% of the variation in mould. If immaturity is included it can explain up to 26%. (the correlation between immaturity and mould is r=0.33)

Factory external discolouration was significantly correlated with water sorting and average consignment moisture content ($\alpha = 0.05$). The negative correlation (r = -0.373) with water sorting indicates that water sorting on-farm can reduce external discolouration at the factory. Factory external discolouration was positively correlated (r = 0.352) with average consignment moisture content, which indicates the higher the moisture content the higher the percentage of factory external discolouration. However, there appears to be no relationship between the use of water sorting and average consignment moisture content. This would indicate that it is other factors such as drying temperatures or the drying system employed that have a greater influence upon the consignment moisture content.

As factory external discolouration has a very strong positive correlation (r = 0.68) with immaturity, including immaturity as an additional explanatory variable in the regression model explained 62% of the total variation in external discolouration. This would indicate that the there is a possible link between the causes of immaturity and factory external discolouration and kernels may be predisposed to external discolouration while they are still on the tree.

Internal discolouration (brown centres) has a strong positive correlation with four operation factors: tree age (r = 0.39), harvest wheel size (r = 0.425), kilograms of nuts dehusked per hour (r = 0.478) and silo size (r = 0.397). These four variables can explain 60% of variation in internal discolouration. The causes of internal discolouration are not known, with Fullerton (2005) finding that the setup of his dehusker had a significant impact upon the levels that occurred. The effect of silo size could be related to drop heights, with only one farm in the sample having easy letdowns installed and the moisture content of the nuts at delivery being higher from larger silos. The impact of tree age and harvester wheel size needs further investigation, as this has never been reported previously. The level of internal discolouration increased with farm size (Table 13), possibly because larger farms also have harvesters with larger wheels, dehuskers that can process more nuts per hour and have larger silos, which also affected internal discoloration.

Table 13. Internal discoloration increases with farm size.

Farm size (number of trees)	< 3000	3000 to 7000	>7000
Sample size (n)	8	7	25
Mean internal discoloration	0.006	0.019	0.037

The level of mould was correlated with the number of harvest rounds (r = -0.337) and harvester wheel size (r = 0.390). The negative correlation with harvest rounds indicates that the less harvest rounds the higher percentage of mould. This is supported by work by Cavaletto (1983) and Wallace and Walton (2005) who found higher levels of mould in nut samples that were left on the ground for longer periods of time.

The positive correlation of mould with harvester wheel size indicates the bigger the wheel size the higher the percentage of mould. Given that there is a significant correlation between harvester wheel size, farm size (r = 0392) and harvest interval (r=0.570) it is logical to assume that larger operations with larger machinery who have longer intervals between harvest rounds are likely to have higher mould reject rates.

Harvester wheel size and harvest rounds can explain 17% of the variation in mould. However when immaturity is included as an additional explanatory variable it can explain up to 26% of the variation in mould (the correlation between immaturity and mould is r=0.33). The relationship between immaturity and mould needs to be investigated.

The relationship between total UKR and farming operations

Seven on farm operational factors: average moisture content, kilograms dehusked per hour, water sorting, average tree age, silo size (tonnes), harvest rounds and harvester wheel size, are associated with three factory reject categories; external discolouration, internal discolouration and mould (Table 12). These seven farming variables explained 56.6% of the total variation in factory UKR (Table 14). However, only four factors (tree age, water sorting, average moisture content and silo size) significantly affected UKR. Tree age is not an operational factor that can be easily modified by management and so was removed from the regression analysis. Further regression analyses (Table 15) show that only two factors (mean moisture content and water sorting) have a significant contribution to UKR, explaining 39% of the total variation in UKR. This result will be explored further in the following section.

Table 14: Variation in factory UKR analysis results.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
A	0.752	0.566	0.421	0.01240072

a Predictors: (Constant), average moisture content, kilograms dehusked per hour, water sorting, average tree age, silo size (tonnes), harvest rounds and harvester wheel size.

Table 15. Two regression models describing the effect of mean NIS moisture content or mean NIS moisture content and water sorting on UKR at the factory

Model	R	R Square	STD
Mean NIS moisture content	0.464	0.215	0.015
Water sorting and mean NIS moisture content	0.624	0.389	0.013

The relationship between on-farm and factory rejects

Seven out of the 42 correlations performed between on-farm reject and factory reject levels were significant (Table 15); positive coefficients mean that the dependent variable increased with the independent variable; negative coefficients mean the dependent variable decreased as the independent variable increased. It is difficult to explain the relationship between these variables so the results should be interpreted cautiously.

Table 15: The relationship between on-farm rejection and factory rejection

		Factory Rejection					
		Immaturity	Discolouration	Internal discolouration	Mould	Insect damage	Germination
On-Farm Rejection	External Discolouration					-0.522*	
	Immaturity					0.570*	
	Insect damage		0.672*				0.65*
	Germination						
	Good nuts rejected					0.613*	
	Rat damage				0.503*		
	Mechanical Damage						

* Significant at the 0.05 level

Regression analysis shows that these five on farm reject categories can explain 48% of the total variation in factory UKR. However, only on-farm immaturity provides a significant contribution to the variation in factory UKR (Table 16). As Immaturity is not explained by on-farm management activities (Table 6), this indicates that management has little or no control over this factor. Since the data was collected over several seasons, immaturity may be related more to the environment than management practices; however this needs to be tested further.

Table 16. The effect of the severity of on-farm sorting on USK measured at the factory.

On-farm rejection	The % change of factory UKR caused by per Unit	Importance of each on farm rejection	Level of significance	Lower bound	Upper Bound

	change of on-farm rejection	to the total factory UKR		95%	95%
On-farm discolouration	-0.0461%	-0.609	0.122	-0.107	0.014
On-farm immaturity	-0.1020%	-0.861	0.040*	-0.199	-0.006
On-farm insect	-0.0085%	-0.038	0.879	-0.129	0.112
On-farm good nuts	-0.1160%	-0.306	0.231	-0.318	0.086
On-farm rats	0.1210%	0.186	0.455	-0.223	0.466

* Significant at the 0.05 level

The economic effect of farming practices

Where initial analyses demonstrated significant effects of farming practices on on-farm rejection or kernel quality at the factory, further analysis was performed to demonstrate the potential economic effects to the grower.

Harvest Interval

There were significant effects of harvest interval on shed reject levels and SKR (Fig. 5, $P < 0.1$). The mean shed reject levels on farms where the mean harvest interval was less than or equal to 4 weeks were 4.6% of the harvested yield, compared to 8.3% on farms where the harvest interval was greater than 4 weeks, a difference of 3.7% of the harvested yield. On a typical macadamia farm producing 40 tonnes NIS, this is approximately 1.5 tonnes extra of NIS that is delivered to the factory. For a price of $2.70 per kg of NIS at 33.4% SKR, this amounts to almost $4000 of additional revenue.

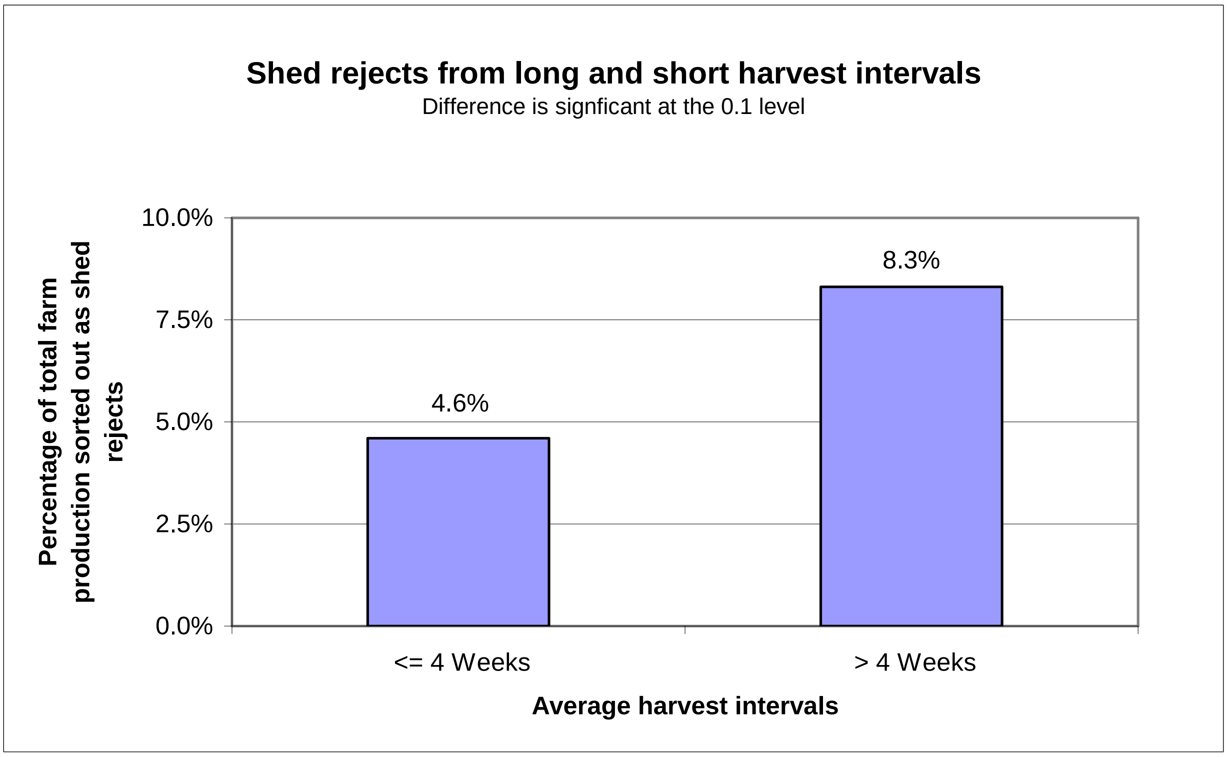

Figure 4. Shed reject levels due to long and short harvest intervals.

The effect of harvest intervals upon the different reject classes is shown in table 17. Germination rejects were significantly less when harvest intervals were less than or equal to four weeks ($P < 0.05$), harvest interval did not significantly effect any of the other reject categories.

Table17. Means (% of total shed rejection) for different categories between short (less than or equal to 4 weeks) and long (greater than four weeks) harvest intervals.

Shed reject category	<= 4 weeks (%)	> 4weeks (%)
Insect	14.3	11
Discoloration	31.2	31.8
Mechanical damage	4.7	5.4
Good nut rejected	2.5	4.9
Immaturity	10.8	18.4
Germination*	5.2	12.2
Rats	4.0	3.9

* Significantly different at 0.05 level

The effect of harvest interval on factory sound kernel recovery was examined (Fig. 5); growers who harvested less than or equal to every 4 weeks (on average) had a mean SKR of 34.2%, while those with harvest intervals longer than every 4 weeks, had a mean SKR of 31.6%. This difference of 2.6% SKR, using current payment scales that add 10c per kg for each 1% increase in SKR, results in a difference of $260 per tonne of NIS delivered to the factory. On a 40 tonne farm, this equates to $10,400 of additional revenue. The actual payment received could be higher or lower, depending on the reject/bonus category it puts the NIS consignment within.
There are many variables that can impact upon the ability to increase harvest frequency, and these need to be assessed against the potential gains from adopting more frequent harvesting rounds. Due to the sample size of the data, it is not possible to break the harvest frequencies up into smaller intervals and examine the effects, eg does harvesting every 2 weeks give even greater benefits than every 3 or 4 weeks?

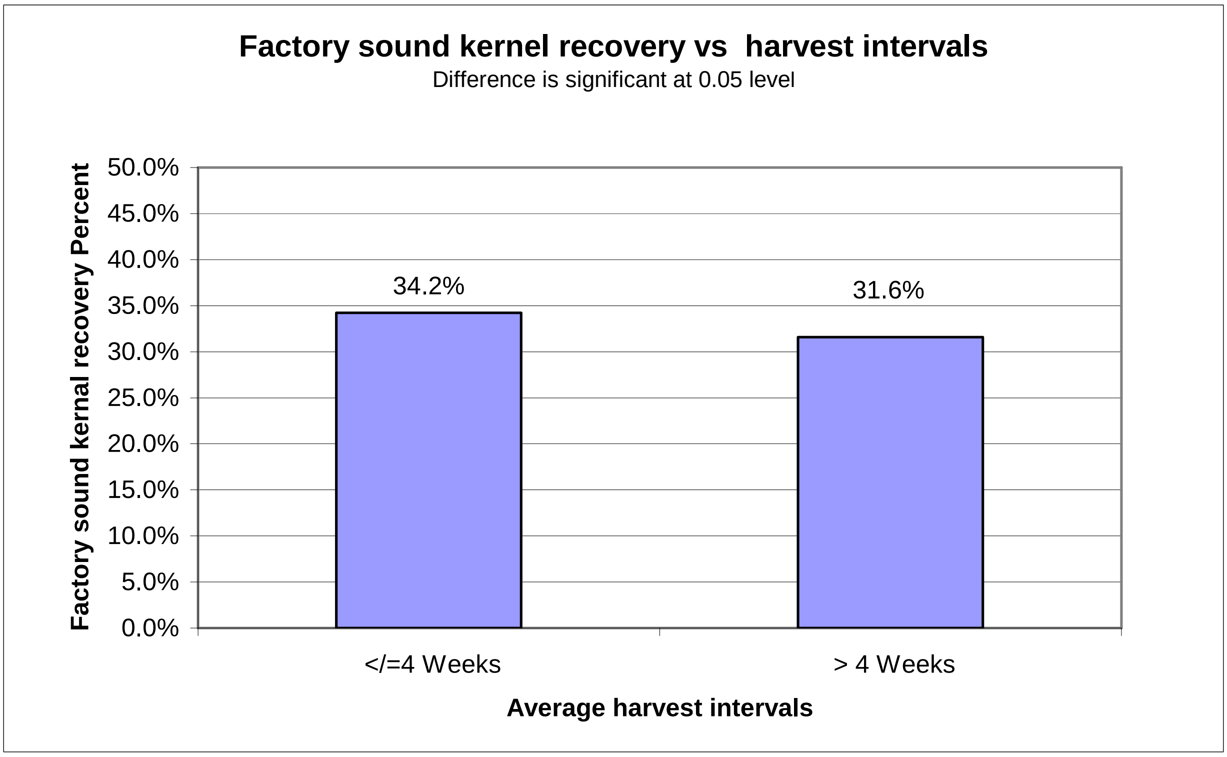

Figure 5. Effect of harvest intervals on sound kernel recoveries.

Water sorting

The effects of water sorting were examined and a significant difference in factory external discolouration reject levels was found. Mean factory external discoloration for growers using water sorting is 0.39%, and 0.71% for those not using water sorting, a difference of 0.32% (Fig. 6). Based on a payment scale that adds10c per kg for each 1% increase in SKR; the mean increase in revenue due to water sorting was $32 per tonne. The potential benefits of water sorting must be balanced against the possibility that good nuts are removed during water sorting. As the majority of growers using water sorting are based within NSW, the same analysis was performed on a location basis and the same result was not achieved. This indicates that it is water sorting that has this impact and not other factors. Immaturity was related to external discolouration (Table 12), and water sorting generally removes immature nuts, however it is unclear why immaturity and external discolouration are related.

One major concern within the industry has been that water sorting increases consignment moisture content and thus NIS quality; there was no correlation between the two variables (Table 17), indicating that water sorting does not increase consignment moisture content.

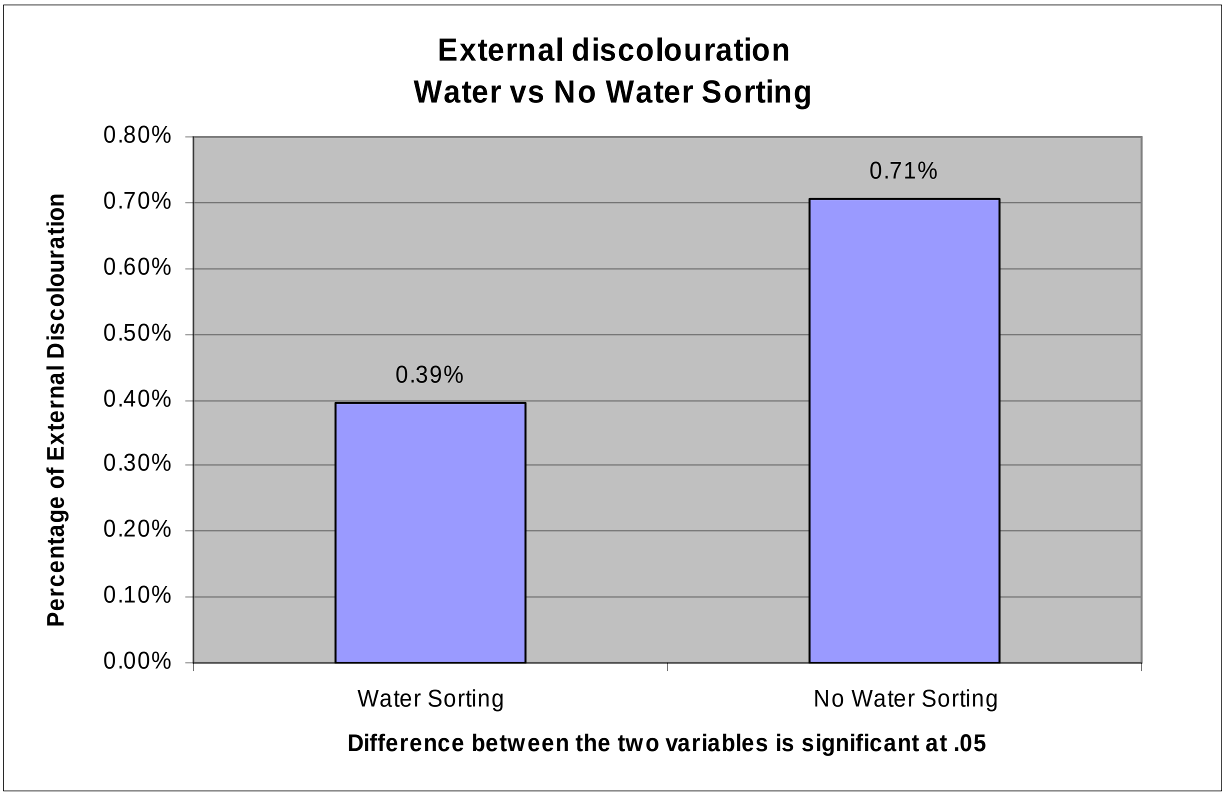

Figure 6: Water sorting significantly decreased the percentage of rejects due to external discolouration at the factory (P < 0.05).

Table 17. Number of water sorts and consignment moisture content

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
A	0.464	0.215	0.186	0.01470053
B	0.624	0.389	0.342	0.01322018

a Predictors: (Constant), average moisture content
b Predictors: (Constant), average moisture content, water sorting

Silo Size

Silo size was strongly correlated with bed depth; silos less than 20 tonnes had a mean bed depth of 2.99 metres whereas silos greater than 20 tonnes had a mean bed depth of 4.55 metres (Fig. 7).

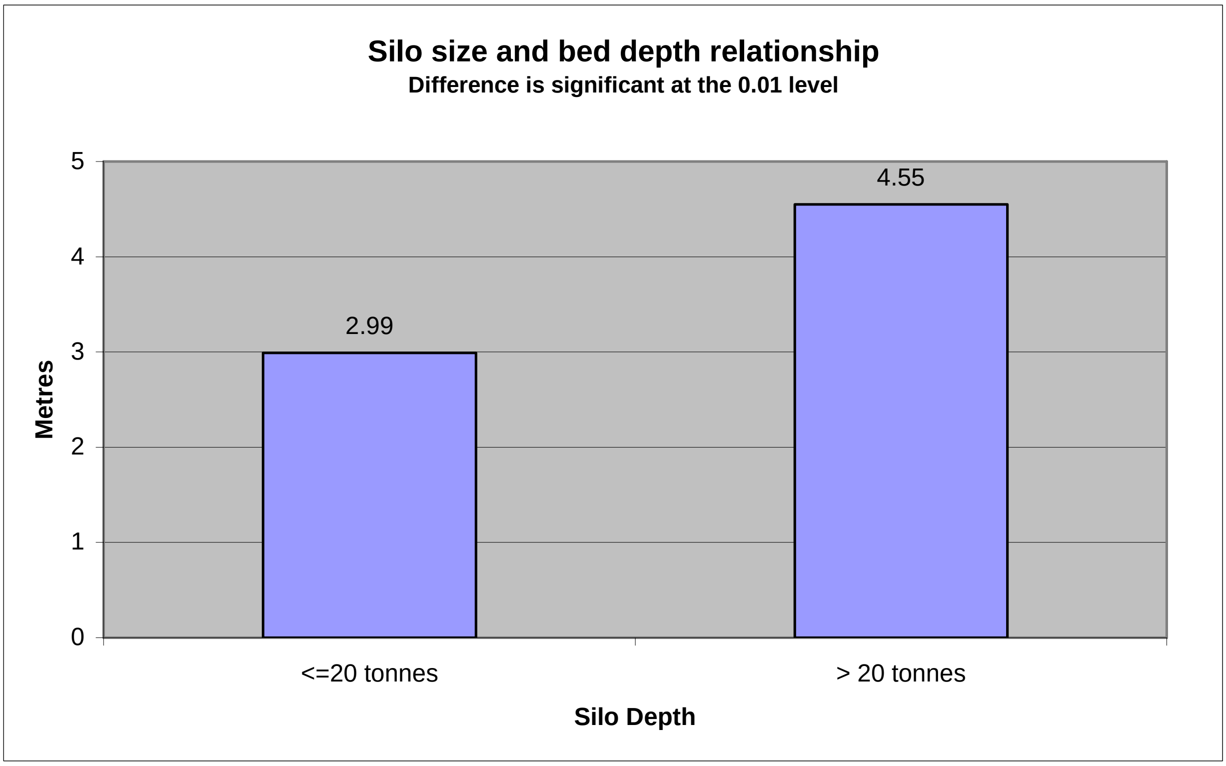

Figure 7. The mean bed depth of nuts in silos on-farm increased with silo size.

Silo size significantly affected NIS consignment moisture content; the consignment moisture content of NIS from silos with a capacity of less than or equal to 20 tonnes was 10.87% and 12.43% when NIS was dried in silos with a capacity of greater than 20 tonnes. Silo size explained 21.7% of the variation in consignment moisture content

(Table 18). Smaller silos with shallower bed depths appear to be more efficient at drying NIS than larger silos. Given that factory rejects due to external discoloration increase with consignment moisture content the use of silos with a capacity of 20 tonnes or less may help reduce UKR at the factory.

Table 18. The relationship between silo size and NIS moisture content at delivery.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
a) average consignment moisture content	0.466(a)	0.217	0.194	1.718

a Predictors: (Constant), Silo Size Tonnes

Kowitz and Mason (2001) found that the ideal bed depth used in any drying system is less than 2.4 metres. NIS is not dried as effectively when bed depth is greater than 2.4 metres which leads to greater levels of external discoloration at the factory. When NIS consignment moisture content was less than 10%, from 11 to 12% and from 13 to 15% external discoloration was 0.32%, 0.65% and 0.62% respectively (expressed as the total kernel recovery rejected due to this disorder) (Fig. 8). If an average value is taken for external discolouration values for moisture contents of 11% up to 15%, it equates to 0.64%. The difference between rejects due to external discolouration from 11 to 15% moisture content and that for 10% is 0.32%. Based on a payment scale that gives 10c per kg for each 1% increment increase in SKR, by reducing consignment moisture content to 10% or below the grower could expect an additional $32 per tonne increase in revenue due to lower external discoloration reject levels. For a 40 tonne farm this is an increase in revenue of $1,300. Kowitz and Mason (2003) found that bed depth was more important for efficient NIS drying than silo size because air gains moisture as it moves through wet NIS and so when the bed depth is too large the upper layers of NIS dry poorly.

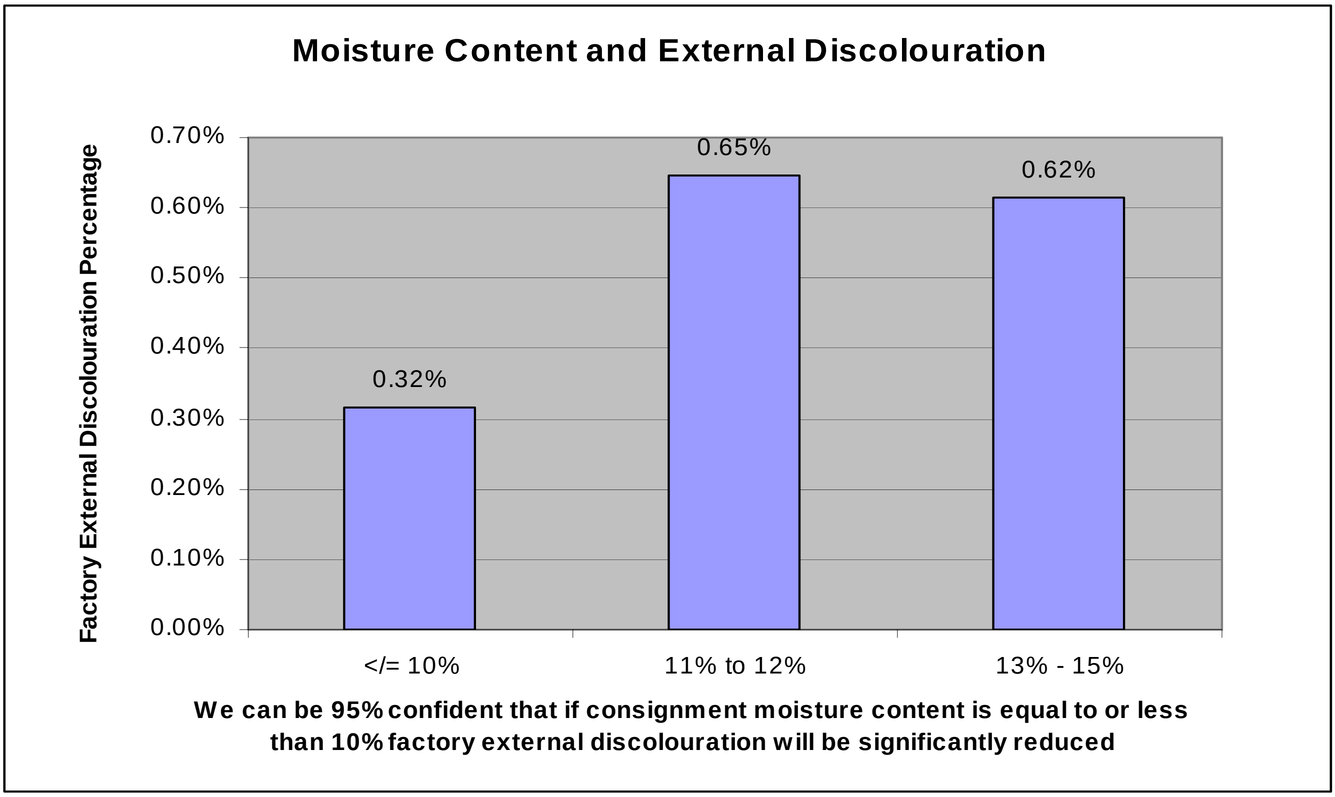

Figure 8. The relationship between moisture content and kernel external discolouration.

Silo size and bed depth also significantly affect the levels of internal discolouration (brown centres) at the factory (Fig. 9). Smaller silos (less than 20 tonnes) have a mean internal discolouration of 0.08% while those with greater than 20 tonne capacity have an average internal discolouration of 0.42%. This difference of 0.34% in internal discolouration based on a payment scale that gives 10c per kg for each 1% increase in SKR, would give an increase of $34 per tonne in revenue from smaller silos. For a 40 tonne NIS farm this is an increase in revenue of $1,400. This result indicates that smaller silos are advantageous in reducing internal discolouration. The causes of internal discolouration are not well understood and these findings would suggest that storage conditions, moisture content and drop heights of NIS could have a significant impact upon the levels of internal discolouration. Prichavudhi and Yamomoto (1965) found that reducing sugars are formed from enzymatic activity when the kernel is subjected to high temperatures in the presence of moisture. The moisture content of NIS in large silos is greater than in small silos (Fig. 10), and respiration of NIS stored at high moisture contents can raise temperatures significantly (Mason *et al.*, 1998); so it is possible then that large silos in this study were warmer than the small silos which may have increased internal discoloration, although this was not tested. It was not possible to investigate the effects of drop height on internal discoloration because only one farm had easy let downs installed.

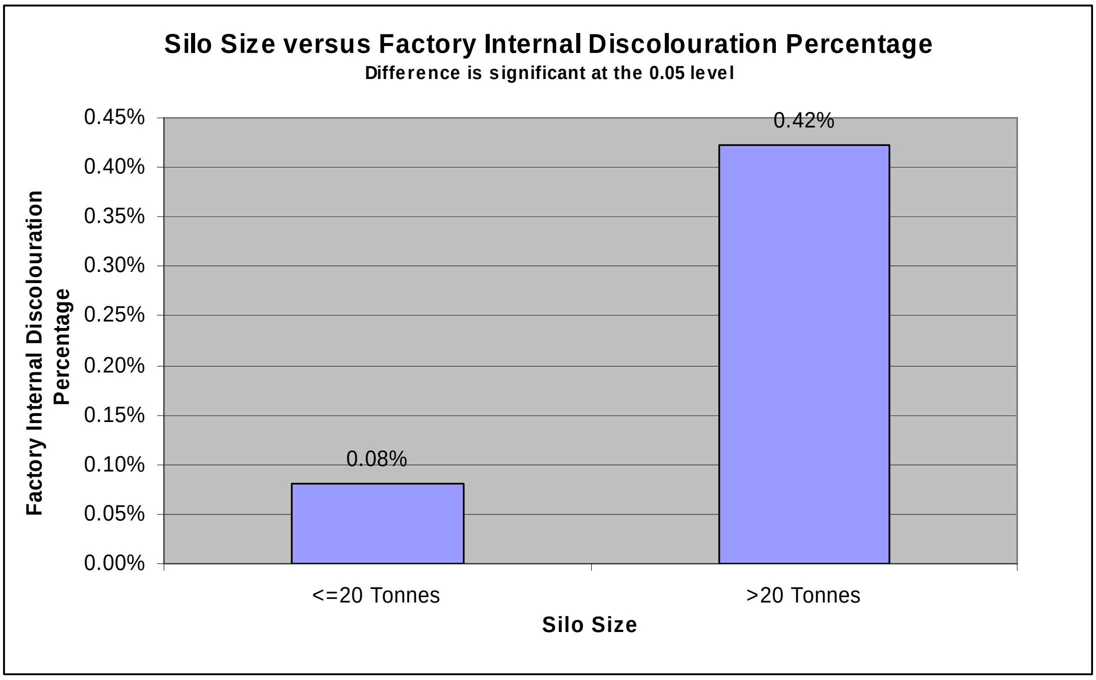

Figure 9. The relationship between silo size and factory internal discolouration (brown centres).

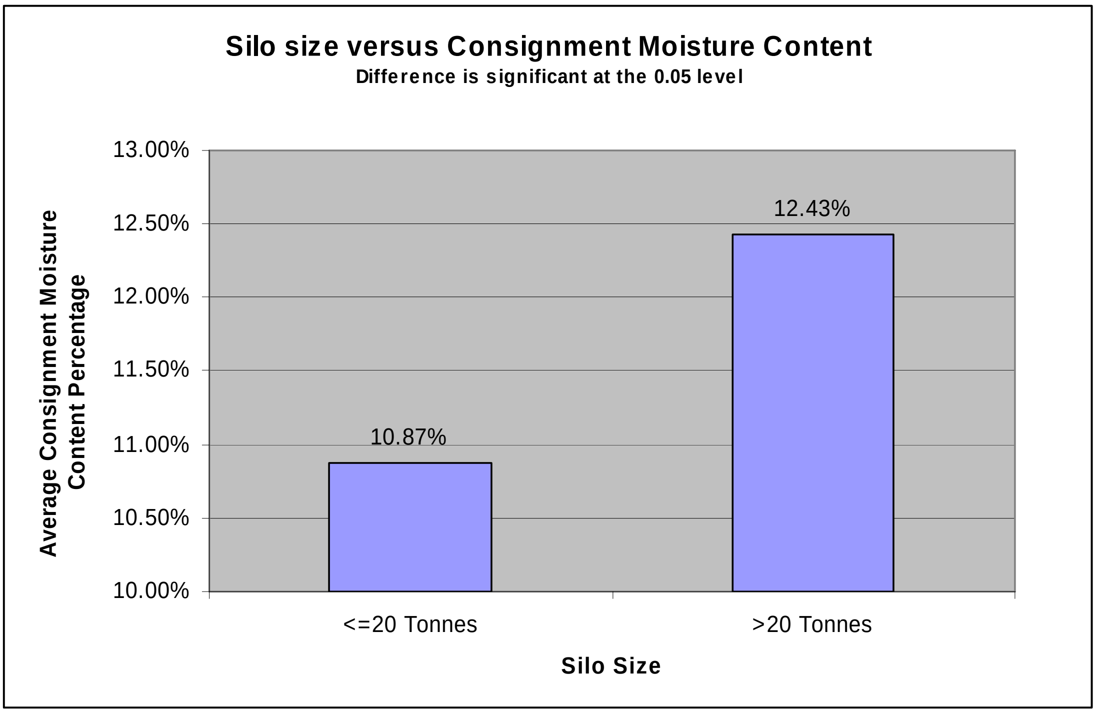

Figure 10. The relationship between silo size and moisture content.

Recommendations

Based on the findings from this work, the following recommendations are made:

- An extension strategy and project be developed to demonstrate the economic results of how farming practices affect quality, using research from both the current and previous projects.
- The economic effects of more frequent harvesting need to be investigated further and demonstrated to growers. First, the costs and benefits of harvesting every one, two, three or four weeks need to be tested. Second the costs and benefits of investing in additional capital to facilitate more frequent harvesting, especially under unfavourable conditions needs to be investigated and extended to growers.
- The industry needs a better understanding of the factors leading to the various reject categories. For example the causes of immaturity are not well understood or quantified but the level of kernel rejected due to this disorder is significant. By understanding the causes, management strategies to target this and other quality disorders can be developed. The cost and benefit of strategies to reduce these problems would need to be part of these studies.

- The industry also needs a better understanding of the farming practices prior to drying and storage that lead to quality loss. The major focus of research previously has been upon drying and storage practices but this study has found that there are major losses due to farming practices prior to storage (such as harvest interval) that have a significant impact upon the quality of NIS delivered. These need further investigation and the economic benefits of improving these farming practices extended to growers.
- There is a need to improve the use of on-farm crop loss monitoring by growers as a high percentage of growers do not measure what they reject on-farm. There is potentially a high level of saleable NIS being discarded on-farm, and by understanding the source and magnitude of their losses growers can change farming practices to minimise this. One way to promote crop measuring crop loss is to develop a re-sorting decisions tool. This system would allow growers to determine costs and benefits of re-sorting based on the quality of their NIS.
- The benefits of reducing the on-farm storage time need to be investigated further and extended to growers, as many are exceeding the recommendations based on research findings. Linked to this will be the need to investigate the drying and storage systems available and highlight the value of each system in achieving this outcome.
- The economic value of adding easy-letdowns to silos needs to be investigated, particularly for quality parameters that growers are not paid upon. Research work has found that easy-letdowns reduce some quality problems observed in markets, but few are using them, so there is a clear need to improve the adoption of this technology. There may be an opportunity to get manufacturers to make them standard in new silos or other drying systems.
- With the co-operation of processors, benefits to or losses of quality realised further along the supply chain due to on-farm practices could be investigated. This information would provide significant advances on the current project, and hopefully also help to improve on-farm practices further.
- There is a clear need to have more resource information on quality management available to growers as this study has found there are significant benefits from adopting strategies that allow them to improve quality.

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Appendix 1

Correlations

Spearman's rho		Factory UKR	Silo Size Tonnes	Silo Depth Metres	Av Moisture content
Silo size tonnes	Correlation Coefficient	.378(*)			
	Sig. (2-tailed)	.019			
	N	38			

Silo depth metres	Correlation Coefficient	.447(**)	.700(**)		
	Sig. (2-tailed)	.005	.000		
	N	38	37		
Average consignment moisture content	Correlation Coefficient	.460(**)	.438(**)	.465(**)	
	Sig. (2-tailed)	.004	.009	.004	
	N	37	35	36	
Easy letdowns	Correlation Coefficient	-.029	-.459(**)	-.092	.178
	Sig. (2-tailed)	.861	.004	.583	.292
	N	40	38	38	37

** Correlation is significant at the 0.01 level (2-tailed).

Independent Samples Test

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Average Consignment Moisture Content	Equal variances assumed	-2.611	33	.013	-1.561	.598	-2.778	-.345
	Equal variances not assumed	-2.616	32.993	.013	-1.561	.597	-2.775	-.347
Water Sorting 1 = yes 2 = no	Equal variances assumed	-2.000	36	.053	-.31667	.15833	-.63778	.00445
	Equal variances not assumed	-2.001	35.647	.053	-.31667	.15826	-.63774	.00441
Factory External Discolouration	Equal variances assumed	-.611	36	.545	-.0008225	.0013471	-.0035546	.0019095
	Equal variances not assumed	-.606	34.160	.548	-.0008225	.0013562	-.0035782	.0019332
Factory Internal Discolouration	Equal variances assumed	-2.543	36	.015	-.0034234	.0013460	-.0061533	-.0006935
	Equal variances not assumed	-2.416	17.829	.027	-.0034234	.0014170	-.0064024	-.0004444
Silo Depth Metres	Equal variances assumed	-3.319	35	.002	-1.5632	.4709	-2.5191	-.6072
	Equal variances not	-3.323	34.987	.002	-1.5632	.4704	-2.5182	-.6081

	assumed							
Easy Letdowns	Equal variances assumed	2.737	36	.010	.339	.124	.088	.590
	Equal variances not assumed	2.640	22.967	.015	.339	.128	.073	.604

Group Statistics

	Silo categories 1 = <=20 tonnes 2 = > 20 tonnes	N	Mean	Std. Deviation	Std. Error Mean
Average Consignment moisture Content	1.00	18	10.87	1.829	.431
	2.00	17	12.43	1.701	.412
Water Sorting 1= yes 2 = no	1.00	20	1.3500	.48936	.10942
	2.00	18	1.6667	.48507	.11433
Factory External Discolouration	1.00	20	.005096	.0038927	.0008704
	2.00	18	.005919	.0044125	.0010400
Factory Internal Discolouration	1.00	20	.000803	.0009776	.0002186
	2.00	18	.004226	.0059398	.0014000
Silo Depth Metres	1.00	19	2.987	1.4567	.3342
	2.00	18	4.550	1.4047	.3311
Easy Letdowns	1.00	20	1.95	.224	.050
	2.00	18	1.61	.502	.118

Chapter 7

A re-sort decisions calculator for Australian macadamia growers

Kevin Quinlan

Summary

Economic analysis has previously demonstrated that de-husking and sorting represent the largest labour costs for macadamia growers. A re-sort decisions calculator was developed to enable growers to make decisions on re-sorting based on the actual quality of their nuts, and the potential costs and benefits of re-sorting. This re-sorting decisions calculator has been promoted to growers.

Introduction

Analysis of data from Mac-Man best practice groups has shown that de-husking and sorting account for the greatest share of labour costs; with an industry mean of 19.4 hours per hectare, or 6 hours per tonne for mature bearing farms within the groups. Growers generally sort NIS for the first time directly after it has been de-husked, and often for a second time to minimise the amount of reject NIS included in the NIS consigned to the factory, for which they may be penalised financially.

NIS quality may vary considerably within farms due to the time of year, for instance immaturity is often high in the first harvest, and NIS quality may also vary between blocks due to different varieties or different environments. Therefore depending on the initial quality of the crop, and the effectiveness of the first sort, the NIS may or may not require re-sorting. The grower survey, undertaken as part of this project (Chapter 5), revealed that almost 70% of growers routinely re-sort NIS, whereas only approximately 15% re-sort after testing a NIS sample after the initial sort.

To help growers minimise post-harvest costs while maintaining quality, we developed a simple re-sort decisions calculator. By using this calculator growers can base a re-sort decision on the quality of a sample taken after the initial sort, and calculate the potential gains in quality compared to the extra labour costs of sorting.

Developing the calculator

No experiments were undertaken in order to develop this calculator; it was developed using knowledge of the on-farm post-harvest process, knowledge of NIS payment sampling protocols and a general knowledge of the payment systems used in the Australian macadamia industry. The initial concept was developed by David Bell, a macadamia grower, and we have built on this concept to build the current version.

Two methods have been developed. The first method is for assessing the value of visual sorting (see Appendix 2 – *Belt sorting method*); the main purpose being to determine if the increased value of the nuts after re-sorting pays for the labour costs of re-sorting. The second method is for assessing the value of water sorting (see Appendix 2 – *water sorting method*); the purpose being to determine if the increased quality due to removing rejects that would not otherwise be removed, out weighs the cost of removing sound NIS.

Using the re-sort calculator

The grower needs to have values for four NIS and operational variables which are used in the calculation process. First, an estimate of the total kernel recovery; this may be based on a long term value for the entire farm or a specific block or variety. Second, an estimate of the total volume of NIS; this is important in determining the total value of the NIS. The estimated rate of sorting and the payment per hour for the staff member sorting the NIS, which are used to determine the cost of sorting the NIS.

Sampling and sub-sampling: To get the best results from this re-sort decisions calculator, the sample which the decision is based on must be representative of the total amount of NIS. The best way to do this is to sample NIS after it has been sorted once from the end of the sorting table at regular intervals throughout the day, maybe every 20 or 30 minutes, the initial sample size should be 2.5% of the total sample size. This large sample should then be sub-sampled, this sub-sample will be tested; between 100 and 300 nuts should be sub-sampled.

The sub-sampled NIS should be divided into ‘Good NIS’ (those nuts that would not be sorted out) and ‘Reject NIS’ (those nuts that would be sorted out). The nuts in each of these groups should be counted, then cracked, and the kernels sorted into sound and reject kernel.

The values of the estimated NIS and operational variables, and the results from the external NIS and kernel assessments should be entered into the ‘Re-sort decisions’ spreadsheet. The cost or benefit of re-sorting is then returned.

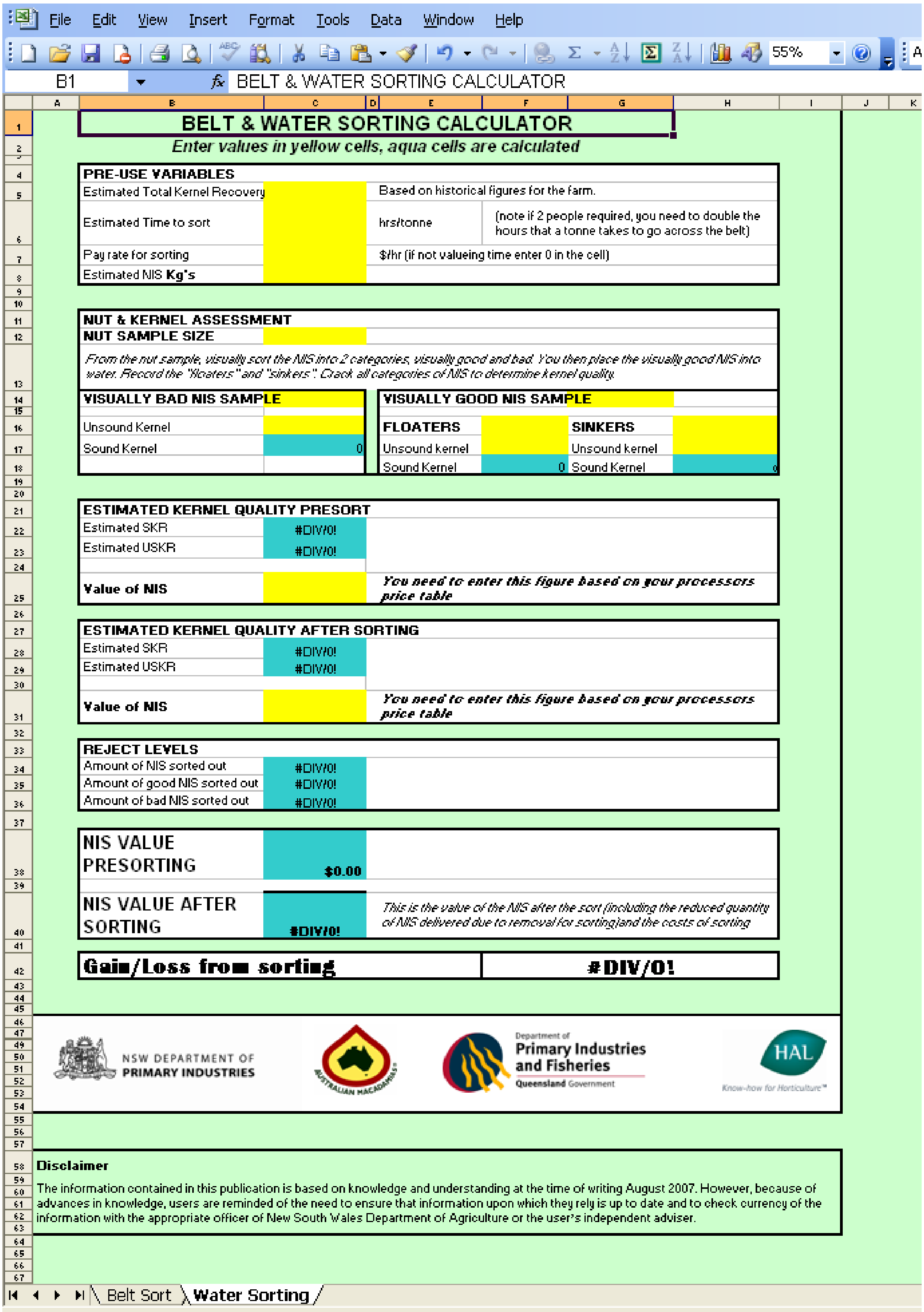
The entire process takes about one hour to complete. The most time consuming operation is cracking the NIS in order to assess the quality. Even though one hour appears to be a time consuming exercise, it may save many re-sorting labour hours.

Assumptions

It is important to note that this tool is based on some assumptions, and as the accuracy of the assumptions decreases, so does the accuracy of the ‘re-sort decisions calculator’. The major assumptions follow:

- The first assumption is that the nuts in the sub-sample are of a similar size, because the nuts are counted and not weighed to determine the proportions of the sample that are sound and unsound. This is probably only a significant issue with large variations in nut size, for instance, when the sample is of mixed varieties.
- Second, as mentioned above, that the sub-sample is representative of the total volume of NIS.
- The third assumption is that the grower is rating the kernel similarly to the processor; deviations may significantly affect the result. The grower will be assessing wet kernel, whereas processors assess dry kernel, and this may affect the results.
- Commercial grade, a determination of commercial grade kernel is not made by the calculator. This category was created to use kernel that was previously classified as unsound kernel but had a commercial value. Determining what kernel is classified as commercial depends upon the severity grading it receives for the particular defect and these have different tolerance values. Therefore even though commercial grade may significantly affect the final value of the NIS, for the sake of simplicity, we do not use it in this tool.

Appendix 1, water sorting re-sort decisions calculator



File Edit View Insert Format Tools Data Window Help

B1 — BELT & WATER SORTING CALCULATOR

BELT & WATER SORTING CALCULATOR

Enter values in yellow cells, aqua cells are calculated

PRE-USE VARIABLES			
Estimated Total Kernel Recovery		Based on historical figures for the farm.	
Estimated Time to sort		hrs/tonne	(note if 2 people required, you need to double the hours that a tonne takes to go across the belt)
Pay rate for sorting		$/hr (if not valueing time enter 0 in the cell)	
Estimated NIS **Kg's**			

NUT & KERNEL ASSESSMENT

NUT SAMPLE SIZE

From the nut sample, visually sort the NIS into 2 categories, visually good and bad. You then place the visually good NIS into water. Record the "floaters" and "sinkers". Crack all categories of NIS to determine kernel quality.

VISUALLY BAD NIS SAMPLE	
Unsound Kernel	
Sound Kernel	0

VISUALLY GOOD NIS SAMPLE			
FLOATERS		SINKERS	
Unsound kernel		Unsound kernel	
Sound Kernel	0	Sound Kernel	0

ESTIMATED KERNEL QUALITY PRESORT		
Estimated SKR	#DIV/0!	
Estimated USKR	#DIV/0!	
Value of NIS		***You need to enter this figure based on your processors price table***

ESTIMATED KERNEL QUALITY AFTER SORTING		
Estimated SKR	#DIV/0!	
Estimated USKR	#DIV/0!	
Value of NIS		***You need to enter this figure based on your processors price table***

REJECT LEVELS	
Amount of NIS sorted out	#DIV/0!
Amount of good NIS sorted out	#DIV/0!
Amount of bad NIS sorted out	#DIV/0!

NIS VALUE PRESORTING	$0.00	
NIS VALUE AFTER SORTING	#DIV/0!	*This is the value of the NIS after the sort (including the reduced quantity of NIS delivered due to removal for sorting)and the costs of sorting*

Gain/Loss from sorting	**#DIV/0!**

NSW DEPARTMENT OF PRIMARY INDUSTRIES

AUSTRALIAN MACADAMIAS

Department of Primary Industries and Fisheries, Queensland Government

HAL — Know-how for Horticulture™

Disclaimer

The information contained in this publication is based on knowledge and understanding at the time of writing August 2007. However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of New South Wales Department of Agriculture or the user's independent adviser.

Belt Sort | Water Sorting

Appendix 2, notes to go with the re-sort decisions calculator

Macadamia Sorting Calculator

Kevin Quinlan, NSW Department of Primary Industries, Alstonville

Why use a sorting calculator?

A large amount of time, effort and money is spent by macadamia farms on the undertaking of post-harvest operations. The MacMan best practice groups have found that dehusking, sorting and handling is the largest labour category, with an average of 19.4 hrs/ha spent. A large amount of this time is spent re-sorting NIS.

The macadamia re-sort calculator provides the benefit of allowing growers to determine the value of a re-sort with regard to the level of nut in shell (NIS) rejected. The results from the best practice groups have found that an average of 6% of the total harvested yield is thrown out, with some farms rejecting considerably more than this. In 2006, 10% of these rejects were good nuts.

The calculator aims to allow growers to determine whether a re-sort will give increased or decreased returns. It also aims to allow them to make informed decisions about re-sorting, by giving them the information they need. Like any decision support system, this system relies upon accurate information, and there are limitations to the method. These are outlined in the 'what affects the accuracy of results?' section.

Method

The aim is to assess a small representative sample of nuts, in order to determine the quality of the whole batch. The processes followed for a belt re-sorting decision and a belt re-sorting and water floatation system are presented below.

Take samples of NIS after the initial sort, from the end of the sorting table or just before they are augered into the silo. Take these samples over the day, to ensure you get a representative sample of the NIS you are putting into storage. The initial sample size should be 2.5% of the total amount, ensuring it is taken over time to get an accurate reflection of the total NIS. From this you will need to sub-sample.

One way of taking samples is as follows: every 20–30 minutes, take a few handfuls of nuts and place them into a lug. From the lug you will need to sub-sample, ensuring you get a representative mix of NIS for the batch you wish to analyse. A sample of 300 nuts or more is recommended. You can vary the size of this sample, remembering that the greater the number of nuts you analyse, the better the results.

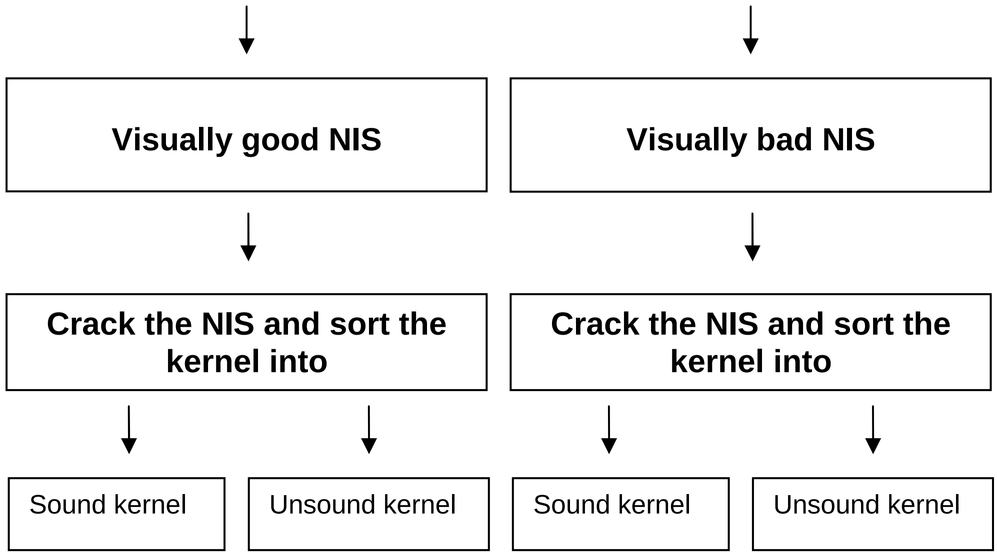
A minimum of 100 nuts should be used, to ensure some degree of accuracy.

Belt sorting

Sort the sample into 'visually good NIS' and 'visually bad NIS', and keep these two categories separate. Crack the NIS of each category, and separate the kernel into 'sound' and 'unsound' groups.

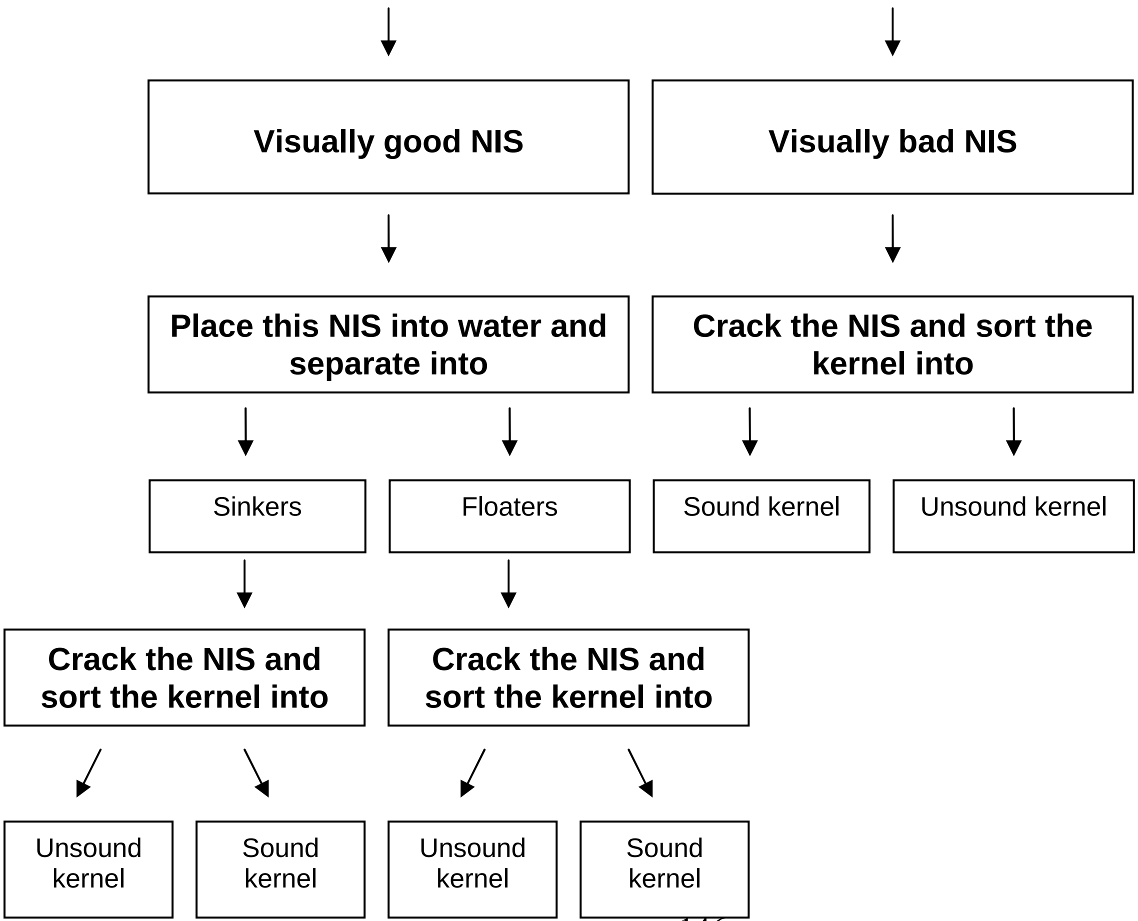
Belt sorting method

Visually sort the NIS sample into:



Water sorting method

Visually sort the NIS sample into:



What affects the accuracy of results?

The factors affecting the accuracy of the system are:

- how representative the sample is of the batch. The sample you take needs to come from the entire batch you wish to re-sort. To be consistent with the method used by processors, the initial sample size you take should be 2.5% of the total amount of NIS in the batch, and then a sub-sample should be taken from that. This requires multiple random samples to be taken over the day, which are added together and then sub-sampled. This will increase the level of accuracy
- sample size – the bigger the sample of nuts you analyse, the better. Initially taking 2.5% of the batch and then sub-sampling 300 nuts will improve the level of accuracy. This is in keeping with the Australian Macadamia Society's guidelines
- wet kernel analysis – the kernel you will assess is wet kernel, while processors will perform their assessment on dry kernel. This can affect the results from the calculator. The differences are mainly due to traits such as discolouration or glassy kernel, which are difficult to remove as they do not present as NIS defects
- commercial grade – a determination of commercial grade kernel is not made by the calculator, because determining what kernel is classified as commercial depends upon the severity grading it receives for the particular defect, and these gradings have different tolerance values. This category was created for the use of kernel that was previously classified as unsound but had a commercial value.

How long does it take?

The entire process takes about one hour to complete. The biggest time factor is cracking the NIS to be able to complete the kernel assessment. The trade-off is that the one hour spent doing an assessment of quality may save you a day's work if you don't have to re-sort.

Chapter 8

The effect of harvest frequency on macadamia quality

Kevin Quinlan,

Summary

A small field trial was conducted to investigate the effects of harvest frequency on macadamia NIS quality. Trees of cultivar ‘344’ were harvested two, four and six weeks after the previous harvest in May and June 2007. There was no significant effect of harvest frequency on the premium or unsound kernel recovery but increasing the harvest interval from two to four weeks significantly increased commercial kernel recovery from 1.46 to 2.78 percent. Previous studies have shown that increasing on-ground storage time decreases macadamia NIS quality; however in the present study there was little effect due to harvest interval, possibly because the harvesting season was exceptionally dry.

Introduction

In Australia, macadamias typically flower in early spring and then set fruits which develop over the spring and summer. Fruits are generally mature by March or April; and then abscise and are mechanically harvested from the orchard floor. Previous research has demonstrated that nut-in-shell (NIS) quality deterioration increases with the time NIS is stored on the orchard floor (Liang, 1996; Mason and Wells, 1984; Chapter 6), and the rate of quality deterioration may vary with environmental conditions.

Maintaining quality is important for growers because payment from processors decreases as the unsound kernel recovery (UKR) increases. The mean price of macadamia NIS decreased by $260 per tonne when harvest frequency increased to greater than four weeks compared to when harvest frequency was less than four weeks. Even though the quality benefits of harvest frequency have been demonstrated previously, many growers often harvest less frequently than every four weeks, for a range of reasons (Chapter 5). To further demonstrate the benefits of increasing harvest frequency on NIS quality we harvested macadamias two, four and six weeks after the previous harvest and analysed NIS quality.

Materials and Methods

The experiment was conducted in a commercial macadamia orchard near Clunes in Northern NSW (28.7°S, 153.4°E) on mature trees of cultivar '344'. Fifteen plots each comprising three trees were grouped into five blocks, each containing 3 plots; within each block the plots were randomly allocated to one of three harvest frequency treatments. The orchard was commercially harvested on the May 9 2007, any nuts remaining on the ground in the trial plots were removed, experimental treatments were then harvested on one of May 23 (two week harvest frequency), June 6 (four weeks) or June 20 (six weeks).

The nuts from each plot were dehusked and a NIS sample of approximately 1 kg was randomly taken. The NIS samples were sent to an accredited commercial testing laboratory and the quality determined. The NIS parameters measured that constitute quality are expressed as the kernel as a percentage of the entire NIS sample: premium kernel recovery, commercial kernel recovery and unsound kernel recovery. The unsound kernel recovery is comprised of several categories of kernel disorders: external discoloration, shrivelled kernel (generally due to immaturity), discoloured crest (generally due to germination), insect damage, mould and internal discoloration.

The effect of harvest frequency on premium kernel recovery, commercial kernel recovery and unsound kernel recovery were tested using ANOVA. The effect of harvest frequency on the individual unsound categories was not analysed because they appeared only inconsistently from plot to plot and so the means of these categories are presented accompanied with a standard error (Table 2).

Results and Discussion

There was no significant effect of harvest frequency on premium or unsound kernel recovery but decreasing the harvest frequency from two to four weeks increased commercial kernel recovery from 1.46 to 2.78 percent (Table 1).

Table 1. Harvest interval significantly affected commercial kernel recovery (P = 0.011), but not sound, premium or unsound kernel recovery. Mean kernel recoveries for each harvest frequency treatment are presented along with standard errors, significant differences between treatments are represented by letters.

Kernel recovery	Harvest interval

	Two weeks	Four weeks	Six weeks
Sound (%)	34.28 (1.06)	34.78 (1.50)	33.76 (1.50)
Premium (%)	32.82 (1.05)	31.96 (1.49)	32.72 (1.49)
Commercial (%)	1.46 (0.35)a	2.78 (0.50)b	1.02 (0.50)a
Unsound (%)	1.56 (0.39)	1.56 (0.55)	1.26 (0.55)

Shrivelled kernel, generally attributed to immaturity, and insect damage combined accounted for at least 50 % and up to 95% of the unsound kernel across harvest interval treatments and it is unlikely that these defects would be affected by storage treatment. So for this harvest at least, the majority of unsound was determined even before the nuts dropped from the tree.

Table 2. Mean unsound kernel for the various categories along with standard error. Statistical analyses were not performed on individual unsound categories because their presence varied so much from plot to plot.

Unsound kernel recovery category	Harvest interval		
	Two weeks	Four weeks	Six weeks
Shrivelled kernel (%)	0.78 (0.42)	1.29 (0.59)	1.22 (0.59)
Insect damage (%)	0.62 (0.29)	0.20 (0.42)	0.20 (0.42)
Discolouration (%)	0.08 (0.09)	0	0.25 (0.13)
Discoloured crest (%)	0	0	0.15 (0.12)
Mould (%)	0	0.08 (0.07)	0.05 (0.07)
Internal discolouration (%)	0.07 (0.04)	0	0

Quality deterioration in NIS stored on the ground increases with soil moisture content as well as on-ground storage time (Liang *et al.*, 1996), and may be due to microbial infection and germination (Cavaletto, 1983) or discoloration. The rainfall at Alstonville over the two months the trial was conducted in 2007 was 38.8 and 87.8 for May and June which was significantly less than the long term average for the same months, 183.8 and 157.8 respectively. It is therefore likely that the lack of response of NIS quality to harvest frequency was due to the un-seasonally dry conditions which reduced on-ground quality deterioration.

Recommendations

There is already considerable scientific evidence confirming the effect of on-ground storage on NIS quality deterioration; as well as credible economic analysis of real farm data which puts a dollar value on losses due to low harvest frequency (Chapter 6). Therefore, even though there was little effect on NIS quality due to harvest frequency in this experiment, the on-farm and extension recommendations originating from this experimental work will remain consistent with other sections of this report; continue extension activities promoting increased harvest frequencies, placing emphasis on the economic outcome of these on-farm practices through both current and future research and extension projects. Further work may include more detailed and extensive harvest frequency trials to determine the financial costs and benefits for growers of harvest frequencies greater than the minimum standards currently recommended. For example, cost benefit analyses on harvesting every one, two, three, four five and six weeks. Of course, a strong extension component would be essential for these potential quality projects.

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Liang T, Meng Q, Fang J. 1996. Prediction of macadamia nut spoilage for harvest decision making. *Journal of Agricultural Engineering Research* **63**: 237-242.

Mason RL and Wells IA. 1984. The effect of harvest interval on the quality of ground-harvested macadamia nuts. *Food Technology in Australia* **36**: 373-378.

Chapter 9

Technology Transfer

During this project the following technology transfer has been undertaken:

- Presentations at the March round of MacGroups in 2004 to outline the project and its linkages with 3 other projects being undertaken jointly between the AMS, QDPI&F, NSW DPI and supported by HAL.
- An article was published in the March 2004 edition of the AMS news bulletin titled "Better management for better returns" outlining the projects work and its linkages to 3 other projects being undertaken concurrently.
- A poster was produced for the 2005 Macadamia society annual conference titled "What's important for Quality?" outlining the projects findings and highlighting future work.
- A poster was produced for the 2006 AMS conference titled "What's important for quality?" outlining the most significant findings from the project.
- A handout for growers was produced and distributed at the 2006 AMS conference titled "The gains from adopting better on farm quality management" outlining the benefits from adopting findings from the project.
- Presentations were given at each MacGroup run in November 2006 titled "Adoption of Quality Management Systems in Macadamia". This outlined the findings from this project and generated a great deal of discussion and questions from growers, processors and those present.
- A session on quality management was held at the 2006 AMS conference where a presentation on the findings from the project was given, titled "Adoption of Quality Management Systems in Macadamia". This outlined the findings from this project and generated a great deal of discussion and questions from growers, processors and those present.

- An article for November 2006 AMS bulletin was published titled "The gains from adopting better on farm quality management" which provided a summary to growers of the most significant findings.
- A radio interview on the projects findings was given in July 2006 to update the industry and general public on the findings from this project.
- A TV news story and interview was aired in July 2006 outlining the findings from the project.
- The re-sort decisions calculator was presented to eight Mac-Groups during July 2007.
- The re-sort decisions calculator was again presented to the industry, this time at the annual conference at the Gold Coast, November 2007.

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