[1] STORAGE OF MACADAMIA NUT-IN-SHELL

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Summary: *The effect of moisture content and storage temperature on the high quality storage life on macadamia nut-in-shell (NIS), and the subsequent influence of NIS storage on the shelf-life of roasted kernel, is being investigated. Macadamia integrifolia 'Keauhou' (HAES 246) NIS is being stored at 5°, 25°C and 40°C with a moisture content of 15.0, 12.5, 10.0, 7.5 and 3.5% for a maximum of 12 months. Preliminary results showed that unacceptable levels of visual mould developed on NIS with 15.0 and 12.5% moisture at 25°C following relatively short periods of storage. Discolouration and the production of an off-flavour in the raw kernel resulted after 1 month's storage of NIS with a moisture content of 10.0% at 40°C. Roasting times were reduced with increased storage duration of NIS with a moisture content of 15.0, 12.5 and 10.0% at 25°C, 15.0 and 12.5% at 5°C and 3.5% at 40°C. The percentage of roasted kernel rejects increased with increased storage duration of NIS with a moisture content of 15.0 and 12.5% at 25°C.*

Introduction

Increasing rates of macadamia production in Australia and world-wide are forcing producers and processors to store macadamia nut-in-shell (NIS) for periods prior to drying and processing because existing facilities are inadequate to cope with the quantity of NIS currently being harvested. There is limited information available on the storage life of macadamia NIS.

At harvest, NIS can have a moisture content up to 30.0% where the kernel fills the entire shell cavity (Leverington, 1971). In Australia, NIS is normally dried to approximately 10.0% moisture content on the farm by passing ambient air through the mass of NIS in silos. They are then consigned to the factory where they are further dried to 1.5% kernel moisture content (equivalent to approximately 3.5% NIS moisture content). They are dried by passing heated air through the mass of NIS in silos or a dehumidifying dryer. Drying to 1.5% kernel moisture facilitates cracking, as the kernel shrinks from the shell wall, thus reducing the risk of physical damage to the kernel. Drying also improves texture and flavour characteristics (Leverington, 1971).

Cavaletto *et al* (1968) reported that NIS can be stored for at least 12 months without any significant effect on kernel quality providing the kernel moisture content is reduced to and maintained at 1.2%. They further reported significant detrimental effects on quality resulting from 6 months storage of the NIS at 3.0% to 3.8% kernel moisture content (equivalent to approximately 8.0% to 9.0% NIS moisture content). Macadamias contain approximately 75% oil. The instability can be attributed to the high content of monounsaturated (84%) and polyunsaturated (4%) fatty acids in the oil. Chu *et al* (1953) reported that the decline in kernel quality during storage of NIS with a high moisture content was due to hydrolytic rancidity, brought about by the activity of respiratory, lipolytic and proteolytic enzymes, and oxidative rancidity.

Processors strongly discourage the drying of NIS to a moisture content less than 10% on the farm due to the risk of physiological damage to the kernel that can occur if drying temperatures are not strictly controlled and physical damage that can result during handling and transportation of the NIS at a low moisture content. Furthermore, the problem exists where producers are unable to sufficiently reduce the moisture content of the NIS due to prevailing local environmental conditions. Under these circumstances, the risk of mould growth and subsequent loss of product is greatly increased. Higaki and Dedolph (1963) reported that the moisture content of NIS during storage influenced the development of internal and external mould, thus causing a complete loss of product. In addition, they found that mould development was reduced when NIS was stored at 7.2°C, irrespective of storage relative humidity. It is unknown whether the kernel may incur any

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additional physiological or chemical damage from even the shortest period of NIS storage at a high moisture content.

Roasting enhances the flavour and increases the stability of macadamias (Leverington, 1971). Mason *et al* (1995) found that the optimum roasting time for sound kernel of *M. integrifolia*, roasted in refined and deodorised coconut oil at 125°C, was between 10 and 14 min. Cavaletto (1983) reported that defects in macadamia kernels may not become apparent until the kernels have been roasted. These defects were manifested in the form of brown spots or excessive browning, resulting in their classification as lower grade kernels. Reducing sugars in the kernel are reported to be responsible for the browning reaction during the roasting process. Cavaletto *et al* (1966) and Dela Cruz *et al* (1966) demonstrated that a kernel moisture content above 1.0% increases the production of reducing sugars via enzymatic reactions, thus reducing the time to achieve optimum colour during roasting and roasted flavour development.

The objectives of this project are to provide detailed information on the effects of moisture content and storage temperature on the high-quality storage life of macadamia NIS and the subsequent effect of NIS storage on the shelf life of the roasted kernel.

Materials and Methods

Storage experiment

NIS of *Macadamia integrifolia* 'Keauhou' (HAES (Hawaiian Agricultural Experiment Station) 246) were used in the storage experiment. Samples of macadamia NIS were obtained from one commercial orchard in the Gympie area of Queensland and from two orchards in the Northern Rivers area of New South Wales. NIS collected from each orchard served as replicates for the experiment. The NIS was mechanically harvested from the ground following natural nut-drop. Approximately 360kg of NIS comprised each replicate.

The NIS was transported to The University of Queensland Gatton College in hessian bags, placed into a dehumidifying dryer and dried to 15.0, 12.5, 10.0, 7.5 and 3.5% NIS moisture content. The lowest moisture content is the most critical as it is an established industry standard for processing and must be determined as a kernel moisture of 1.5% (approximately equivalent to 3.5% NIS moisture). The drying parameters constituted 36°C dry bulb and 19°C wet bulb temperatures. The moisture content of the NIS and kernels was determined by withdrawing a 250g random sample of NIS and placing into a vacuum oven operating at 75°C and -70kPa until constant mass was reached.

When the desired moisture content was reached, approximately 30kg of NIS was removed from the dryer and placed into storage at 5°C, 25°C and 40°C. The NIS was stored in 60L plastic drums, each containing a perforated steel false-floor, creating a plenum chamber for uniform air movement through the mass of NIS. Air was passed through each container at a velocity 0f approximately $11Lh^{-1}$. The relative humidity of the air was controlled using a system where saturated and dry air are mixed proportionally to achieve an equilibrium relative humidity (ERH) corresponding to each NIS moisture content and storage temperature. The ERH for each storage temperature was calculated using the Guggenheim, Anderson and de Boer (GAB) equation, using the six constants from the sorption isotherms obtained from the work published by Palipane and Driscoll (1992). The NIS and kernel moisture content of each treatment were monitored regularly and the ERH adjusted accordingly. The ERH was measured using an optical dew point meter.

The maximum storage period for the experiment was 12 months. Following the expiration of a predetermined storage period (Table 1), a 6kg sample of NIS was withdrawn from storage and dried to 1.5% kernel moisture content. Sub-samples, consisting of 20 NIS, were removed for microbiological testing both prior to and after drying. A kernel recovery test was conducted on a NIS sub-sample of 500g and the percentage sound kernel and unsound kernel categories determined, as per Recommended Standards for Sampling and Nut-in-Shell Evaluation (AMS, 1994). The remainder of the NIS sample was cracked and sorted into sound and unsound kernel. Sound raw kernel sub-samples of 50g and 200g were removed for chemical testing and sensory evaluation, respectively. Sub-samples were placed into individual lacquered cans, sealed under -65kPa vacuum, and stored in a coolroom at 0°C until analyses and sensory evaluation could be conducted.

Table 1. Treatments used in the macadamia NIS storage experiment. A treatment constitutes the combination of a storage temperature, a moisture content and a storage duration.

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Temp. (°C)	NIS moisture content (%)	Storage duration (Months)				
5	3.5	0	4	8	12	
5	7.5	0	4	8	12	
5	10.0	0	4	8	12	
5	12.5	0	4	8	12	
5	15.0	0	4	8	12	
25	3.5	0	4	8	12	
25	7.5	0	2	4	8	12
25	10.0	0	1	2	4	8
25	12.5	0	1	2	4	8
25	15.0	0	0.5	1	2	4
40	3.5	0	1	2	4	8
40	10.0	0	1	2	3	4

Roasting
The remainder of the sound raw kernel was roasted in refined and deodorised coconut oil at 125°C until the optimum colour was achieved as per Macadamia Industry Standard Colour Chart (AMS, 1994). The time to reach optimum colour was recorded. The roasted kernel was sorted, reject kernels removed and the percentage of roasted kernel rejected determined (AMS, 1994). The sound roasted kernel was divided into three 50g sub-samples for objective tests and three 200g sub-samples for sensory evaluation. All sub-samples were sealed into individual lacquered cans as previously described. Two sub-samples, of 50g and 200g respectively, were placed into storage at 0°C until sensory evaluation and chemical analyses could be conducted. The remaining sub-samples were placed into further storage at 25°C for 4 and 8 months. At the end of each roasted storage period, one 50g and one 200g sub-sample were then placed into storage at 0°C until chemical analyses and sensory evaluation could be conducted.

Quality evaluation
The percentage of sound and unsound kernel was determined from the industry standard kernel recovery test (AMS, 1994). Microbiological activity was quantified by the percentage of mouldy kernel resulting from the kernel recovery test. Standard plate counts (AS1766.2.1 - 1991) and yeast and mould counts (AS1766.2.2 - 1994) were conducted on all sub-samples withdrawn both before and after drying. Sensory evaluation will be conducted on both raw and roasted kernel using a trained taste panel under controlled conditions. The time taken to roast sound raw kernel to optimum colour was recorded for each roasting and the percentage of kernel rejected after roasting was determined (AMS, 1994). The oil will be extracted from both raw and roasted kernel using a hydraulic press. The oil will then be analysed by conducting standard analytical tests including peroxide value (AOAC (1990) 965.33), free fatty acid value (AOAC (1990) 940.28) and fatty acid profile (AOAC (1990) 963.22). The percentage of total sugars and reducing sugars in the raw kernel will also be determined.

Experimental design
The storage experiment conformed to a randomised block design. Statistical analysis will be performed on all data, except that resulting from sensory evaluation, using a two way factorial analysis of variance. Factors include three locations, considered as replicates, and 43 NIS moisture content/storage temperature/storage duration combinations, designated as treatments.

The statistical design for the sensory evaluation is that of an incomplete block design, consisting of three locations considered as replicates, 35 treatments (NIS moisture content/storage temperature/storage duration combinations and 24 taste panellists. The roasted kernel will be analysed similarly at each of the three storage periods (0, 4 and 8 Months). Only those treatments with less than 5% visual mould will be tasted, thus reducing the number of treatment samples.

Results
Only preliminary results are presented, and no statistical analysis has been conducted on data to date, as the trial is incomplete.

Raw kernel
The development of visual mould was affected by the combination of storage temperature, moisture content and storage duration (Fig. 1). The presence of visual mould exceeding 1% of the sample was found only on NIS with 15.0 and 12.5% moisture content at 25°C and after 0.5 and 1 month respectively and 15.0% moisture at 5°C after 5 months. A reduction in moisture content and temperature suppressed the development of mould. The rate of increase in the percentage of visual mould with increasing storage duration was greater at 25°C than at 5°C. NIS stored with 15.0 and 12.5% moisture at 25°C reached levels of 15.2% after 3 months and 17.7% after 4 months respectively while NIS with 15.0% moisture at 5°C took 8 months to reach a 2.6% level of visual mould. No visual mould developed on any other treatments.

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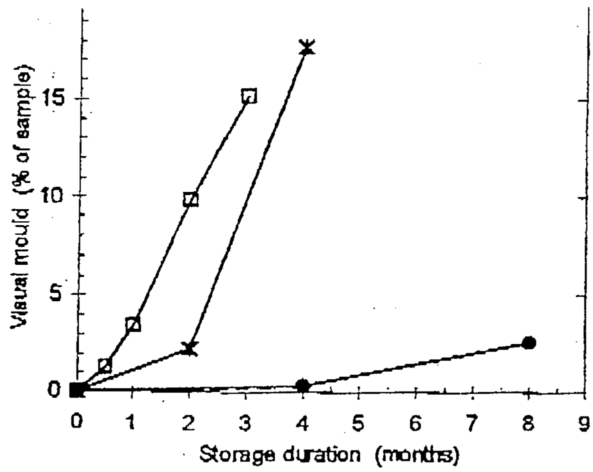

Fig.1. Effect of storage duration on the presence of visual mould in *Macadamia integrifolia* 'Keauhou' (HAES 246) NIS stored with a moisture content of 15.0 at 25°C (□), 12.5% at 25°C (✻) and 15.0% at 5°C (•). (Results are the mean of three replicates.)

Slight discolouration and the production of an off-flavour in the raw kernel resulted, after 1 month's storage of NIS with 10.0% moisture at 40°C. The discolouration and off-flavour was increased after 2 months' storage. No other treatments displayed these characteristics, including NIS with a moisture content of 3.5% at 40°C for the same durations.

Roasted kernel

The time taken to roast the raw kernel to optimum colour was affected by the NIS moisture content, storage temperature and duration of NIS storage. The roasting times for kernels roasted without any NIS storage was 10.5 min. Generally, roasting time decreased below 10.5 min. with increased storage duration for NIS stored with a moisture content of 15.0, 12.5 and 10.0% at 25°C, 15.0 and 12.5% at 5°C, and 3.5% at 40°C (Fig.2). NIS with a moisture content of 15.0, 12.5 and 10.0% at 25°C showed the most dramatic decrease in roasting time. NIS stored with a moisture content of 15.0 and 12.5% at 5°C and 3.5% at 40°C showed a similar response to each other but with a much smaller time reduction in comparison to those stored at 25°C. The roasting time for all other treatments remained constant and above the roasting time recorded for kernels roasted without any prior NIS storage, despite increased storage duration.

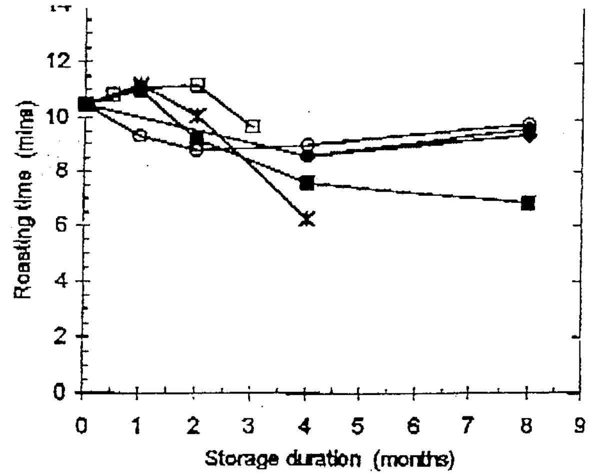

Fig.2. Effect of storage duration on the time to roast *Macadamia integrifolia* 'Keauhou' (HAES 246) kernels to optimum colour in refined and deodorised coconut oil at 125°C following storage of NIS with a moisture content of 15.0% at 25°C (□), 12.5% at 25°C (✻), 10.0% at 25°C (■), 15.0% at 5°C (•), 12.5% at 5°C (◆) and 3.5% at 40°C (O). (Results are the mean of 3 replicates.)

The percentage of kernels rejected after roasting, due to excessive browning or brown spotting, was affected by NIS moisture content, storage temperature and storage duration. NIS without any storage prior to roasting yielded a level of 4.6 of kernels rejected after roasting. The percentage of roasted kernel rejects increased with increased storage time for NIS stored with a moisture content of 15.0 and 12.5% at 25°C and 15.0% at 5°C (fig.3). The combination of NIS stored with moisture content of 15.0 and 12.5% at 25°C resulted in a rapid increase in roasted kernel rejects to 33.4% after 3 months and 48.7% after 4 months respectively. In comparison, NIS stored with a moisture content of 15.0% at 5°C took an eight month period to reach a level of 11.6%. All other treatments yielded a similar percentage of roasted kernel rejects to those roasted without any NIS storage.

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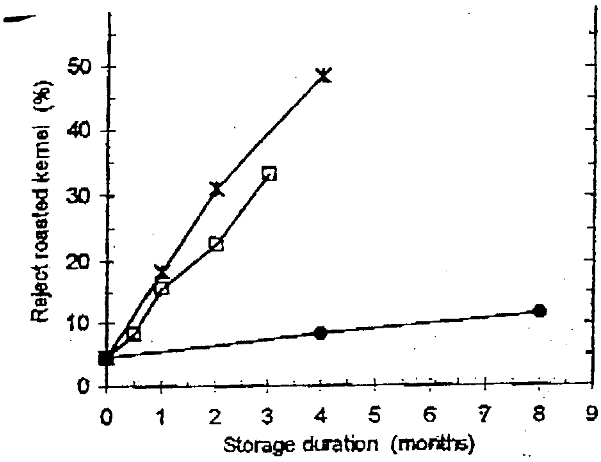

Fig.3. Effect of storage duration on the percentage of reject kernels after roasting *Macadamia integrifolia* 'Keauhou' (HAES 246) kernels in refined and deodorised coconut oil at 125°C following storage of NIS with a moisture content of 15.0% at 25°C (□), 12.5% at 25°C (*, 15.0% at 5°C (•). (Results are the mean of 3 replicates.)

Postharvest pests
Populations of astigmatid mites, *Tyrophagus* sp., were found in association with mould growth on NIS where the storage environment produced a high relative humidity at 25°C. Mites were found to reach massive populations in the storage containers where NIS was stored with a moisture content of 15.0 and 12.5% at 25°C. The mite population in the 12.5% treatment was observed to be substantially reduced in comparison to the population in the 15.0% treatment. Minor damage, not previously recognised by processors, was observed on some raw kernel. It is unknown whether this damage was caused by the mites. No mites were found in any other moisture content/storage temperature treatment combination.

Minor to severe damage not previously identified by processors, was found on a number of raw kernels after cracking the NIS. The damage was observed in all NIS samples cracked throughout the storage experiment and represented less than 1% of each of the NIS samples. It is suspected that the damage is being caused by an adult beetle, and its larvae, found in association with some of the macadamia kernels displaying this damage. The beetle was identified as *Tribolium* sp. and is yet to be identified to species level.

Discussion
Raw kernel
It was demonstrated that the combination of a high moisture content and 25°C caused the development of visual mould within a relatively short storage duration. Storage of NIS with a high moisture content produces a high ERH within the storage container, thus creating the optimum environment conducive for mould development. Therefore, by lowering the moisture content of the NIS during storage, the ERH of the storage environment is subsequently reduced, thereby creating undesirable conditions for mould development. This was demonstrated where the NIS was stored with a moisture content below 12.5%, totally suppressing mould development, irrespective of temperature or storage duration. These results support the findings of Higaki and Dedolph (1963) who reported that the moisture content of NIS during storage influenced the development of external mould.

Development of visual mould was shown to be dramatically retarded by storage at 5°C despite a high NIS moisture content and increased storage duration. Storage at 5°C is sub-optimal for mould development and any mould growth associated with storage at this temperature may be due to fungal species that can survive and reproduce at this temperature. This is supported by Pelczar *et al* (1986) who states that the majority of moulds generally require a temperature between 20°C and 25°C for growth. However, there are moulds that can grow at or near 0°C. Once again, these results substantiate the findings of Higaki and Dedolph (1963) who reported that mould growth was not prevalent at 7.2°C regardless of the storage relative humidity or equivalent NIS moisture content.

Roasted kernel
The time taken to roast the raw kernel without any prior NIS storage to optimum colour was 10.5 min. This supports the findings of Mason *et al* (1995) where it was found that the optimum roasting time was between 10 and 14 min. It is thought that the time to roast to optimum colour is a reflection of the low percentage of reducing sugars present in mature macadamia kernels. The reducing sugars are responsible for the non-enzymatic browning or Maillard reaction that occurs during roasting. Roasting times below 10.5 min. may be due to increased production of reducing sugars in the kernels. The conversion of non-reducing sugars to reducing sugars can be caused by enzymatic reactions occurring in the kernels during storage (Cavaletto *et al*, 1966).

NIS stored with a moisture content of 12.5 and 10.0% at 25°C showed the greatest reduction in roasting time with increasing storage duration.

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This temperature/moisture content combination may encourage enzyme activity responsible for the increased production of reducing sugars. This would support the findings of Cavaletto *et al* (1966) and Dela Cruz *et al* (1966) who demonstrated that a kernel moisture content above 1.0% increases the production of reducing sugars which, in turn, reduces the time to achieve optimum colour development during the roasting process. Storage of NIS with a moisture content below 10.0% at 25°C or below 12.5% at 5°C appears to slow the rate of reducing sugar production, despite increased storage duration.

The occurrence of brown spotting or excessive browning of the kernels after roasting resulted in their rejection. NIS stored with a moisture content of 15.0 and 12.5% at 25°C and 15.0% at 5°C were the only treatments to display the brown spotting characteristic. These same treatments were also the only treatments to yield a percentage of roasted kernel rejects higher in comparison with the yield from those kernels roasted without any prior NIS storage. The combination of high NIS moisture content and 25°C results in a substantial loss of product after roasting. The longer the storage duration under these conditions, the greater the loss of product. In comparison, storage of NIS with a moisture content of 15.0% at 5°C dramatically reduced the percentage of roasted kernel displaying brown spotting, despite an increased storage duration.

The raw kernels used for roasting in these treatments had no apparent defects and were classified as sound prior to roasting. Therefore, it has been demonstrated that it is possible for latent defects to be caused by the storage conditions and not manifest themselves until the kernel is roasted. This result reinforces the findings of Cavaletto (1983) who reported that defects in macadamia kernels may not become apparent until the kernels have been roasted. As yet, there is no explanation as to why this latent reaction occurs. However, it is apparent that it is caused by storage of NIS with a high moisture content at 25°C and that the problem is exacerbated with increased storage duration. The problem is eliminated by storage at a lower moisture content and temperature.

Postharvest pests

Populations of astigmatid mites, *Tyrophagus* sp., were found in the storage containers where NIS was stored with a moisture content of 15.0 and 12.5% at 25°C. This mite species is known to infest stored products but, until now, was unrecorded in conjunction with the storage of macadamia NIS. The mites require a humid environment for survival due to their epidermis which is highly susceptible to desiccation. *Tyrophagus* sp. is a fungivore and it is therefore not surprising that the mites were found in treatments where the environmental conditions were conducive to mould development. The combination of high NIS moisture content and 25°C creates a high relative humidity (RH). These conditions are optimal for mite reproduction, reducing the life cycle to a minimum and providing a suitable and plentiful food source for their survival. While this mite is thought to be primarily a fungivore, it is unknown whether it causes any damage to the raw kernel.

Due to the above considerations, the only means of controlling the pest, during NIS storage, is by maintaining a low relative humidity storage environment and storing the NIS at a moisture content below 12.5% or by storage of the NIS at refrigerated temperature. This was demonstrated where a reduction in the NIS moisture content below 12.5% during storage at 25°C resulted in the absence of mites. It was also shown that storage of NIS at 5°C, irrespective of the moisture content, resulted in the absence of mites. This is not unexpected as *Tyrophagus* sp. cannot survive and reproduce at this temperature. Fumigation of the storage facilities is not an option for control as there are no registered chemicals in Australia for the control of this mite in stored macadamias.

Tribolium sp. is thought to be causing the severe type of damage to the raw kernel that was found on some kernels. This beetle is a major insect pest of stored products, such as cereal grains, but has not been previously recorded as causing damage to macadamia kernels. Reproduction occurs between 25°C and 35°C with the number of eggs laid dependant upon the temperature. The life cycle can be completed within 20 days under optimum conditions of 32°C and 75% RH. This beetle can survive dry conditions and is highly mobile. While the percentage of damage found in this experiment was extremely low, this beetle non-the-less has the propensity to cause damage to kernels while stored as NIS. Coupled with the beetle's basic biology and ecology, future recommendations regarding the optimum storage conditions for macadamia NIS must take this pest into consideration.

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