MACADAMIA NUT PROCESSING

Ingrid A G Weinert
Divisie vir Voedselwetenskap en -tegnologie, Posbus 395, Pretoria

Source: The Southern African Macadamia Growers Association Yearbook 1993, pp. 54-75

INTRODUCTION

Macadamia nuts are a very highly regarded nut (Anon, 1978). The macadamia belongs to the family Proteaceae, which also contains a number of poisonous species (Menninger, 1977). Apparently it is the only indigenous industrial food crop to have come out of the Australian continent. Macadamia nuts can be eaten raw, roasted, coated, salted, flavoured, etc. Sharma (1985) was awarded a patent for the coating of nuts with a syrup mixture.

The smooth shell type macadamia nut *(M. integrifolia)* is the only species planted in Hawaii and most other countries, but the rough shell type (M. *tetraphylla)* and hybrids between the two are also grown on a smaller commercial scale (Cavaletto, 1981). Since these species differ in the chemical composition of the nuts, they should be processed separately. Hamilton *et al.* (1980) discusses the Hawaiian macadamia nut, its propagation, climatic adaptation, fertilization, diseases and pests as well as harvesting and processing.

The nutrient composition of the macadamia kernel is given in Tables 1A and 1B (Watt & Merril, 1963; Cavaletto, 1980; NFRI, 1977). The kernel has a high fat content combined with relatively high protein and carbohydrate contents. In addition, the kernels can be regarded as a good source of the B-vitamins (thiamin, riboflavin and niacin). However, the high calorie content of the kernel will probably decrease the usefulness of the high protein, mineral and vitamin contents. The values differ between cultivars, maturity and regions.

Table 1A: Nutrient composition of macadamia kernels (Wenkarn and Miller (1955) in Cavaletto (1980); Watt & Merrill, 1963)

Nutrient	Cavaletto	Watt & Merrill
	(per 100 g edible portion)	
Moisture (g)	1,19	3,0
Fag (g)	78,21	71,6
Protein (g)	9,23	7,8
Total carbohydrate (g)	9,97	15,9
Fibre (g)	1,84	2,5
Ash (g)	1,40	1,7
Ca (mg)	53,40	48,0
P (mg)	240,80	161,0
Fe (mg)	1,99	2,0
K (mg)		264,0
Thiamin (mg)	0,216	0,34
Riboflavin (mg)	0,119	0,11
Niacin (mg)	1,60	1,3
Energy (cal)		691,0

In the following report an overview of factors influencing macadamia nut quality is given. Since macadamia characteristics and the unit processes are interrelated, it is difficult to compartmentalize the information and duplication cannot always be avoided.

PROCESSING (see also Quality Factors)

The sequence of processes that macadamia nuts are subjected to are harvesting, dehusking, drying, cracking, separating, grading, roasting, salting and packaging. These processes and their influences on product quality are described here.

Table 1: B Nutrient composition of South African macadamia kernels analyzed in 1977 (NFRI, 1977)

Nutrient	Nelmak 2	Nelmak 26	Keauhou	Nelmak 2	Nelmak 11
	(per 100 g edible portion)				
Moisture (g)	2,94	3,09	0,70	0,71	0,62
Fat(g)	68,10	68,83	76,79	74,98	78,84
Protein (g)	7,88	8,09	8,88	8,06	7,75
Total carbohydrate (g)	11,8	11,4	8,9	9,7	8,4
Fibre (g)	7,88	7,15	3,52	4,77	2,49
Ash (g)	1,39	1,36	1,15	1,73	1,85
Ca (mg)	16,57	6,23	11,13	62,70	36,74
P (mg)	168	168	185	221	203
Fe (mg)	5,59	2,62	2,40	1,77	1,97
K (mg)	525,7	469,9	356,27	584,32	673,18
Thiamin B1 (mg)	0,653	0,533	0,550	0,697	0,491
Riboflavin B2 (mg)	0,09	0,05	0,056	0,055	0,079
Nicotinic acid B5 (mg)	2,92	2,40	1,988	3,254	2,329

1. Harvesting

Macadamia trees in Hawaii are selected according to several tree characteristics (size, shape, yields and health) and nut characteristics, such as size and shape, kernel size and shape, kernel-nut ratio, kernel yield, oil content, kernel colour, flavour and roasting characteristics (Cavaletto, 1981: Hobson, 1976a, b). Selection of macadamia trees in Kenya is described by Gathungu and Ukimani (1975). Cavaletto (1981) stresses that cultivar selection must suit the local conditions, since location appears to significantly affect nut quality. Kadman and Slor (1982) also mention this in their discussion of the characteristics of a macadamia variety ("Yonik") which was derived from a seedling population from the Kona-778 type. These plants were recommended by A. Hamilton (University of Hawaii) as a rootstock. One of the trees from this population showed outstanding behaviour (fast growth, good kernel quality) and was selected as "Yonik".

The oil content is probably the single most important criterion for selection and should range between 72 and 79% for top-grade kernels (Cavaletto, 1981). Second grade kernels have oil contents of 67-71% (Grimwood, 1971). Flavour differences are usually minimal between selections, but the occasional seedling may produce bitter nuts (Cavaletto, 1981). This bitter principle is due to the presence of a cyanogenic glucoside called proteacin. Bitter nuts cannot be detected visually and trees producing these nuts should be eliminated during selection (Cavaletto, 1980) Dark varietal rings around the centre of the kernel and colour differences between the top and the bottom should be minimal. These defects are apparently genetically determined and such plants should be discarded during cultivar selection (Cavaletto, 1981).

New macadamia cultivars should be evaluated according to various criteria and compared with similar data from existing good performers in order to establish an industry which can produce consistent high quality. Cavaletto (1978, 1981) mentions the evaluation of new cultivars according to:

Oil content: specific gravity test; immersion of kernels dried to 1,5% moisture in tap water. Floaters contain 72% oil, Grade 1.
Kernel yield: Nuts with thinner shells yield more nut meat, but too thin shells give problems in cracking.
Kernel size: Middle sized nuts should be used.
Kernel shape: Rounder kernels are preferred and should not have a prominent suture ridge which could be broken off during handling and detract from appearance.
Kernel colour: Even brown colour after roasting is desired. Any discolourations are undesirable.
Kernel maturity: Shrivelling and prominent suture ridges are often signs of immaturity.
Stuck kernels: In some cases kernels stay attached to the shoulder area of the nut after drying. During cracking, a chip is broken off the kernel and the damaged area browns more during roasting. More broken kernels also result from this sticking. It would appear that this phenomenon occurs more often in certain cultivars.

A little information on acceptable cultivars is also given by the author.

Leverington (1962) evaluated a number of Australian macadamia cultivars according to the following criteria: shape and size of nut, thickness of shell, kernel diameter, kernel colour, kernel recovery, quality of kernel (specific gravity) and palatability of roasted nuts. They decided to use kernel recovery and the percentage of first-grade kernels as principal measures of processing quality and to take the other characteristics into consideration during final selection.

Human (1979) reports on the evaluation of South African macadamia nut cultivars. The cultivars which were used in the tests were: Nelmak 1, Nelmak 2, Nelmak 26, Keaau (660), Keauhou, lkaika (333), Kakea (508), 791, 42, 695 and Elimbah. The cultivars were compared sensorially after roasting, with Nelmak 2. Keaau (660) was rated the best and Nelmak 2 second best according to the taste panel of 10 persons. Third was Kakea (508) and 42 was rated fourth. All the nuts were accepted and the texture was good. In comparison to an imported sample of Hawaiian nuts, Nelmak 2 was rated better by 70% of panelists. Thus, according to the author, the *M. tetraphylla* hybrid was acceptable and it appears that such a hybrid can produce the same or better quality processed nuts as *M. integrifolia.*

Oosthuizen *et at*. (1989) evaluated data of 18 years to recommend cultivars for specific areas in the Southern Lowveld and Soutpansberg areas. The selections were evaluated according to yield, nuts/kg, percentage kernel, average kernel mass and percentage whole nut. They report that climate has an important influence on the performance of the various cultivars and selections. In order of preference they recommend the following cultivars:

Southern Lowveld:	Keaau, Kau, Kakea, Nelmak 2, Keauhou, lkaika.
Soutpansberg area:	Keaau, Kakea, Kau, Selection 26, Keauhou, lkaika.

The physiological development of the macadamia nut (*Macadamia ternifolia* F.v.M. var *integrifolia* Maiden) from flowering to maturity was studied by Jones and Shaw in 1943. In the first 90 days after flowering the structures of the fruit is formed and the shell, husk and endosperm grow. After 90 days, oil starts forming and sucrose and proteins accumulate. Between 90 and 185 days after flowering (i.e. 44% of total growth period), 70% of the total oil is formed. Reducing sugars and sucrose reach their maximum around 111 days after flowering and decrease until maturity is reached. Total nitrogen increases throughout growth, but declines after 90 days if expressed as percentage of dry weight. Between 90 and 111 days after flowering there are significant changes: acid value, saponification number and soluble acids decrease sharply whereas an increase in iodine number occurs (Table 2). In the early stages of oil formation, short chain fatty acids accumulate and are only esterified later. According to the authors, macadamia oil is formed from carbohydrates, which are hexoses or sucrose since no starch has ever been found in macadamias. It appears as if short chain saturated fatty acids are first formed which are converted into long chain unsaturated fatty acids later on. In addition, the short chain acids are not esterified with glycerol in the beginning, probably because the relevant esterase is absent. The mature macadamia oil has high percentages of mono-unsaturated fatty acids, of which palmitoleic and oleic acids predominate (Bridge & Hilditch, 1950; Cavaletto, 1980). The high content of palmitoleic acid is unique to the Proteaceae (Table 3).

Table 2: Carbohydrates, nitrogen and oil changes In the macadamia embryo in relation to age (a« % of dry weight) (Jones and Shaw, 1934)

Constituent	**Days after flowering**				
	90	**111**	**136**	**185**	**215**
Reducing sugars	1,47	3,21	1,07	0,41	0,30
Sucrose	6,07	24,07	21,91	9,19	5,50
Total sugar	7,54	27,28	22,98	9,60	5,80
Soluble nitrogen	2,92	1,13	0,61	0,33	0,27
Insoluble nitrogen	1,96	1,91	1,58	1,39	1,43
Total nitrogen	4,88	3,04	2,19	1,72	1,70
Acid-hydrolyzable matter	4,54	4,88	3,85	2,56	2,16
Soluble solids (80 % alcohol)	60,10	39,92	28,36	14,82	9,88
Ether & alcohol Insoluble material	36,43	28,88	23,69	17,89	16,68
Petroleum ether extract	3,46	31,19	47,94	67,28	73,44

Table 3: Fatty acid composition of macadamia oil (*M. integrifolia)*

Fatty acid	**%Composition**	
	Cavaletto *et al* (1966)	**DFST (1991)**
Lauric (C12:0)	trace	0,07
Myristic (C14:1)	0,8	0,8
Palmitic (C16:0)	7,4	9,0
Stearic (C18:0)	18,5	22,7
Oleic (C18:1)	2,8	3,2
Linoleic (C18:2)	65,0	57,5
Linolenic (C18:3)	1,5	1,9
Arachidonic (C20:4)		0,1
Eicosenoic	1,9	2,2
Behenic	2,3	2,0
		0,4

In Hawaii, harvesting is done mechanically or by hand (Foss, 1983). This includes sweeping, shakers and hand collecting. Nuts must be separated from leaves, twigs, rocks, etc. before further processing to preserve quality and prevent damage to equipment. The area under the trees should preferably be kept clean from debris (Leverington, 1971; Grimwood, 1971). Blowing away of leaves under the trees as well as nets to funnel falling nuts to a central point, have been suggested. Quality aspects of the nuts which are linked to harvest and tree health, are the most important considerations to determine the correct point for mechanical harvest as described below.

Physiological development

The time it takes for the nut to reach maturity apparently varies throughout the world. In Hawaii it was found that nuts harvested prior to maturity were dark and shrivelled after roasting due to low oil and higher sugar contents. The husk contains fairly high amounts of tannin (6-14% in nuts from the two varieties and different regions) (Cavaletto, 1980). The moisture of the husk decreases and ash content increases during maturation. These two factors appear to influence the electrical impedance which is being evaluated as a measure of maturity.

Orchard maturity

After shell hardening, the internal husk colour browns - this can be used to assess maturity 3-4 weeks before harvest.

Harvest maturity

Preliminary harvest maturity is based on the internal husk colour. The correlation of oil content of nuts (dried for 18 hours at 93°C) with specific gravity is often used for maturity determination.

Harvesting is usually done by picking up the nuts. Nut quality is not affected by mechanical harvesting or collection after they have dropped, but the quality is reduced when nuts are allowed to lie on the ground (Moltzau & Ripperton, 1939, Leverington, 1971). Delayed harvesting or too long periods on the ground, may cause mouldiness, germination or rancidity. Harvesting is usually done in 3-4 week intervals in Hawaii (Leverington, 1971), but more frequent picking up of fruit is advised in the peak harvest period (two to three times per week) and also during wet periods (Moltzau & Ripperton, 1939; Grimwood, 1971). Damage from rats has also been recorded. Mason (1983) evaluated the effect of harvest time and method on the quality of macadamia nuts. Nuts were harvested at four times during the harvest season. They dried the kernels after dehusking (30°C for 3-4 days: 40°C for 2-3 days and 50°C until kernel moisture had reached 1-1,5°C), cracked the nuts manually and determined the yield of sound kernels. Kernel size, specific gravity, roasting quality (fried in coconut oil) and storage stability was evaluated. They found that harvest from the tree or from the ground resulted in the same quality, but nuts from later harvest times were of better quality than earlier harvests. Nuts should therefore only be harvested at a maturity corresponding to optimum quality which the author determined by sensory evaluation. This point was reached at the second harvest date, when only 30% of the nuts had fallen - the other nuts could therefore have been harvested at any time thereafter without affecting the quality. However, Mason concludes that tree harvesting can only be used once a reliable method for determining nut maturity has been reached.

Insect damage occurs and the stinkbug apparently is the worst of these pests. At present the insect is controlled with pesticides, but other solutions (e.g. biological control) are being sought. According to the Plant Protection Research Institute (1990), cypermethrin and aldicarb are used against stinkbugs and their withholding period of the insecticides is 30 and 100 days respectively. The maximum level permitted in the kernel (i.e. shelled nut) is 0,05 mg/kg for both pesticides. These pesticides have to be applied as specified, in order to be effective.

Husks must be removed within 24 hours after harvest to prevent heating of the nuts resulting in spoilage and off-flavours (Moltzau & Ripperton, 1939; Grimwood, 1971; Cavaletto, 1980; Hand, 1983) (see below).

The nuts usually fall off at a moisture content around 25%. The kernel is then still attached to the inside of the shell, but pulls away during subsequent drying. Cavaletto (1966) describes the influence of rough handling on the quality (breakage) of macadamia nuts. Nuts of moisture contents varying between 25 and 5% moisture were shock-treated. All the kernels were damaged in the process and the author concludes that the thick shell of the macadamia does not protect it against severe damage. Nuts should therefore be handled with extreme care during all stages of processing. Damage to kernels containing % moisture increased as the moisture content decreased and the kernels are more vulnerable when removed from the shell (Hand, 1983).

It is always advisable to keep nuts of the two macadamia species separate for processing, since they differ in characteristics (Leverington, 1971).

2. Dehusking

The first step after harvesting is the removal of the husk, which should be done within 24 hours. This is to prevent the build-up of respiration heat which can cause deterioration of quality (Moltzau & Ripperton, 1939: Grimwood, 1971; Cavaletto, 1980; Hand, 1983). Increases of approximately 10°C can occur within 10 hours if the kernels are not stored well ventilated. The husk can contain up to 45% moisture. If the nuts cannot be dehusked they should at least be spread out and stored in such a way that there is sufficient air movement around the kernels to prevent heat build-up (Grimwood, 1971). The dehusker should be adjusted to prevent damage to the nuts, since this can show up as broken raw kernels or marks on roasted nuts (Moltzau & Ripperton, 1939; Hand, 1983). The simplest dehusker uses revolving rubber wheels, while a revolving disc fitted with blades below a static labyrinth or a rotary wire brush have also been used (Grim-wood, 1971).

Husks can be used as mulch for soil. The mixing of the husk with pineapple bran and molasses for animal feed, has been researched (Grimwood, 1971).

Nuts should be delivered to the processor and paid for on a quality basis, which includes criteria such as recovery of whole nuts, absence of blemishes and insect or mould infestation as well as oil content and roasting quality (Anon, 1980:

Cavaletto, 1978, 1981: Hobson, 1976a, b: Leverington, 1971).

3. Drying (see also Decortication / Cracking)
Drying is the most critical step in macadamia processing: actual conditions are kept confidential by processors (Grimwood, 1971). The drying process is often carried out in bins and may last 2-3 weeks. Artificial drying is the preferred method. Nuts must be dried to a moisture content less than 1,5% before cracking to prevent flavour deterioration, harden the shell and result in shrinkage of the kernels and weakening of the shell-kernel attachment. The drying rate and final moisture content of the nuts is of utmost importance to the quality of the kernels (Hand, 1983). Cavaletto *et al.* (1968) found that the kernels should be dried to 1,2% moisture and Dela Cruz *et al.* (1966) found that 1,1% moisture was the most stable. Since the enzymes responsible for product deterioration are dependent on moisture, the low moisture content as recommended prevents enzymatic reactions to take place to any significant degree during storage for more than one month under sealed airtight conditions. Low storage temperatures in combination with low moisture content, increases the shelf-life of the kernels.

Airdrying may be used to dry the nuts, but the effectivity of the drying step depends on the relative humidity (RH) of the ambient air during this period. The nuts will lose or absorb moisture to remain in equilibrium with the surrounding atmosphere. Moltzau & Ripperton (1939) already found that a RH of 60% or more is not suitable for the air drying of macadamia nuts, since moisture is then absorbed by the nuts. Air drying also requires space and is labour intensive. Sundrying or air drying does not reduce the moisture levels below 3,5% and these nuts must still be dried to below 1,5% (Grimwood, 1971). Moltzau & Ripperton found that sundrying provided nuts of excellent quality, but similar to nuts dried with artificial heat, the sundried kernels required 25% more cooking time to acquire the same degree of browness as airdried kernels (Moltzau & Ripperton, 1939). In addition, they maintained that artificial drying at temperatures up to 78°C had no negative effect on kernel quality. They manufactured a stack-dryer which handled the nuts mechanically, since they found that the kernels were not damaged in the process. However, studies conducted since then have revealed that kernels need to be handled with care since any damage from harvest till baking will show up as marks on the cooked kernels (Cavaletto, 1978; Hand, 1983; Grimwood, 1971).

Hamilton *et al.* (1980) and Cavaletto (1980, 1981) recommend lower drying temperatures, i.e. starting at 38°C and raising up to 52 or even 60°C. High moisture nuts must be dried initially at low temperature (ambient to 38°C). The maximum drying temperature which can be used depends on the kernel moisture. If too high drying temperatures (e.g. 51 °C with no pre-drying at lower temperature, kernel moisture 28%) was used, the kernels developed brown centres due to increasing reducing sugars (Prichavudhi & Yamamoto, 1965). They found that 1) macadamia nuts with a low reducing sugar content have the best roasting quality, 2) the brown centres of macadamia nuts, damaged by higher temperature drying, contain more reducing sugars than the light outer layer, and 3) temperature sensitivity of macadamia was moisture dependent. Physiological changes are given as the reason for this. At low temperatures, there is a general decrease in sugar concentration but at high temperatures the reducing sugar concentration increases because of enzymatic inversion of non-reducing sugars to reducing sugars. Brown-centering or localized browning is probably the net result of both moisture gradient in the kernels and increased enzymatic activity in the moist centre. They tested the hypothesis that enzymatic reactions are responsible for these changes, by blanching fresh nuts (97°C core temperature), before drying at 52°C. This reduced the browning, but the nuts roasted slightly darker than those dried at an initially low temperature. Thus the best regime is to dry the fresh nuts at a low temperature until the moisture content has been reduced to 8% or 6%, whereafter the kernels can be dried at 52°C or 60°C respectively. Predrying of only 4 days at ambient temperatures prevented browning (Cavaletto, 1980).

Hansen and Gough (1977) determined the moisture characteristics of macadamia kernels in relation to storage. They determined that the maximum safe relative humidity for storage corresponded to 11,8% moisture content for one batch and 12,4-12,0% in another batch. At a low whole nut moisture content (around 10%), the shell contains most of the water, whereas at a high whole nut moisture content (around 18%), the shell has approximately the same water content as the whole nut. The authors also evaluated a *Kappa Janes* moisture meter for the rapid determination of the overall moisture content of macadamia nuts. They found that the meter provided a rapid and convenient method for moisture determination, but that the use of the larger and probably more reliable cell of the meter still needs to be evaluated.

Joubert and Joubert (1969) recommend that nuts be stored uncracked if they have to be kept for extended periods since insect damage is greatly reduced. Infestation should always be reduced by keeping the storage area very clean. Low temperature storage is recommended for cracked nuts.

4. Decortication or cracking
Macadamia nuts contain between 35 and 40% kernel by weight (Hansen and Gough, 1977). It is usually recommended to grade the nuts into various sizes to improve the cracking efficiency, particularly where rollers are used (Grimwood, 1971). Factors such as the moisture contents of the nut, kernel and shell, the cracking principle, the adherence of the kernel to the shell and the method of drying have been mentioned as important in the recovery of whole macadamia kernels.

Moltzau & Ripperton (1939) describe the difficulty of cracking macadamia nuts, particularly the fact that too hard impacts needed to crack the shell, also result in shell fragments being pushed into the kernel, causing damage. Liang *et al.* (1988) determined the effect of freezing and notching on the recovery of macadamia nuts. The authors define failure deformation as the deformation to which a nut must be compressed for the shell to break. It was determined whether notching would be effective to reduce the magnitude of the failure deformation. Notching was able to increase the percentage whole kernels from 28% to 42% white half kernels remained constant at 46%. Uncracked kernels were decreased significantly from 12 to 6%. Freezing (-18C in a home freezer) alone before cracking, increased the recovery of whole kernels from 38% to 83% while half kernels decreased from 46% to 7%. The uncracked nuts remained high at almost 10%. The freezing apparently did not have an influence on the quality of the nuts, but the kernels were not roasted. Freezing and notching combined did not have any improved effect on kernel recovery. The authors make the following conclusions:

- Notching reduced the force and the deformation required to crack the nuts.
- Freezing alone of nuts before cracking, increased the whole and half kernel recovery rate and reduced the uncracked nuts.
- The best kernel extraction was obtained by combining notching and freezing. Whole and half kernels increased to 90% and uncracked nuts decreased to 2% from 14%.
- The major advantages of notching and freezing are higher kernel recovery rates and reduction in uncracked nuts. The capital investment and running costs would increase, but at US $10 per kg of kernel, the authors expect an economic gain.

Leverington (1971) mentions types of cracking machines. Examples are one designed on a rock-crusher principle, another using splined rollers which nip and crack the nuts, whereas a third has a split anvil with tapered holes. Dust and noise protection should be used in the cracking area. Macfarlane and Harris (1981b) developed an adjustable jaw cracker which allowed continuous cracking without excessive breakage after size grading and drying. Unfortunately, they do not give more information. A patent was awarded to Price (1985) for a nutcracker requiring an anvil and a device which cracks the nut by hitting it. An improvement on the cracker was also registered. This consisted of a specially formed anvil which surrounds the nuts to a large extent and a different impact device, shaped largely like the nut. These two devices apparently apply a more uniform cracking force to the nut.

Liang (1977) evaluated an existing macadamia cracking operation to determine the areas where largest nut losses occurred. They identified these as:

- the amount of kernel chips which are so small they are near impossible to recover
- kernels discarded in the bulk of shells due to imperfect shell and kernel separation
- mouldy and discoloured kernels.

The first problem could be reduced by improving cracker efficiency, the second by improving separation and the third by more frequent harvesting. They therefore developed a system which used an experimental cracker with smaller drum size (11,43cm diameter) than usual, since they hypothesized that this would reduce the time that the nut is exposed to deformation forces and thus reduce shattering. This apparently was the case and improved kernel recovery (no values given). In addition, they related kernel quality to shell moisture. In their system it appeared that shell moisture of between 7 and 12% seemed to give the best recovery. They also found that the amount of uncracked nuts increased with shell moisture. Too dry nuts resulted in broken kernels - thus an optimum must be found between reduced cracking damage of high moisture nuts and increased damage of low moisture nuts, but less uncracked nuts. Brine separation was also evaluated and proved to be advantageous above air separation if the processor was prepared to dry the kernels after flotation.

Liang (1980) designed a nut cracker which had a tapered mechanical feeding device which was used to sort the nuts into sizes and maintain a desirable nut orientation immediately before the nut is fed between the rollers of the cracker. The device needs to be designed to feed a single layer of nuts to the rollers. Although this feeder improved whole kernel recovery it would still appear that individual nuts respond differently to compression resulting in splintered or partially cracked nuts.

A prototype mechanical nut cracker was developed in Israel by Sarig *et at*. (1980). The cracker utilised a constant deformation rate. It consisted of a rotating drum (constant velocity) which pressed sized nuts against an eccentric plate for cracking. The nuts were positioned on the drum in a hollow and a counterpressure against the plate was effected by a variable air-pressure operated piston. The authors found that the best results were obtained in a moisture range of 7-12%. They shook the nuts to loosen the kernels (a practice which is not recommended by other authors due to damage to the kernels) and then passed them through the cracker at 7,6% moisture. The nuts were dried from 14% to 7,6% moisture at 65C for 24h. They divided the nuts into whole, half kernels, other fractions and uncracked nuts. They obtained 75% whole or half-kernels, 15% fractions and 6% uncracked nuts, which apparently is better than other values reported in literature.

Patel (1982) developed a nutcracker using two laser beams. One laser beam (high power cw laser beam, e.g. C02) cuts a thin groove around the nut while the second beam (low power) is directed collinearly to the direction of the first beam. This second laser has a different wavelength than the first and is of such low power that it does not cause disintegration of the nut meat. The reflectivity of the second beam is different for meat and shell, resulting in a means to detect the stage when the first high power beam has cut through the shell. A thin stream of nitrogen is used to blow away the debris formed by the cutting action of the first beam. The nuts to be cut are mounted on a holder which can be rotated to place the nuts in the path of the laser beam.

Coward *et al*. (1974) found that the pretreatment (drying) of the nut was of utmost importance for the efficient removal of the nut shell. Higher moisture contents of nuts resulted in less broken nuts than drier nuts: a compromise needs to be reached between moisture content for good yield on whole cracked nuts and moisture content for optimal storage quality. According to Moltzau and Ripperton (1939), nuts should optimally be cracked at 3,5% moisture and then dried to 1,5% moisture at an initial temperature of about 44°C and thereafter up to 77°C, before cooking. The lower temperature should be maintained until all the moisture taken up by the nuts during grading, has been removed. Cracks in the nut resulted in pieces of shell cutting into the nut during cracking (Coward *et al'*, 1974). They devised a machine which cuts a groove around the circumference of the nut after which the two halves of the nut are forced apart by wedges. The machine produced approximately 90% whole kernels at 45 kg/hour. The authors are of the opinion that although the machine has a low throughput, the improved yield of whole kernels makes it a viable proposition.

Liang *et al*. (1989) evaluated a curing system to improve kernel recovery. The recommended maximum allowable temperature of 49°C (Prichavudhi & Yamamoto, 1965) is used in order to find a compromise between curing time and product quality. Since nuts in a batch drier run the risk of creating a mixture of under- and overdried nuts, the authors developed a semi-continuous batch drier with a specially designed *wire gate* which released all nuts of desired moisture content without ejecting underdried nuts. They also found that the temperature gradient along a drying column was a suitable indirect parameter for monitoring moisture content for known drying air conditions.

Tang *et al*. (1982) evaluated flash drying of macadamia nuts to improve yield on cracking. According to the authors, the shell moisture content of nuts with a moisture of 3% would be 10%, which made the shell too pliable to break and increased the amount of partially cracked nuts. They found that the initial moisture content of the nuts immediately prior to flame drying was important to kernel recovery. This could pose problems if a large amount of nuts need to be brought to a specific desired moisture. Apparently predrying the nuts at 50°C for 36h (which decreased the moisture contents from 25% shell moisture and 22% kernel moisture down to 6% moisture of both kernel and shell) followed by 1,5 minutes of flaming yielded an average of whole kernels of 90%. No burnt kernels were observed.

In a study on the influence of moisture on macadamia kernel recovery, Liang *et al*. (1984) developed a model which related the kernel and shell moisture to the diameters and failure deformations of the nut and kernel. The failure deformation was defined as the maximum total deformation which the kernel or nut shell can withstand without failure or cracking. The clearance between the kernel and the shell was also brought into consideration. They found that larger nuts and higher kernel moisture could withstand higher nut deformations. If the clearance between the kernel and the shell were negligible, the probability that the kernel would break on cracking, would be great. The difference between the failure deformation of the shell and the kernel appeared to be a dependable indicator for predicting the effect of moisture and the compression magnitude on kernel damage. This value is process and equipment independent and confirmed that the kernel would only be damaged if the failure deformation of the whole nut exceeds that of the kernel. However, the application of the mentioned value is limited, since the failure deformations of the shell and the nut are very random in nature.

The waste shells have been used as fuel in Hawaii. Apparently macadamia shell flour (300 mesh) can make a good substitute for coconut shell flour as a filler in the plastics and adhesives industry (Leverington, 1971).

Information on macadamia processing equipment and in particular cracking equipment, was obtained from the United States. A report is contained in Appendix 1. It is clear that the change in the macadamia industry worldwide also has had an influence on the status of the equipment manufacturers. Only two types of crackers are manufactured, i.e. roller- and the Shaw-cracker.

5. Separating and grading

Cracked shells and kernels or their fragments must be separated (Leverington, 1971). In Australia this is usually done on vibrating screens with or without blowers, which separate the nuts into whole or half kemels, broken kernels or chips (Leverington, 1971). Mouldy or insect-damaged kernels are removed by hand-sorting. In Hawaii electronic sorting by kernel colour differences is done (Anon, 1982). This manner of sorting has reduced the manpower required by 50%, with a simultaneous increase in production of 50%. Quality grading by water flotation or pneumatic means (air flotation), is advocated.

Grades of macadamia kernels have been defined based on water flotation, which separates the kernels according to their behaviour in solutions of differing SG (see Quality Factors). Air flotation for separation is also used and eliminates the need for further drying before cracking (Grimwood, 1971).

6. Roasting

According to Moltzau and Ripperton (1939), macadamia nuts should be at a moisture content of 1,5% or below before roasting, to provide the best quality product. High moisture kernels have a soft texture and brown more rapidly during roasting (Cavaletto, 1980). Dela Cruz *et at*., (1966) recommend that the moisture of the raw kernels be reduced to approximately 1% before roasting in order to have a moisture content of 1% after roasting, since this moisture content proved to result in the most stable product. Similar to raw kernels, the moisture content and storage temperature influences the shelf-life of the product. The lower the moisture content and the storage temperature, the longer the shelf-life.

Since nuts of *M. tetraphylla* usually have a higher sugar and lower oil content than those of *M. integrifolia,* they have different processing characteristics (the first browns faster and is less uniform in colour) and should therefore be processed separately (Grimwood, 1971; Cavaletto, 1981). It was found that when the specific gravity of nuts was greater than 1 (lower oil content), the total sugar increases and is highly correlated with specific gravity (Cavaletto, 1980). A high sugar content and high specific gravity are associated with a dark brown roasted colour and a hard and tough texture.

Mason and Wills (1983) have evaluated the use of flotation to predict the roasting quality of Australian macadamia nuts. They found that sensory acceptability of the roasted nuts decreased as the specific gravity (SG) increased: 80% panelists found nuts with SG ,00 acceptable, 50% still accepted nuts with SG between 1,00 and 1,025, whereas nuts with SG l,025 were not acceptable. However, since they manually harvested the nuts used in the experiment and treated them under optimal conditions, they doubt the applicability of the flotation method in practice, where nuts lie on the ground for up to four weeks. The flotation method should still be statistically evaluated under field conditions before general acceptance.

According to Leverington (1971) cooked macadamia nuts are more stable than raw nuts and have an enhanced flavour. However, Cavaletto *et al.* (1968) found that the largest deterioration in nut quality occurred after cracking (see Product Quality and Storage). In Hawaii, the kernels are all deep-fried (batch or continuous) in a highly refined hydrogenated coconut oil for 12-15 minutes at 135°C (275 5°F) for *M. integrifolia* and 127°C (260°F) for 12 minutes in the case of *M. tetraphylla* (Grimwood, 1971; Hamilton *et at.,* 1980). The latter has a higher sugar content and a higher temperature may result in unacceptable browning of the kernels (Leverington, 1971). The kernels are removed from the oil when they have reached the desired brown colour and are separated from the oil by draining or centrifugation and cooled in cold air as quickly as possible to prevent overcooking.

Cavaletto and Yamamoto (1971) evaluated the quality of roasting oil on roasted macadamia nut quality. They found considerable exchange of oil between the coconut oil and the macadamias: the oil composition changed from 100% coconut to containing 21% macadamia oil after two weeks and 77% after 13 weeks. The coconut oil deteriorated relatively slowly, which may be due to the stability of the macadamia-coconut oil mixture.

Moltzau & Ripperton (1939) recommend a general oven roasting temperature 135°C (275°F) for 40-50 minutes with frequent stirring of the nuts to produce even heat transfer. According to Grimwood (1971), oven roasting is done at an air temperature of 163 - 191°C for 15-20 minutes in a rotating stainless steel drum and Hamilton *et at.* C1980) recommends 176°C for 20-30 minutes in a rotary oven. Rosenthal *et al.* (1986) evaluated two macadamia varieties found in Israel, i.e. *Yonik* and *Beaumont,* for their chemical composition and its influence on quality. They recommend that the two cultivars be kept separate, since the *Beaumont* variety contains more sugar and would brown more extensively if roasted too long.

Leverington (1961) found that early rancidity developed if the nuts were fried in oil for less than 12 minutes. In their experiments, they evaluated frying and oven roasting. The oven roasted nuts were inferior in appearance, but more stable during storage (longer than 12 months at room temperature). A heat treatment of less than 12 minutes was insufficient to prevent rancidity. In the case of the oil-frying method, early development of rancidity was ascribed to difficulty in efficient control of fryer temperature as well as the degradation of the frying oil.

Due to the above mentioned development of rancidity, dry roasting of macadamia kernels in an infrared oven with rotary perforated drum was developed (Leverington, 1971). The same temperatures as above (135°C for *M. integrifolia* and 127°C for *M. tetraphylla)* were used, but the roasting time was increased to 25 minutes.

Macfarlane and Harris (1981 a; b) used a small expeller in Malawi to extract oil from macadamias with the aim of using this for frying of the nuts. Coconut oil has to be imported into Malawi at great expense. It was possible to recover 85% of the total available oil with one pressing and 90% with a double pressing. Apparently the presscake is high in lysine and sulfur-containing amino acids, which together with its high nitrogen-free extract and low crude fibre content, should make the presscake a valuable feedstock for nonruminants.

Crain and Tang evaluated the volatile components of roasted macadamia nuts (Cavaletto, 1980). Most of the components found in the macadamias are also present in other roasted nuts. The only major compound unique to macadamias is methyl sulfide. The authors suggest that the loss of typical macadamia flavour on over-roasting is due to volatilization of methyl sulfide. Over-roasted macadamia nuts taste more like other nuts.

7. Grading

After roasting, the nuts are again sorted into grades according to colour (Leverington, 1971). Light coloured nuts are destined for retail packs, darker kernels for confectionery or chopped nuts and the darkest are rejected.

8. Salting and packaging

Cooled nuts can be salted whereafter they are packed in cans, jars or flexible pouches and sealed under vacuum or nitrogen (Leverington, 1971). Grimwood (1971) recommends the coating of the roasted kernels with coconut oil to improve the adhesion of salt and provide an attractive shiny appearance. Low temperature storage should improve the keeping quality of the nuts (Allan, 1984). Moltzau and Ripperton (1939) recommended the salting of kernels at a lukewarm temperature after cooking, and found that a 15% water solution of gum arabic or a low-melting oil (e.g. 32°C) can be used effectively as adhesive for the salt.

The water activity (aw) of products is a measure of the water available for microbial growth and is indirectly related to moisture content. Usually, the lower the aw, the more stable a product will be during storage from a microbiological point of view; however, rancidity or physical changes may still occur. The lower the aw of the product, the less permeable to water should the packaging be (Hand, 1983), thus moisture movement into the package should be zero or as low as possible (Grimwood, 1971). Macadamia nuts should be packed as soon as possible after roasting to also prevent absorption of moisture.

The off-flavour of macadamias was thought to be caused by oxidation after processing (Grimwood, 1971). This problem has been greatly reduced by using appropriate packaging methods which exclude oxygen. Deterioration of quality has, however, also been ascribed to the action of lipid enzymes.

Cavaletto and Yamamoto (1971) evaluated the use of antioxidants in the salt mixture on the prevention of rancidity in stored nuts packed under different levels of vacuum. They used dry roasting (161°C for 15 minutes) to prevent any influences of roasting oil components. The results indicated that the use of antioxidant (20% BHA, 20% BHT) is very effective in extending the shelf-life of roasted macadamia nuts and was better than vacuum packaging.

Flexible packaging was compared to storage in glass and cans with reference to sensory quality and moisture content (Cavaletto and Yamamoto, 1968). The packaging materials used, with their water vapour transmission rate (WVTR) in brackets, were:

- 30 lb opaque superglaze/0,7 mil polyethylene /0.35 mil aluminium foil/2 mil polyethylene (WVTR 0,01-0,02g/100 sq. in./24h at 90% RH and 100F)
- 195 RS2E cellophane/0,7 mil polyethylene/0,35 mil aluminium foil/0,7 mil polyethylene (WVTR 0,01-0,02g/100 sq. in./24h at 90% RH and 100F)
- 1 mil nylon/0,11 mil Saran/2 mil polyethylene (WVTR 0,15-0,18g/100 sq. in./24h at 90% RH and 100°F)
- 0,5 mil Mylar/2 mil polyethylene (WVTR 0,20-0,24g/100 sq. in./24h at 90% RH and 100°F)
- 195 K 204 cellophane/2 mil polyethylene/0,2 mil Saran (WVTR 0,08-0,10g/100 sq. in./24h at 90% RH and 100F)

The authors found that no staleness developed in foil-packed macadamias in the first 5 months, but flavour loss was evident after 9 months storage. Kernels in the polyethylene/nylon film were rated significantly lower than all other samples: this already appeared at 3 months and they were rancid after 9 months. The two cellophane-containing materials were not significantly different from the control. The other films could not prevent loss of crispness of the nuts.

The increase in moisture content of the macadamia nuts correlated with the water vapour transmission rate of the films. The authors conclude that the suitability of a packaging film can be evaluated by comparing its WVTR with those used in the experiment, since the moisture barrier capacity is the most important criterion for selection. A shelf-life of 6-7 months can be expected if the material has a WVTR of less than 0,02g/100 sq. in./24h at 90% RH and 100°F.

Bowden and Reeves (1983) investigated the packaging of raw Australian macadamia nuts destined for export. These nuts developed rancid flavours and showed excessive browning during roasting. They evaluated four types of packaging film, namely

- Nylon (25)/suriyn (10)/LD polyethylene (80)
- Biaxially coated PVDC-orientated nylon/LD polyethylene (200)
- Biaxially coated PVDC-orientated metalized nylon (15)/LLD polyethylene (100)
- Biaxially orientated nylon (25)/aluminium foil (18)/LLD polyethylene (76)

All the products were vacuum-packed, but the latter was also packed under atmospheric pressure. Factors such as sensory quality, peroxide value, reducing sugars and moisture content were analyzed over a storage period of 16 months at ambient conditions. The authors found that raw kernels packed in biaxially orientated nylon/aluminium foil/LLD polyethylene showed virtually no deterioration under Brisbane conditions for at least 18 months. The nylon/suriyn/LD polyethylene film normally used was inadequate to preserve product quality. The kernels also showed significant deterioration in the other two films during long-term storage. These two films can however be used for short-term storage (up to 4 months).

Storage temperature is a very important factor for macadamia quality: the lower the storage temperature, the longer the shelf-life of the product (Cavaletto *et al.*, 1966). At a temperature of 1,5°C, vacuum-packed raw kernels (2,3% moisture content) had a shelf life of up to 16 months, but storage at 37°C resulted in rapid deterioration of kernel quality and storage life of less than 8 months. At higher moisture contents (e.g. 4,3%) the storage life was even shorter at the above mentioned temperatures. Increasing storage temperatures resulted in increasing darkening of the kernels during storage. Higher storage temperatures and increasing moisture contents also resulted in less total sugars, but increasing reducing sugar contents. The free fatty acids also increased with temperature and moisture contents. The authors ascribed the negative reactions to enzymatic reactions in the kernels. They recommend storage at a moisture content of 1%, or low temperatures (frozen) if higher moisture contents occur.

QUALITY FACTORS

Various characteristics of macadamia nuts and the handling of the nut during processing, are interrelated factors which determine the quality of the final product. Negative factors occurring during processing will have an additive effect on the reduction of product quality.

Ripperton *et al.* (1938) and Moltzau and Ripperton (1939) already determined quality factors of nuts as related to age, trees and cultivars with the aim of establishing standards for the macadamia producer and processor. The authors evaluated the shelled roasted product and applied the results to nuts from commercial orchards. They found that the specific gravity (SG) of the macadamia kernel has a high negative correlation with percentage oil of the nut and can be used as a quick method to determine the oil content.

The specific gravity is also related to the roasting quality of the kernels as follows (Grimwood, 1971):

- Grade 1: SG
- Grade 2: 1 SG 1,025
- Grade 3: SG 1.025

Grade 1 gives the best roasting quality and is used in commercial packs. The harvest from various trees and areas in Hawaii were evaluated and results are given. The grading can also be used during processing of nuts and provision should be made to remove the 8-10% moisture taken up by the kernels during immersion in the solutions used during grading (Moltzau and Ripperton, 1939).

New macadamia cultivars should be evaluated according to various criteria and compared with similar data from existing good performers in order to establish an industry which can produce consistent high quality (Cavaletto, 1978; 1981). These criteria have been described before (1. Harvesting).

Leverington (1971) discusses the macadamia nut industry with regard to cultivars, evaluation of selections, nut quality and processing. It is a well-established fact that the oil content and specific gravity of the nuts can be used to predict the quality of the roasted product. Kernels of low specific gravity and high oil content develop a light golden colour, a mild nutty flavour and crisp texture against dark brown, scorched and hard tough consistency from kernels of high specific gravity and low oil content. Grade 1 nuts have a specific gravity and have good roasting properties. In Australia, nut processors have strict standards with regard to size and blemishes, to apply to nuts before acceptance. Nuts should be at least 1,91 cm in diameter and free of blemishes and insect damage. They also purchase on a "sound kernel recovered" basis, which has resulted in an increase in grower standards.

More extensive quality criteria for nuts are described by Leverington (1971), Cavaletto, (1981), and Hobson, (1976a, b):

Moisture content

At harvest, the moisture can vary from 10 - 29%. The processor should know the moisture content of the macadamias to evaluate the price he will pay. Moisture determinations may be done by various techniques which differ in accuracy and speed.

Shape

Spherical or near to spherical nuts are preferred for their better cracking properties. Nuts of ellipsoidal or other shapes present difficulties in mechanical cracking. Doubles (twin nuts) are also eliminated.

Size

Size ranges should be small and between 1,91 and 2,79cm in diameter, but this differs from processor to processor. According to Cavaletto (1981), the minimum size should be in a range from 1,6 to 2,2cm in diameter. Too small nuts result in high handling costs and large percentage shattered nuts after cracking, due to too small an air gap between kernel and shell. Too large kernels will result in heat penetration problems and too few nuts per package. The ideal nut size corresponds to 99 nuts per kg (45 nuts per pound). In general, *M. integrifolia* produces larger kernels than *M. tetraphylla* (Moltzau and Ripperton, 1939).

Shell thickness

Shells should be of moderate thickness: too thin shells shatter easily resulting in kernel damage. Thick shells crack easily, but low kernel-recovery is found.

Kernel recovery

Lowest acceptable kernel recovery is 33%, but 38-42% is desirable. It is important to note that shells should be of uniform thickness for improved recovery. The value of in-shell nuts can be determined based on the differences in specific gravity of nuts of uniform moisture, after spoiled, mouldy or badly discoloured have been discarded (Cavaletto, 1981).

Kernel mass

Between 2,5-3g is the most desirable size with a range of 2-4g. Larger kernels may break during cracking.

Spoilage

Kernels are most commonly spoiled by mould growth, insect infestation and rodent damage. The percentage spoiled nuts are determined before acceptance.

Kernel colour

Freshly cracked kernels should be white to cream-coloured. Some greying on the rounded portion is allowable, but dark brown discolouration is unacceptable. *M. integrifolia* kernels usually roast to an even light colour, whereas *M. tetraphylla* are often variable in colour. Dark varietal rings around the centre of the kernel and colour differences between the top and the bottom should be minimal. These defects are apparently genetically determined and such plants should be discarded during cultivar selection (Cavaletto, 1981).

Kernel quality (oil content)

Kernels should preferably have a specific gravity less than 1. Usually *M. integrifolia* kernels perform better than *M. tetraphylla* in this regard. Moltzau and Ripperton (1939) developed a specific gravity method for this evaluation.

Kernel flavour and texture

Flavour should be delicate, mild and uniform and the texture tender and crisp. Again *M. integrifolia* performs better than *M. tetraphylla*. The latter often have a firm, hard texture and sweet but variable flavour. Differences become more pronounced after roasting.

Product quality and storage

Cavaletto (1981) mentions moisture content, flavour, colour, texture and defects as important criteria for final product quality and storage life evaluation. The final moisture content should be 1,5% or lower and kept at that level through appropriate packaging such as cans or flexible packaging with very low water permeability rates. The development of a good roasted flavour and prevention of off-flavours are very important aspects of macadamia processing. Too high moisture contents, storage temperatures or storage periods and combinations thereof, can result in the development of staleness or rancidity. Roasted colour is closely related to flavour and is related to cooking time and temperature. Colour defects may, however, also occur naturally and must be sorted out. Low moisture content is associated with a crisp texture and must be maintained.

Macadamia kernels are highly susceptible to enzymic rancidity and enzymes must be inhibited by heat treatment (Leverington, 1971: Allan, 1984). The flavour of the nuts changes during storage from freshly cooked to bland (neutral) to slightly bitter and then stale.

The intense browning which occurs in high-moisture nuts dried at elevated temperatures, is due to enzymic reactions in the nuts which cause high reducing sugar contents (Prichavudhi & Yamamoto, 1965) or naturally occurring differences in sugar content (Rosenthal et al,, 1986). Immature kernels can contain up to 10-16% sugar which decline to 3-5% in normal mature kernels - thus the correct harvest maturity is also of crucial importance. Kernels should be at moisture %, since a higher moisture content resulted in enzymic production of reducing sugars and free fatty acids in raw kernels and hydrolytic reactions in roasted nuts (Prichavudhi & Yamamoto, 1965: Cavaletto *et at.*, 1966; Dela Cruz *et al.*, 1966; Rockland, 1966). Prichavudhi & Yamamoto (1965) found that the total and reducing sugar content of freshly fallen macadamia nuts decreased during low temperature drying. The authors showed that:

- macadamia nuts with low reducing sugar content have the best roasting quality
- the brown centres of nuts damaged by high temperature drying, contain more reducing sugars than the light outer layer
- temperature sensitivity of macadamia nuts is moisture dependent.

Too rapid processing resulted in lipolytic enzymes surviving in the centre of the kernels, which led to rancidity (Cavaletto *et al.*, 1966; Dela Cruz *et at.*, 1966). Rancidity can be prevented by the use of antioxidants, but, provided that the recommended manufacturing and packaging procedures are followed, the use of antioxidants are unnecessary (Leverington, 1971). Rosenthal *et al*. (1986) found that the cultivar *Yonik* had a more stable oil composition than the *Beaumont* cultivar. The *Beaumont* cultivar contained more linoleic acid, which would make its oil more susceptible to oxidation.

Cavaletto *et al* (1968) evaluated in-shell storage on the quality of processed macadamia nuts. They stored air-dried macadamias (3,8% moisture) under ambient air; macadamias dried to 1,2% moisture under ambient air or nitrogen and roasted nuts (1,2% moisture) under vacuum at temperatures of -18°C and 38°C. At various storage intervals (1,3,6,9 and 12 months), the air-dried nuts were dried, cracked and roasted. The nuts were evaluated according to sensory characteristics, moisture, free fatty acids, oil, reducing sugars and total sugars. The air-dried nuts stored in-shell (3,8% moisture) for 6 months or longer were in general of lowest quality. However, all nuts deteriorated during storage, particularly the roasted stored nuts. The chemical analyses were not sensitive enough to show the changes identified by sensory analyses. The authors found that roasted nuts prepared from nuts with 12 months in-shell storage at 1,2% moisture had the same roasting quality as nuts with no in-shell storage. Nitrogen made no significant difference. The authors conclude that storage in-shell was the most stable and the highest loss of quality occurred after cracking.

According to Rockland (1966) kernel stability was nearly independent of moisture content during storage at 2°C. At 1% moisture, raw and roasted kernels kept the same quality during storage at 38C for 16 months. The higher the moisture content of both raw and roasted nuts, the shorter the shelf-life at 38C (8 months at 2,5% moisture and 4 months at 4% moisture). The author makes the following general conclusions:

- Roasted kernels maintained their quality better than raw kernels.
- Kernel darkening closely paralleled flavour deterioration.
- Kernel stability increased with decreasing moisture content.
- Kernel stability decreased with increasing storage temperature.
- Quality changes were essentially identical for kernels stored in light or darkness.

Beuchat and Worthington (1978) analysed the oil content and fatty acid composition of thirteen different tree nuts. Macadamia nuts contain a fairly stable oil with an unsaturated to saturated fatty acid ratio of 6 which compares to that of the chestnut and hickory, but is slightly lower, and the oil probably more stable, than almonds and pecan nuts.

According to Rosenthal *et al.* (1984) the macadamia cultivar "Yonik", which grows in Israel, has a stable oil. The lipid composition of the oil, i.e. a low linoleic acid content (C18:2), rather than a natural antioxidant, is responsible for this stability. The development of rancidity during long-term storage of nuts was ascribed to lipolytic decomposition.

Another very important factor related to the moisture content of the nuts, is the development of moulds during storage (Hand, 1983). Beuchat (1978) determined the relationship of water activity (aw) to moisture content in 13 tree nuts, one of which were macadamias. Since nuts are often incorporated into foods without receiving commercial sterilization treatments, the occurrence of aflatoxin-producing moulds on them are of concern. Moulds also detract from the appearance of the product. Data for aw and moisture contents of nuts were plotted on an isotherm curve (Fig. 1). The aw corresponding with a particular moisture content (for macadamias containing 73,2% oil and 9,6% protein) can be determined by placing a ruler in line with the specific moisture on the top and bottom scales. The moisture content of nuts at a given aw depends on the amount of protein and carbohydrate in the nutmeat. Treatment during and after harvest will also affect the relationship between the two physical characteristics. The authors found that for pecan nuts there was an inverse relationship between oil content and moisture content of the nuts. Thus at lower oil content (higher moisture) the nuts would have a higher equilibrium aw. They recommend that unless the oil content is also taken into account, the moisture content of pecans and other nut meats may be a poor index of aw and of the potential risk of fungal spoilage. The safe aw of 0,70 at 25C recommended by the FDA as a safe moisture level for nut meats corresponds to a moisture of approximately 3,9% in the macadamias used by the researchers. The moisture content of 1,5% recommended for the storage of macadamias, therefore lies well below this limit.

Fourie and Basson (1989) determined the correlation between peroxide values of stored pecans, macadamias and almonds (not packed, 30°C, 55% RH) and the onset of rancidity as detected by sensory evaluation. From the results of their study they conclude that changes in peroxide values can be used to predict detectable rancidity in nuts without using a taste panel, provided that the threshold peroxide value for rancidity in the nut is known.

STANDARDS AND SPECIFICATIONS

Standards and specifications are necessary to maintain consistent quality and satisfy consumer expectations. Various criteria which have been discussed already are combined in different standards of companies and countries which export and import macadamias.

South African standards as published in a SAMAC newsletter (SAMAC, 1990) are:

- Well developed clean dry kernel free from loose extraneous material, mould, decay, infestation, insect or rodent damage, hollow centres and off-odours/flavours with no shell, scar or discolouration.
- No chemical residues.
- Less than 20ppb aflatoxin.
- Less than 200 coliforms per gram product.
- No *E. coli*.
- Peroxide value less than 5Meq/kg
- Free fatty acids less than 1,5%.
- Moisture content of raw nuts after processing less than 1,5%.

The standards for macadamia kernels of the 1991 season published by SAD are:

Size:

0	+22mm
1	19-22mm
2	12-19mm
4	9-12mm
5	6-9mm

Infestation: none
Moisture content: 1,5% max.
Roasting defects: 2,5% max.
Vacuum (with N2): 180-220mm Hg
Aflatoxins (Bl, B2, Gl, G2): 4ppb max with Bl 2ppb max.
Peroxide value: 5 Meq / kg max.

Free fatty acids: 1,5% max
Coliforms: 200/g max
Colour: cream-coloured
Appearance: Free of dust and no oiliness on surface

Nuts for export should have the following standards (Oosthuizen *et at.*, 1989):

- Number of nuts/kg: between 120 and 170.
- Percentage kernels: more than 33%.
- Kernel mass between 2 and 3g.
- Oil content: more than 75%.

Australian specifications for export nuts are given by Anon (1980) (see Table 4). More recently the following standards, nutritional data and approximate composition were acquired:

Macadamia Magic, (1991)

Style 0: "Super Macs" contains no less than 95% large whole kernels. This style is perfect for gourmet snack packs or for handmade confectionery. Size range upwards of 22mm.
Style 1: 'Wholes" contains at least 90% whole kernels. Are specialty product for snack packs and chocolate coating. Size range 17mm minimum.
Style 2: 'Wholes and halves" contains at least 50% whole kernels. The most versatile product suitable for snack packs, confectionery and bakery products. Size range upwards of 13mm.
Style 4: 'Tidbits" contains at least 80% half kernels and no more than 5% wholes. Excellent for use as an ingredient in bakery products, confectionery and small snack packs. Size range upwards of 9mm.
Style 6: "Chips" is suitable for confectionery, ice cream, baking, topping and as an ingredient in other food preparations. Size range 5mm to 9mm.
Style 7: "Bits" are used as topping in breakfast cereals and in fine food preparations. Size range 3mm to 6mm.

Nutritional data (per l00g):

Calories	727
Cholesterol	0mg
Vitamins A, I, U	21mg
Vitamin C	0mg
Thiamine (B1)	0,22mg
Riboflavin (B2)	0,12mg
Niacin	1,60mg
Calcium	53mg
Iron	2mg
Phosphorus	241 mg
Magnesium	149mg
Potassium	409mg
Sodium	<10mg

Approximate composition (%):

Moisture	1,2
Protein	9,2
Natural oils	76,4
Carbohydrates	10,0
Ash	1,8
Crude fibre	1,4
Total	100,0

Blue Diamond (1991)

Blue Diamond Growers is in partnership with MacFarms International, Inc., which is a well-established company with macadamia orchards in Hawaii, Australia and Costa Rica. Together the two firms market over 30% of the macadamias available worldwide.

Standards set by them are:
Style 1: 90% whole
Style 2: 50% whole, halves and pieces larger than 7,8mm.
Style 4: 50% halves, pieces larger than 6,3mm.
Style 6: Smaller than 7,8mm, but larger than 4,7mm.
Style 8: Smaller than 2,3mm.

Dry roasted diced 24/larger. larger than 9,4mm.
Dry roasted diced 24/8: smaller than 9,4mm and larger than 3,13mm.
Dry roasted diced 8/0: smaller than 3,1 mm.

SOUTH AFRICAN INDUSTRY

The South African macadamia industry generally uses the processing methods as described in this report, but specific conditions differ.

During discussions with producers and processors various problem areas were mentioned which are briefly discussed below in order of occurrence during processing. This summary does not claim to be exhaustive, since any optimisation process is iterative. Some of these problems can be addressed in the production process as indicated, while others will have to be investigated in experiments which are planned for the future.

- Onion ring, i.e. brown discolouration on one half of the kernel. This phenomenon apparently does not always occur. The only reference made to this problem in literature is that it is due to genetic characteristics of the tree and such material should be discarded during selection. It could, however, be investigated whether the browning may be a result of growth conditions in trees which are susceptible to this phenomenon.
- Nut quality is affected while lying on the ground. This is mainly ascribed to stink bug damage, since the nuts may not be sprayed within 30 to 100 days of harvest depending on the pesticide used. It can be investigated to what extent Cypermetrin (or Aldicarb) penetrates the husk and shell and possibly presents health risks if used closer to the harvest date than presently prescribed. Damage due to moisture can be prevented by keeping the areas under the trees clean, picking up the nuts frequently, dehusking them within 24 hours **or less** and drying them to less than 1,5% moisture as quickly and carefully as possible to prevent browning.
- Mechanical harvesting has been evaluated, but it is very important that the correct maturity stage has been reached before this is used, since nuts would otherwise not have the right oil and sugar contents and possibly be underdeveloped.
- Nuts-in-shell and cracked nuts are easily damaged. This shows up as marks and unevenly coloured areas on roasted nuts. The most probable unit processes where damage may occur, are during any transport process, dehusking and cracking, but may also be influenced by drying and storage conditions. Nuts should, therefore, always be handled with care. Options to decrease damage will have to be investigated during optimisation of nut processing.
- Care should be taken that drying of high moisture nuts takes place at low temperatures (ambient to 38°C) until the moisture content is 8 or 6%, whereafter the temperature can be increased to 52°C or maximally 60°C.
- Storage of nuts should be done at a low temperature if possible to preserve sensory quality. Insect infestation and relative humidity which result in an increase in kernel moisture level, should be prevented. The optimum storage relative humidity should be determined to be in equilibrium with the water activity of the kernels.
- Nuts should always be bought by processors on the basis of standardized quality specifications. These have to be set in accordance with the local and international market and consumer needs. Minimum standards should ideally be coordinated throughout the industry.
- The efficiency of macadamia crackers used locally is poor, i.e. the percentage whole nuts is low. This is one of the most important criteria for nut quality and price. This problem was investigated on a very limited scale. The cracking efficiency of three crackers used locally are given in Table 5. These values only present an indication of yields, since the samples taken were very small. However, it can be seen that the percentage half kernels is high and the whole kernels are low. In addition, high percentages of broken kernels occur.

This problem should be addressed as soon as possible. Since the literature as well as practical experience has shown that achieving a high degree of whole nuts is a complex process, data on the performance of existing crackers under controlled conditions should first be gathered. Improvements can then be evaluated.

Table 5: Yield of kernel* after cracking from three South African processors

Identification	**Processor 1**		**Processor 2**		**Processor 3**	
	g	**%**	**g**	**%**	**g**	**%**
Total yield						
Kernel* (whole)	20,45	6,1	181,52	7,9	171,52	5,6
Kernel* (halves)	91,57	27,2	354,19	15,4	632,97	20,7
Kernel* (fines)	9,22	2,7	81,69	3,6	277,05	9,1
Not/partly hulled	23,23	6,9	179,9	7	111,7	3,7
Hulls	192,7	57,15	1506,69	65,4,8	1868,65	61,0
Total	337,15	100,0	2304,1	100,0	3061,9	100,0
% Kernel/nut	337,15	36,0	2304,1	26,8	3061,9	35,3
Kernel yield						
Kernel* (whole)	20,45	16,9	181,52	29,4	171,52	15,9
Kernel* (halves)	91,57	75,5	354,19	57,4	632,97	58,5
Kernel* (fines)	9,22	7,6	81,69	13,2	277,05	25,6
Total	121,24	100,0	617,40	100,0	1081,54	100,0

Roasting of macadamia nuts should be done according to methods developed specifically for the local macadamia cultivars. No conclusive evidence could be found in literature that the *Integrifolia* group of cultivars is better than *Tetraphylla* or its hybrids. *Integrifolia* appears to produce nuts of more uniform size and roasting quality, but studies have shown that *Tetraphylla* can also be roasted satisfactorily and may even taste better than *Integrifolia*. Since acceptability of a product to a consumer is a variable which can be influenced by factors such as taste, culture, income, preset ideas, other products, etc., a market for both cultivars could be envisaged. Thus until proven unnecessary, it would be advisable to keep cultivars (or at least *Integrifolias* and *Tetraphyllas)* separate and evaluate the acceptability of the cultivars in a controlled way.

Packaging materials for the final product should be selected according to low moisture and O_2-permeabilities to prevent moisture increases or oxidative rancidity. The latter can be reduced by low temperature storage, N_2-flushing (and/or antioxidants if necessary).

REFERENCES

Allan, P. (1984) Report on first Australian Macadamia Research Workshop: Marcoola, Queensland, 12-16 September 1983. *The Citrus and Subtropical Fruit Journal Aug.: 6-8,* 10-12.

Anon. (1978) Nuts and candied products. *Zuckeru. Susswarenwirtschaft 31(12):435-438.* (German)

Anon (1980) Macadamia nuts. *Gordian* 80(10):244-245. (German)

Anon (1982)Electronic colour sorting boosts nut production 66%. *Food Engng* 54(5): 150.

Beuchat, L.R. (1978) Relationship of water activity to moisture content in tree nuts. *J. Food* Sci 43:754, 755,758.

Beuchat, L.R. & Worthington, R.E. (1978)Technical note: Fatty acid composition of tree nut oils. *J. Food Technol.* 13:355-358.

Bowden, R.P. & Reeves, R.K. (1983) Packaging of raw macadamia kernels, pp 287-291.

Bridge, R.E. & Hilditch, T.P. (1950) The seed fat *of Macadamia ternifolia. J. Chem-Soc.-.2396-2399.*

Cavaletto, C. (1978) Quality evaluation of new macadamia varieties, pp 42-51. (Incomplete reference)

Cavaletto, C. (1966) Assessment of in-shell damage to macadamia kernels, pp 65-74. (Incomplete reference)

Cavaletto, C. (1980) Macadamia Nuts. In *Tropical and Subtropical Fruits.* (Nagy, S & Shaw, P.E., eds.) AVI Publishing Inc., Westport, Connecticut, pp 542-562.

Cavaletto, C. (1981) Quality evaluation of macadamia nuts. In *Quality of Foods and Beverages: Chemistry and Technology* (Vol 2) (Charalambous, G. & Inglett, G.; eds.). Academic Press, New York. pp 71-82.

Cavaletto, C; Dela Cruz, A; Ross, E. & Yamamoto, H.Y. (1966)Factors affecting macadamia nut stability: 1. Raw kernels. *Food Technol.* 20(8):1084-1087.

Cavaletto, C.G., Ross, E. & Yamamoto, H. Y. (1968) In-shell storage effects on quality of processed macadamia nuts. *Food Technol.* 22(4):517-519.

Cavaletto, C.G. & Yamamoto, H.Y. 1968. Criteria for selection of packaging materials for roasted macadamia kernels. *Food Technol.* 22:97.

Cavaletto, C.G. & Yamamoto, H. Y. (1971) Factors affecting macadamia nut stability. 3. Effects of roasting oil quality and antioxidants. *J. Food Sci.* 36:81-83.

Coward, L.D.G., Beaumont, J.H. & Manser, P.J. (1974)The decortication of some tropical nuts. *Proc. IV Int. Congress of Food Sci. and Technol.* V:407-411

Dela Cruz, A.; Cavaletto, C.; Yamamoto, H.Y. & Ross, E. (1966) Factors affecting macadamia nut stability. II. Roasted kernels. *Food Technol.* 209): 1217-1218.

DFST (1991)Composition of macadamia oil. Division of Food Science and Technology, CSIR. Unpublished results.

Fourie, P.C. & Basson, D.S. (1989) Predicting rancidity in stored nuts by means of chemical analyses. *Lebensm. -Wiss. u. -Technol.* 22:251-253.

Foss, S.L. (1983) Mechanical harvesting of macadamia in Hawaii, pp l-3.

Gathungu, C.N. & Likimani, E.P. (1975)Macadamia nut selection programme in Kenya *Acta Hort.* 49:231-237.

Grimwood, B.E. (1971)The processing of macadamia nuts. *Report; Trop. Prod. Inst.* G66:5pp.

Hamilton, R.A.; Yee, W. & Ito, P. (1980) Macadamia: Hawaii's dessert nuts. *Circular, Cooperative Extension Service,* Univ. Hawaii 485:10pp.

Hand, (1983) Quality at the factory and beyond. Session 11, Paper 4. CSR Macadamia Factory, Queensland, Australia.

Hansen, G.P. & Gough, M.C. (1977)Moisture characteristics of macadamia nuts in relation to storage. *J. Sci. Food Agric.* 28:990-995.

Hobson, L. (1976a) Macadamia quality - some questions answered; Part 1. *Citrus Subtrop. Fruit J* (Nov.):5-7,9.

Hobson, L. (1976b) Macadamia quality - some questions answered; Part II. *Citrus Subtrop. Fruit* J. (Dec.): 14-15, 19-22.

Human, T.P (1979)'n Re-evaluasie van makadamia-kultivars soos aangeplant in Oos-Transvaal. *Citrus Subtrop. Fruit J.{Apr):7*,10.

Jones, W. & Shaw, L. 1943. The process of oil formation and accumulation in the macadamia. Plant Physiol. 18:1-7.

Joubert, A.J. & Joubert, P.C.(1969) Pekan- en makadamianeute - veilige bewaring. *Boerdery in* SA (aug):41,48.

Kadman, A. & Slor, E. 1982. "Yonik" macadamia. *Hort. Sci.* 77(6):991.

Leverington, R.E. 1962. Evaluation of methods of roasting macadamia nuts. *Queensland J. Agric. Sci.* 79.-131-132.

Leverington, 1962 Evaluation of macadamia nut varieties for Processing. *Queensland J. Agric' Soc.* 79:33-46.

Leverington, R.E. (1971)The macadamia nut industry. Paper presented at *43rd ANZAAS conference,* Brisbane.

Liang, T. (1977) A new processing system for maximizing macadamia nut kernel recovery. *Trans. ASAE-.43Q-443*

Liang, T. (1980) Designing a constant deformation macadamia nut cracker. Trans. *ASAE* 23:1093-1096.

Liang, T,, Loren, C. & Mitchell, J.B. (1984) Modeling moisture influence on macadamia nut kernel recovery. Trans. *ASAE 25:*1538-1541.

Liang, T.; Chou, J. & Knapp, R. (1988) Notching and freezing effect on macadamia nut kernel recovery. *J. Agric. Engng Res. 41:43-52.*

Liang, T.; Mehra, S.K. & Khan, M.A. (1989) A macadamia nut curing system for improving kernel recovery. *J. Agric. Engng Res.* 43:103-111.

Macadamia Magic (1991) Macadamia nut specifications of an Australian company.

Macfarlane, N. & Harris, R.V. (1981a) Extraction of macadamia oil using a small expeller. *Trop. Sci.* 23(3):205-215.

Macfarlane, N. & Harris, R.V. (1981 Macadamia nuts as edible oil source. *AOCS Monograph* 9:103-108.

Mason, R.L. (1983) The effect of harvest time and method on the quality of macadamia nuts. *Food Technol. Austr.* 35(4): 184-185.

Mason, R.L. & Wills, R.B.H. (1983) Evaluation of the use of specific gravity as an objective index of the quality of Australian macadamias. *Food Technol. Austr.* 35(5) :245,247-248.

Menninger, E.A. (1977)The macadamia. In *Edible Nuts of the World'* Horticultural Books, Florida. ISBN 0-9600046-4-5. pp 21-25.

Moltzau, R.H. & Ripperton, J.C. (1939)Processing of macadamia. *Hawaii Agricultural Experiment Station, University of Hawaii; Bulletin no.* 83' June: 31 pp.

NFRI. 1977. Nutrient composition of macadamia kernels from Levubu. Unpublished results.

Oosthuizen, J.H,, Alberts, A.J. & Joubert, AJ. (1989). Evaluasie van Makadamianeutcultivars en seleksies in twee gebiede in Suid Afrika. *Subtropica 10(7)* :9-12.

Patel, C.K.N. (1982)Method for shelling of nuts with a laser beam. *United States Patent* US 4 358 467. Plant

Protection Research Institute (1990)Guide *to the use of pesticides and fungicides in the Republic of South Africa* Department of Agricultural Development (34th revised ed). pp. 94, 247, 251.

Price, W.M. (1985)Nutcracker for cracking hard-shell nuts such as black walnuts and macadamia nuts. *United States Patent* US 4 520 719. (abstract)

Prichavudhi, K. & Yamamoto, H.Y.(1965) Effect of drying temperature on chemical composition and quality of macadamia nuts. Food *Technology* 19:129-132.

Redelinghuys, H.J.P.; Van Wyk, P.J. & Frisby, O.J. (1978)Die verwerking van makadamianeute. *Vorderingsversiga, NVNI, WNNR.*

Ripperton, J.C.; Moltzau, R.H. & Edwards, D.W. (1938)Methods of evaluating the macadamia nut for commercial use and the variation occurring among seedling plantings in Hawaii. *Hawaii Agricultural Experiment Station, University of Hawaii; Bulletin no. 79*. April :26 pp.

Rockland, L.B. (1966)Factors affecting the stability of raw and roasted macadamia nuts: a summary of USDA-supported research at the University of Hawaii. *California Macadamia Society Yearbook* pp. 52-55.

Rosenthal, I,, Merin, U,, Basker, D. & Kadman, A. (1984). A study of macadamia nuts of the "Yonik" variety. *J. Food Qual. 7:67-73*.

Rosenthal, 1., Merin, U. & Kadman, A. (1986)Comparison of some properties of macadamia nuts of the *Yonik* and *Beaumont* cultivars. *Lebensm. -Wiss. u. -Technol. 19:53-55*.

SAMAC (1990) Newsletter, South African Macadamia Growers Association 3 (March):2.

Sarig, Y.; Grosz, F. & Rasis, S. (1980) The development of a mechanical cracker for macadamia nuts. J. Agric. Engng Res. 25:367-374.

Sharma, S.C. (1985) Roasted, coated nut product and process therefor. *United States Patent* US 4 522 833.

Scott, F.S., Jr. (19) Sales potentials and the methods and costs of market development for macadamia nuts. pp 11-18. (Incomplete reference)

Tang, G.P.; Snobar, B. & Liang, T. (1982) Flash drying macadamia nuts for improved kernel extraction. *Trans. ASAE 24:*1733-1736.

Watt, B.K. & Merrill, A.L. (1963)Composition of Foods. Agriculture Handbook no. 8. USDA, Washington, DC. 189 pp.

ADDITIONAL REFERENCES

Bridge, R.E. & Hilditch, T.P. 1950. The seed ^*Macadamia ternifolia. J. Chem. Soc.* 2396.

Cavaletto, C.G. & Monroe, G. 1970. *Hawaii Fd Proc. 18:4*.

Cavaletto, C.G. & Yamamoto, H.Y. 1968. Criteria for selection of packaging materials for roasted macadamia kernels.
Food Technol. 22:97.

Desai, M. & Liang, T. 1977. Electrical impedance as an index of macadamia nut ripeness. *Trans. Am. Soc. Agric. Eng.* 20:444-449.

FAO/WHO Codex Alimentarius Commission. 1972. Recommended international code of hygiene for tree nuts.

Fuller, G, Spooner, W.W, King Jr, A.D, Schade, . & Mackey, B. 1977. Survey of aflatoxins in California tree nuts. *J. Am. Oil Chem. Soc.* 54:231A-234A.

Hamilton, R.A. & Fukunaga, E.T. (1959) Growing macadamia nuts in Hawaii. Hawaii Agr. Expt. Sta. Bull. 121.

Jakeway, L.A. 1977. Analysis of simulated compression cracking of *M. integrifolia*. MS Thesis, University of Hawaii, Honolulu, HI, USA.

Jones, W. & Shaw, L. 1943. The process of oil formation and accumulation in the macadamia. *Plant Physiol. 18:t.*

Kadman, A. & Slor, E. 1983. "Yonik" macadamia. *Hort. Sci. 17:99).*

Leverington, 1962 *Queensland J. Agric. Soc. 19:33.*

Leverington, R.E. 1962. Evaluation of methods of roasting macadamia nuts. *Queensland J. Agr. Sci. 19:* 131-132.

Liang, T. & Myers, A.L. 1975. Monitoring macadamia nut quality in an orchard to determine optimal shaker harvest date. *Trans. Am. Soc. Agric. Eng.* 78:233-235

Mason, R.L. 1975. Macadamia production in Australia. *Hawaii Mac. Prod. Assoc'* 15th Annual Proceedings.

Mason, R.L. 1980. What affects quality in macadamia nuts. *Austr. Mac. Soc. Newsbull.* 6(7): 10-16.

Mason, R.L. 1982. Harvest and postharvest handling of macadamia nuts. *Austr. Mac. Soc. Fact Sheet* 9.

McConachie, 1. 1975. Macadamias in Australia. *California mac. Soc. Yr.bk.* Vol. 21.

Monroe, G.E., Liang, T. & Cavaletto, C.G. 1972. Quality and yield of tree-harvested macadamia nuts. Washington DC: US Department of Agriculture: ARS 42-196.

Rosenthal, I., Merin, U, Basker, D.& Kadman, A. (1984). A study of macadamia nuts of the "Yonik" variety. *J. Food Qual. 7:67-73.*

Storey, W.B. 1957. *Ternifolia (integrifolia)* or *tetraphylla* - which should we grow? *Calif. Macadamia Soc. Yr.bk.* 3:15-18.

Storey, W.B. *et at.* (1960) Yb. Calif. Macad. Soc. 6:85.

Storey, W.B. 1965. "Beaumont": a new dual purpose macadamia variety. *Yb. Calif. Macad. Soc. 11:i9-25.*

Tang, G.P. 1981. Deformation and moisture content in machine cracking of macadamia. MS Thesis, University of Hawaii, Honolulu.

Tang, G.P., Liang, T. & Munchmeyer, F. 1982. A variable deformation macadamia nut cracker. *Trans. Am. Soc. Agr. Engin.* 25:1505-1511.

Winterton, D. 1966. *Fd Technol. Austr. 19:74.*

Winterton, D. 1968. *Fd Technol. Austr.* 20:119.

Yamamoto, H.Y. 1963. Research in processing of macadamia. Conference sponsored by Chamber of Commerce of Honolulu and Hawaii Macadamia Prod. Assoc. 29-30.

ADDITIONAL REFERENCES (unsorted)

Hamilton, R.A. & Fukunaga, E.T. (1959) Growing macadamia nuts in Hawaii. Hawaii Agr. Expt. Sta. Bull. 121.

Cavaletto, C.G. & Yamamoto, H.Y. 1968. Criteria for selection of packaging materials for roasted macadamia kernels. *Food Technol.* 22:97.

Bridge, R.E. & Hilditch, T.P. 1950. The seed of *Macadamia ternifolia. J. Chem. Soc.* 2396.

Jones, W. & Shaw, L. 1943. The process of oil formation and accumulation in the macadamia. *Plant Physiol. 18:*-\.

Leverington, R.E. 1962. Evaluation of methods of roasting macadamia nuts. *Queensland J. Agr. Sci.* 79:131-132.

Storey, W.B. 1957. *Ternifolia (integrifolia)* or *tetraphylla* - which should we grow? *Calif. Macadamia Soc. Yr.bk.* 3.-15-18.

FAO/WHO Codex Alimentarius Commission. 1972. Recommended international code of hygiene for tree nuts.

Fuller, G., pooner, W.W., King Jr,, A.D., Schade, . & Mackey, B. 1977. Survey of aflatoxins in California tree nuts. *J. Am. Oil Chem. Soc.* 54.-231A-234A.

Mason, R.L. 1982. Harvest and postharvest handling of macadamia nuts. *Austr. Mac. Soc. Fact Sheet* 9.

Mason, R.L. 1975. Macadamia production in Australia. *Hawaii Mac. Prod. Assoc.* 15th Annual Proceedings.

Mason, R.L. 1980. What affects quality in macadamia nuts. *Austr. Mac. Soc. Newsbull.* 6(7):10-16.

McConachie, 1. 1975. Macadamias in Australia. *California mac. Soc. Yr.bk.* Vol. 21.

Storey, *et al*. (9160) Yb. Calif. Macad. Soc. 6:85.

Leverington, 1962 *Queensland J. Agric. Soc. 19:33.*

Leverington, 1962 *Queensland J. Agric. Soc.* 79:131.

Cavaletto, C.G. & Monroe, G. 1970. Hawaii Fd Proc. 18:4.

Winterton, D. 1966. *Fd Technol. Austr. 19:74.*

Winterton, D. 1968. *Fd Technol. Austr.* 20:119.

Jakeway, L.A. 1977. Analysis of simulated compression cracking of *M. integrifolia*. MS Thesis, University of Hawaii, Honolulu, HI, USA.

Tang, G.P., Liang, T. & Munchmeyer, F. 1982. A variable deformation macadamia nut cracker. Trans. Am. Soc. Agr. *Engin*. 25:1505-1511.

Desai, M. & Liang, T. 1977. Electrical impedance as an index of macadamia nut ripeness. *Trans. Am. Soc. Agric. Eng.* 20:444-449.

Liang, T. & Myers, A.L. 1975. Monitoring macadamia nut quality in an orchard to determine optimal shaker harvest date. *Trans. Am. Soc. Agric. Eng.* 78:233-235

Monroe, G.E,, Liang, T. & Cavaletto, C.G. 1972. Quality and yield of tree-harvested macadamia nuts. Washington DC: US Department of Agriculture: ARS 42-196.

Kadman, A. & Slor, E. 1983. "Yonik" macadamia. *Hort. Sci. 17:991.*

Rosenthal, 1., Merin, U,, Basker, D. & Kadman, A. (1984). A study of macadamia nuts of the "Yonik" variety. *J. Food Qual. 7:67-73.*

Storey, W.B. 1965. "Beaumont": a new dual purpose macadamia variety. *Yb. Calif. Macad. Soc.* 77:19-25.

Yamamoto, H.Y. 1963. Research in processing of macadamia. Conference sponsored by Chamber of Commerce of Honolulu and Hawaii Macadamia Prod. Assoc. 29-30.

Tang, G.P. 1981. Deformation and moisture content in machine cracking of macadamia. MS Thesis, University of Hawaii, Honolulu.

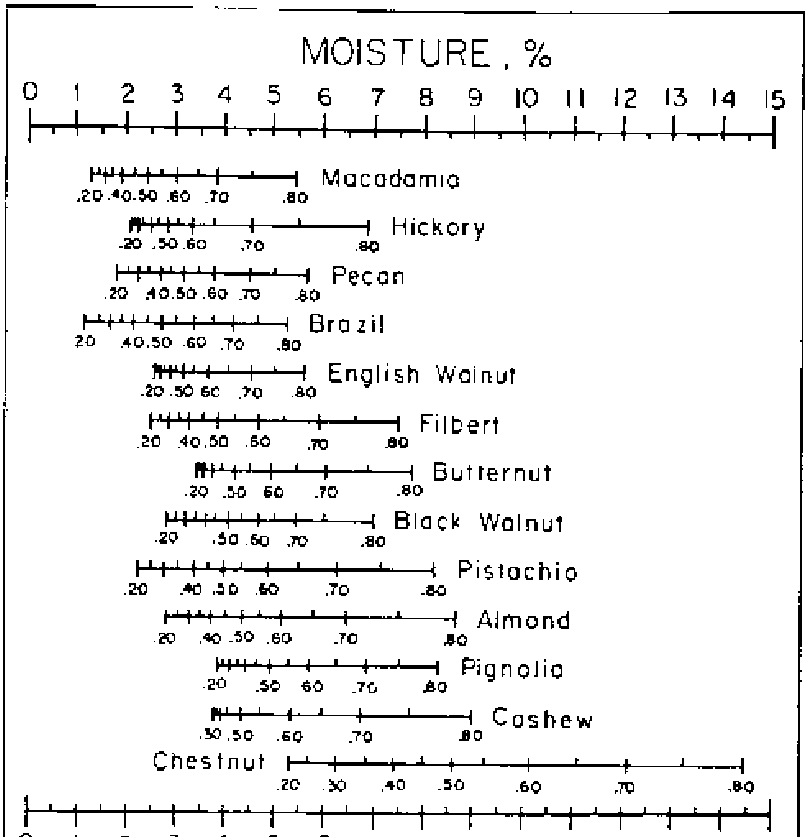

Fig. 1: Relationship between aw and moisture content of tree nut meats at 21 C (Beuchat, 1978)