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Full Length Research Paper

Genetic and postharvest factors affecting macadamia kernel quality

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Macadamia (*Macadamia integrifolia*, *Macadamia tetraphylla* and hybrids) is cultivated in regions of Eastern Australia. Genotype and geographical location, a factor seldom studied, may influence kernel quality. Macadamias from three cultivars were harvested from three commercial plantations, each in a different region of Eastern Australia over three consecutive seasons. Kernel quality was assessed by whole kernel, shoulder damage, weight of pieces, oily kernels and dusty kernels. Whole kernel was strongly influenced by genotype. Shoulder damage and weight of pieces were variable and not related to genotype. Shoulder damage rates were low and numbers of oily and dusty kernels were negligible. The influence of genotype on whole kernel highlights the importance of cultivar selection from macadamia quality management. High kernel quality of kernels from nuts harvested and handled with care in this study emphasizes that the best practice postharvest management of macadamia nut-in-shell is the most important means of maintaining kernel quality.

Key words: Macadamia, kernel quality, genotype, whole kernel, shoulder damage, geographical location, post-harvest handling.

INTRODUCTION

Macadamia integrifolia (Maiden and Betche), *Macadamia tetraphylla* (L.A.S. Johnson) (Proteaceae) and their hybrids are cultivated for their edible kernels. In Australia, South Africa and Hawaii, they are an important horticultural crop with smaller industries in numerous countries including Brazil, Guatemala, Kenya and New Zealand. Both species are indigenous to subtropical coastal rainforests of the East coast of Australia (Gross, 1995). The main growing locations in Australia are the Bundaberg region (25°S), southeast Queensland (27°S) and Northern New South Wales (28°S). Genotype (cultivar) and other factors such as geographical location may affect certain quality parameters.

Much research in macadamia has concentrated on issues that affected yield such as pollination (Wallace et al., 1996), cultivar selection (Stephenson and Gallagher, 2000), controlling harvest (Trueman et al., 2002; Trueman, 2003), physiology (Trueman, 2010) and canopy management (Olesen et al., 2008). The need to focus on kernel quality has recently been identified (Mason, 2000; Mason et al., 2004).

Postharvest practices affect kernel quality, for example, dropping nut-in-shell reduces raw and roasted kernel quality (Walton and Wallace, 2008, 2010), mechanical dehusking reduces raw kernel quality by increasing ‘shoulder damage’ (Walton and Wallace, 2005a) and quality can be lost while nuts are handled and stored on-farm before consignment to a processor (Walton and Wallace, 2011).

Pre-harvest factors such as temperature during nut development and nutrition also influence macadamia kernel quality (Stephenson and Gallagher, 1986, 1990). Other pre-harvest factors such as geographical location (site) and genotype may also influence quality, for example, different almond genotypes perform differently in different districts (Pérez-Campos et al., 2011).

High oil content is an important indicator of macadamia kernel quality (Mason, 2000). Macadamia whole kernel is another important quality parameter and whole kernel

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recovery is related to genotype (Walton and Wallace, 2005b, 2008). Quality of macadamias can vary for different cultivars at different sites. Different macadamia cultivars at different sites varied in percent weight of kernel, percent grade one kernel (the percentage of kernels with oil content greater than 72%) (Radspinner, 1971), fatty acid profile and percentage content of oil (Himstedt, 2002). However, there is limited information on the effect of site on other quality attributes such as whole kernel and shoulder damage.

This study was designed to examine differences in kernel quality of three macadamia cultivars in three macadamia growing regions of Eastern Australia over three consecutive seasons, evaluated by whole kernel, shoulder damage, loss as pieces, oily kernels and dusty kernels. The aim was to determine the influence of pre-harvest factors such as genotype and site on kernel quality when postharvest factors are carefully controlled.

MATERIALS AND METHODS

Plant material and study sites

Three cultivars were used in this study, one high whole kernel cultivar, HV A38 (Wallace et al., 2001; Walton and Wallace, 2008), and two widely planted low whole kernel cultivars, HAES 344 and HAES 741 (Stephenson and Gallagher, 2000; Walton and Wallace, 2005b, 2008). Three locations in Eastern Australia were selected to examine the variation in quality between sites, Bundaberg (24°49.79'S, 152°17.23'E), Wolvi (26°9.63'S, 152°48.65'E), and Clunes (28°45.76'S, 153°30.77'E).

Experimental design

Two replicate samples, each consisting of 50 fruit were collected from the ground for each of 5 trees per cultivar, giving a total of 10 replicates of 50 nuts per cultivar. Nuts were sampled at Bundaberg, Wolvi and Clunes in April in each of the three harvest seasons, 2002, 2003 and 2004.

Kernel evaluation

All fruit was hand-harvested to avoid mechanical damage. Fruits were dehusked within 24 h of harvest using a 'Shaw' type mechanical dehusker adjusted to ensure minimal dehusker damage to kernels (Walton and Wallace, 2005a). Immediately following dehusking, nut-in-shell was dried in laboratory fan-forced ovens (Memmert and Co. KG, Schwabach, Germany) for 2 days at 38°C, two days at 45°C, followed by the required time at 58°C to dry nuts to 3% nut-in-shell moisture content wet basis (w. b.) (Meyers et al., 1999). Nut-in-shell was cracked by hand using a "T J's" TM nutcracker to minimize damage to kernels and all possible care was taken to minimize stresses on kernels during cracking by careful alignment of the nuts in the cracker (Braga et al*.,* 1999). Kernel quality was assessed immediately following cracking. Whole kernel number and weight, shoulder damage, weight of pieces, dusty kernels and oily kernels were assessed as in previous studies (Walton and Wallace, 2008, 2009).

Statistical analysis

Whole kernel was calculated as:

$$\text{Whole kernel weight (\%)} = \frac{\text{Weight of whole kernel}}{\text{Total weight of sound kernel}} \times 100$$

Total weight of sound kernel = weight of wholes + weight of halves + total weight of pieces

Weight of pieces (% wt of sound kernel), shoulder damage (% of whole number), pieces weight (% wt of sound kernel), oily kernels (% of whole number) and dusty kernels (% of whole number) were calculated. Because of missing data, HV A38 was not included in the analysis for weight of pieces in 2002. Statistical analyses were conducted using SPSS 10.0 (SPSS Science, Chicago, Illinois). All data were normally distributed and were initially analysed with a factorial ANOVA with year, site and cultivar as factors, identifying significant interactions between year and cultivar, year and site, site and cultivar, and year, site and cultivar (P <0.001) (Table 1). Therefore, for each year, means were compared for each combination of cultivar and site (nine combinations for each year), using a series of one-way ANOVAs with eight degrees of freedom. Where significant differences were found, Duncan's multiple range test was applied for comparison of means.

RESULTS

Whole kernel weight

The main factor affecting whole kernel was cultivar. In 2002, HV A38 produced significantly more whole kernel than HAES 344 and HAES 741 (P < 0.05) at all sites (Figure 1). Values in 2002 ranged from 72% at Wolvi and 78% at Clunes for HV A38, to a low of 29% for HAES 741 at Bundaberg. Whole kernel in 2003 was generally higher, and HV A38 produced significantly more than the other cultivars except at Wolvi (Figure 1). Results were most variable in 2004 and HAES 344 at Wolvi and HAES 741 at Clunes produced high whole kernel, but HV A38 still performed strongly and was not lower than the other cultivars at each site (Figure 1). There was no consistent pattern of differences in whole kernel for each cultivar at the three sites.

Shoulder damage and weight of pieces

Shoulder damage was more variable than whole kernel, and not consistently related to cultivar, for example, in 2002, shoulder damage for HV A38 was higher at Wolvi than for all other cultivars at all sites, while in 2003, HAES 344 recorded the highest value for all cultivars at all sites. Shoulder damage was generally lower in 2002, with the majority of results approximately 5 to 12%. In 2003, shoulder damage increased to approximately 10 to 15% and to approximately 10 to 20% in 2004 (Figure 2).

Results for weight of pieces were variable from year to year and there was no discernible pattern (Figure 3). The most notable feature was that weight of pieces for 2003 and 2004 was less than 3%, compared with from 5 to 15% in 2002.

Table 1. Factorial ANOVA for weight of whole kernel (%), shoulder damage (%) and weight of pieces for 3 cultivars at 3 sites over 3 years.

Variable	Source	Sum of squares	Df	Mean square	F	Sig.
Whole kernel (%wt)	Year	10115.828	2	5057.914	66.834	0.000
	Site	578.304	2	289.152	3.821	0.023
	Cultivar	22587.383	2	11293.691	149.233	0.000
	Year * site	3541.765	4	885.441	11.700	0.000
	Year * cultivar	7099.768	4	1774.942	23.454	0.000
	Site * cultivar	4299.996	4	1074.999	14.205	0.000
	Year * site * cultivar	3494.467	8	436.808	5.772	0.000
	Error	18314.176	242	75.678		
	Total	1049040.368	269			
Shoulder damage	Year	887.840	2	443.920	21.516	0.000
	Site	154.685	2	77.343	3.749	0.025
	Cultivar	189.381	2	94.691	4.589	0.011
	Year * site	2077.357	4	519.339	25.171	0.000
	Year * cultivar	2101.660	4	525.415	25.465	0.000
	Site * cultivar	1190.663	4	297.666	14.427	0.000
	Year * site * cultivar	806.550	8	100.819	4.886	0.000
	Error	4993.059	242	20.632		
	Total	57402.759	269			
Weight of pieces	Year	4460.444	2	2230.222	231.834	0.000
	Site	6.635	2	3.317	.345	0.709
	Cultivar	1474.359	2	737.180	76.631	0.000
	Year * site	17.084	4	4.271	.444	0.777
	Year * cultivar	2243.452	4	560.863	58.302	0.000
	Site * cultivar	294.765	4	73.691	7.660	0.000
	Year * site * cultivar	544.517	8	68.065	7.075	0.000
	Error	2328.015	242	9.620		
	Total	17470.365	269			

Oily and dusty kernels

There were very few oily kernels and dusty kernels in this study. Oily kernels occurred only in 2003 when there were 6 oily kernels out of 869 whole kernels at Wolvi, and only 1 oily kernel out of 969 at Clunes. Similarly, there were very few dusty kernels, with HAES 741 recording 1.37% dusty kernels at Wolvi in 2002, compared with 0.53% for HAES 344. All other values in 2002 were zero. The only other record for dusty kernels was 0.21% for HV A38 in 2003. All other values in 2003 and 2004 were zero.

DISCUSSION

This study showed that genotype and careful postharvest handling of macadamias were more important than pre-harvest factors such as site for maintaining kernel quality. The most consistent producer of high whole kernel at each site was cultivar HV A38, which yielded more than both HAES 344 and HAES 741 in 2002 and 2003 at all sites except Wolvi in 2003. While both HAES 344 and HAES 741 are able to produce high whole kernel in some seasons (as in 2004) they can also return very low percentages, and are less consistent for whole kernel. This strong genetic control on whole kernel agrees with previous work (Walton and Wallace, 2005b, 2008; Stephenson and Gallagher, 2000). In 2002 HV A38 produced significantly more whole kernel than the other cultivars at every site, more than double that from HAES 741 at Bundaberg and Clunes. The effect of genotype on whole kernel is the most important pre-harvest effect on quality revealed in this study. Seasonal effects may help to explain the low whole kernel for HAES 344 and HAES 741 in 2002, when all sites experienced below average rainfall.

Shoulder damage rates in this study were not related to cultivar or site and were low compared to those produced by dropping nuts, delaying harvest and during on-farm postharvest handling (Walton and Wallace 2008, 2009, 2011). Dropping nut-in-shell can cause rates of 30 to

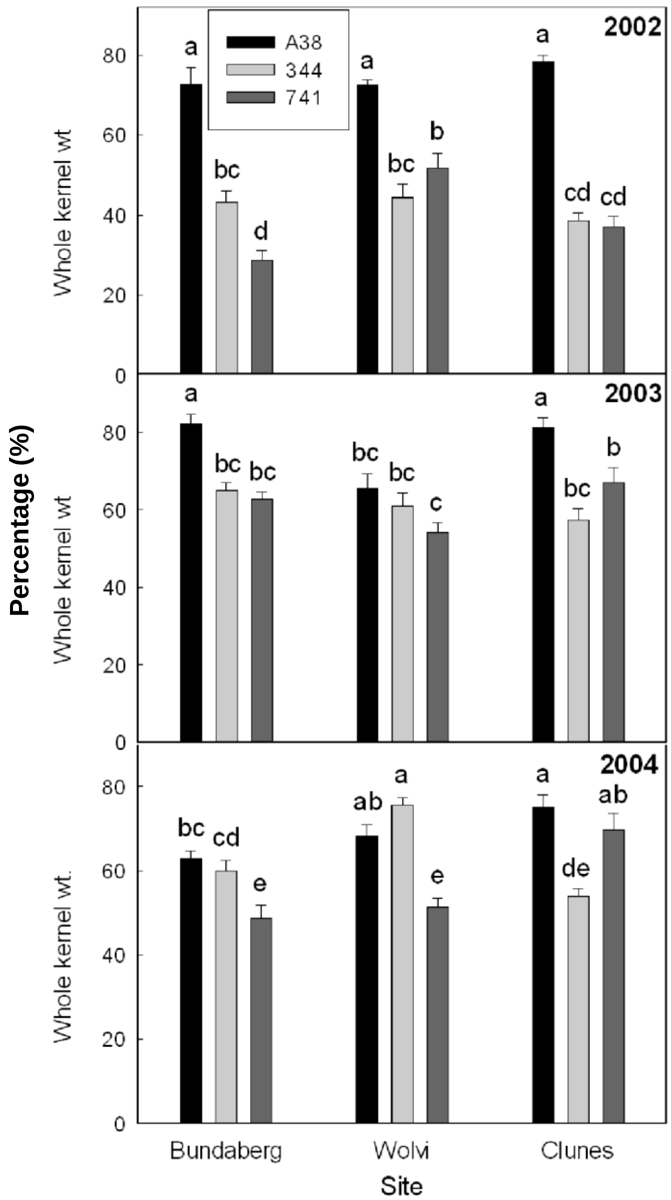

Figure 1. Whole kernel weight (%) for 3 macadamia cultivars at 3 sites during 3 seasons. Means and standard errors are presented, means with different letters are significantly different (Duncan's Multiple Range test, $P < 0.05$).

60% shoulder damage (Walton and Wallace, 2008). The shoulder damage rates in this study could be seen as typical of damage caused by mechanical dehusking (Gautz and Ying, 1993). Some shoulder damage is unavoidable, but careful attention to optimal dehusker adjustment will minimize shoulder damage. Shoulder damage is related to kernel characteristics. Some kernels adhere to the white enamelled surface of the shell interior (Hartung and Storey, 1939), and as the kernel dries and shrinks, it pulls away from the shell, leaving tissue attached to the shell. The result is shoulder damage.

Shoulder damage in this study does not follow a pattern and is not related to cultivar.

Weight of pieces for 2003 and 2004 was greatly reduced when compared to 2002, perhaps because of improved rainfall in these seasons. Environmental factors may have again exerted more influence than genetic factors. In contrast, there was more shoulder damage in 2003 and 2004 than 2002, suggesting that the kernel tissue was more likely to break in a season of low rainfall, but also less likely to adhere to the enamelled shell area and cause shoulder damage when the shell is removed (Hartung and Storey, 1939). Loss as pieces can also be increased by delaying harvest for more than three weeks (Walton and Wallace, 2009) and postharvest practices during on-farm handling and storage (Walton and Wallace, 2011) while nut-in-shell may be subjected to many impacts during sorting and movement prior to cracking. Nuts in this study were dried immediately following dehusking and were not subjected to storage.

Pieces are important because they represent economic loss through lost product or reduced value and are an indicator of kernel damage. In commercial operations, loss of kernel in the form of pieces too small to recover can be as high as 6% of total kernel weight (Liang et al., 1984). On average, pieces are worth 18% less than whole kernel and 7% less than halves.

Negligible quantities of oily and dusty kernels were generated in this study. This is an indication of maintenance of kernel quality. Oily and dusty kernels are indicators of damage from postharvest handling or processing procedures for pecans (Wakeling et al., 2002, 2003) almonds (Altan et al., 2011) and macadamias (Walton and Wallace, 2008). Oiliness is an evidence of bruising, oleosome disruption and cell membrane damage (Wakeling et al., 2002, 2003; Altan et al., 2011). After-roast-darkening of macadamias, results when bruised, oily kernels are roasted (Albertson et al., 2005, 2006; Walton and Wallace, 2010). Oiliness of kernels from dropped nuts increases over time as damaged membranes leak oil (Walton and Wallace, 2008). Dustiness is due to abrasion of the kernel surface and is found when kernels are damaged by dropping impacts to nut-in-shell (Walton and Wallace, 2008). The nuts in the current study were handled carefully, maintaining optimal quality by good postharvest practices.

Conclusion

This study showed that whole kernel was consistently determined by genotype. Cultivar selection offers a cost-effective means of improving macadamia quality. Because of careful postharvest management including prompt dehusking with a carefully adjusted dehusker, avoidance of dropping, no storage time, hand cracking and prompt kernel assessment, negligible oily and dusty kernels were found in this study, and shoulder damage was relatively low. Best practice postharvest management of nuts and genotype have a greater effect

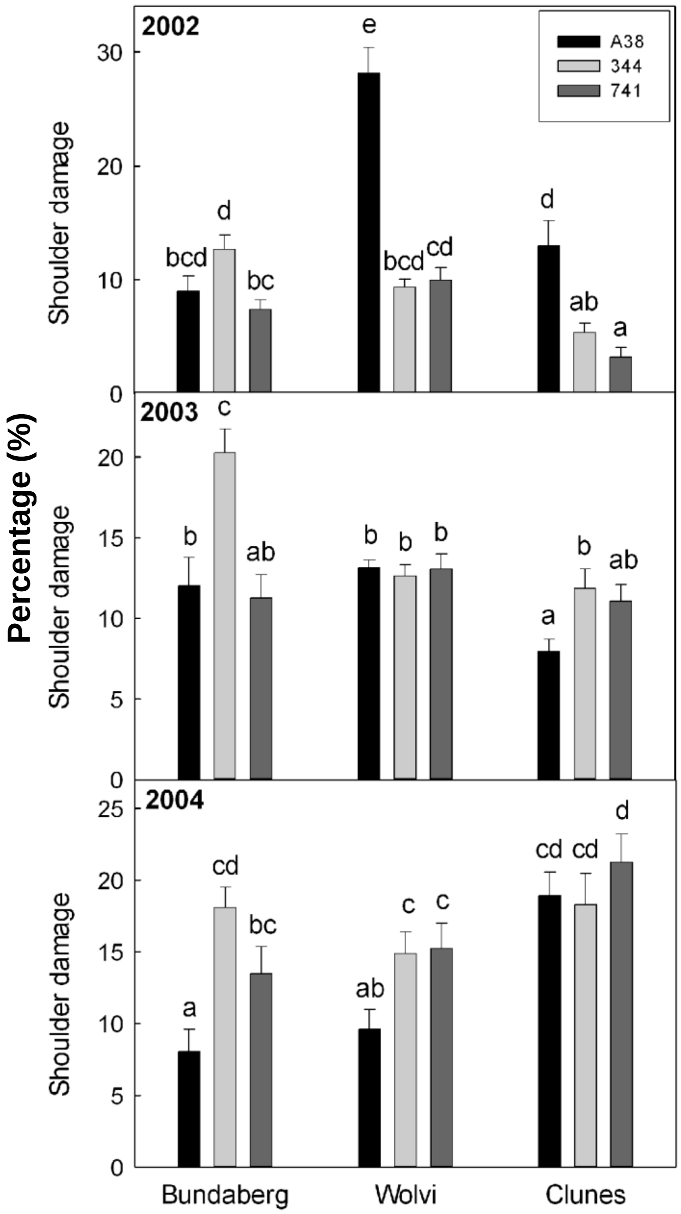

Figure 2. Shoulder damage (%) for macadamia kernels from 3 cultivars at 3 sites, over three seasons. Means and standard errors are presented; means with different letters are significantly different (Duncan's Multiple Range Test, $P < 0.05$)
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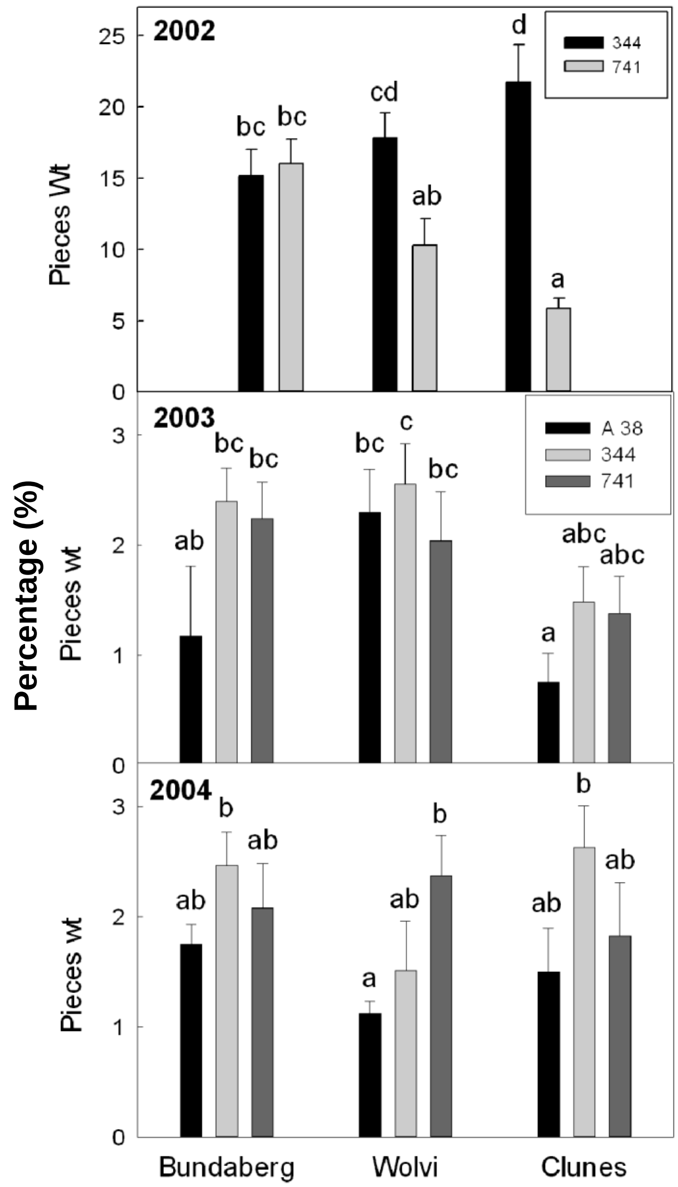

Figure 3. Total pieces weight (%) for three macadamia cultivars at 3 sites over 3 seasons. Means and standard errors are presented; means with different letters are significantly different (Duncan's Multiple Range Test, $P < 0.05$).

on macadamia kernel quality than pre-harvest factors such as growing site.

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