INTRODUCTION

The South African macadamia industry, in common with other agricultural industries, has been placed under increasing pressure in recent years. Factors affecting profitability include rising labour costs, as well as increasing input costs – especially in terms of imported goods such as fertiliser. A weakening rand also exacerbates the negative effect of imported goods, although it should improve profitability of exported kernel. However, the biggest contributor to reduced profitability in recent years has been the decline in the price of macadamia kernel. Table 1 shows that between 2005 and 2007, the average kernel price across all styles declined by 37%.

Table 1. Changes in macadamia kernel prices (Rand/kg) between 2005 and 2007.

<table>
<thead>
<tr>
<th>Style</th>
<th>2005</th>
<th>2007</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>84.44</td>
<td>61.10</td>
<td>-27.6</td>
</tr>
<tr>
<td>1</td>
<td>79.42</td>
<td>61.10</td>
<td>-26.2</td>
</tr>
<tr>
<td>2</td>
<td>75.28</td>
<td>53.16</td>
<td>-29.4</td>
</tr>
<tr>
<td>3</td>
<td>71.58</td>
<td>40.08</td>
<td>-44.0</td>
</tr>
<tr>
<td>4</td>
<td>71.27</td>
<td>40.32</td>
<td>-43.4</td>
</tr>
<tr>
<td>5</td>
<td>68.19</td>
<td>40.32</td>
<td>-43.4</td>
</tr>
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<td>6</td>
<td>64.51</td>
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</tr>
<tr>
<td>S</td>
<td>83.95</td>
<td>51.09</td>
<td>-39.1</td>
</tr>
<tr>
<td>Average</td>
<td>73.36</td>
<td>46.25</td>
<td>-37.0</td>
</tr>
</tbody>
</table>

Source of data: Bekker, 2008

It can also be seen from Table 1 that not all styles lost value to the same extent. Those styles which comprised predominantly large whole kernel (style 0 and style 1) and mixtures of whole and larger half kernel (style 2) declined by less than 30%, compared to styles comprising mostly broken kernel which lost up to 47% of their value. With favourable styles selling at prices of 50% more than unfavourable styles, one way to increase industry profitability without increasing input costs and yields would be to increase the proportion of favourable styles. In 2007, of the 4550 tons of kernel sold, only a quarter (1090 tons) were in the form of style 0 and 1 kernel. Clearly there is considerable potential to increase the proportions of more valuable kernel, and thus profits.

To date very little work has been done to determine the factors leading to kernel breakage. All of the available literature refers to work done by Helen Wallace, David Walton and colleagues at the University of the Sunshine Coast in Australia. The studies carried out by these researchers can be divided into three categories, namely:

- The effect of rough handling (NIH and NIS) on macadamia kernel
- The effect of dehuskers on kernel integrity
- Microscopy studies showing the differences in ultrastructure between cultivars with high breakage and those with low breakage.

Rough handling of macadamias

Wallace et al. (2000) examined the effect of impacts on whole kernel when NIS at 15, 10 and 3% moisture were dropped onto a hard surface. This was done for the cultivars A38 (usually has high percentage whole kernel) and 246 (produces low percentage whole kernel). It was found that cultivar plays the largest role in the extent of whole kernel, but dropping NIS at 15% moisture reduced whole kernel by 3 - 5% and dropping cultivar 246 at 3% moisture onto a steel surface reduced wholes by 10%. It was also found that NIS dropped at 15% moisture had more chipped kernel.

A series of trials carried out between 2002 and 2004 (Walton and Wallace, 2008) again looked at the effect of dropping NIS at various moisture contents onto different surfaces (either NIS or an aluminium plate). The cultivars A38, 344 and 741 were examined. Again, there were significant differences between cultivars in terms of whole kernel. However, none of the treatments had an effect on kernel breakage. Dropping of NIS did lead to increases in shoulder damage, oily kernel and dusty kernel – particularly for nuts dropped at 3% moisture.

Dehusker effects

Walton and Wallace (2005a) reported that nuts dehusked at both 22% and 10% moisture showed no significant reduction in whole kernel due to the mechanical dehusking. However, there were increases in shoulder damage – particularly with the Admac type dehusker. It is not certain whether this was due to poor adjustment of the machine.

Ultrastructure studies

In this study (Walton and Wallace, 2005b) the ultrastructure of the adaxial surface between the cotyledons of several macadamia cultivars was examined using both light and transmission electron microscopy. One obvious difference between cultivars was that those with more wholes
have thinner cuticles. It was shown that in cultivars with high percentages of whole kernel the surfaces of the two cotyledons are closely fused, while in cultivars with low levels of whole kernel the cotyledon cuticles are convoluted and in poor contact. This appears to explain the physical basis for differences between cultivars. It also suggests that certain cultivars are genetically pre-disposed to kernel breakage, and that it may be difficult to influence the ratio of whole to half kernel in those cultivars.

The above studies were used as a basis for examining the issue of kernel breakage in South Africa.

TRIALS CONDUCTED
A survey of existing data was carried out to determine whether South African cultivars also display differences in the extent of kernel breakage. In addition, a number of trials were set up using the Beaumont cultivar in order to examine the effect of three factors on whole kernel in the South African macadamia industry, namely:

- Handling of nut in husk (NIH) and nut in shell (NIS)
- Dehusking
- Curing (drying) of NIS.

South African cultivar survey
The ARC-ITSC macadamia cultivar evaluation program has accumulated considerable data on the performance of various cultivars under local conditions. Table 2 shows the percentage whole kernel for nine-year-old trees of nine cultivars grown in three different regions. It can be seen that there are considerable differences between cultivars as well as differences between the same cultivar in different regions. The 816 cultivar tends to produce the highest percentage whole kernel in all of the regions, although the figure ranges from 35% to 53%. In contrast, the Nelmak 2 cultivar (a South African selected hybrid) tends to produce the least whole kernel, with figures ranging from 11% to 26%. Other cultivars, like 788 and 814, tend to provide more consistent whole kernel percentages across the regions. This data suggests that in the long term, growers should focus on characteristics other than yield when selecting cultivars. Many growers with 816 report higher profits for this cultivar despite it delivering lower yields than other cultivars that they grow. This is due largely to the high proportion of whole kernel (pers. com.).

Effect of NIH and NIS handling on kernel breakage
Several trials were conducted to examine the effect of rough handling on the proportion of whole kernel in the Beaumont cultivar. Two of these trials – one for NIH and one for NIS – will be discussed. For the NIH trial, nuts were hand-picked from the trees. These nuts were dropped onto a concrete slab from heights of 0 (control), 2.5, 4.2 and 5.85 m. Each treatment was replicated three times with 75 nuts per replicate in the control and 30 nuts per replicate in the dropping treatments. A further sample was removed from the tree by knocking them to the ground with sticks – standard practice for ‘Beaumont’ in the South African industry. This rough “handling” comprised an additional treatment, with three replicates of 75 nuts each. Figure 1 shows the extent of damage to the husk for nuts dropped 5.85 m.

All nuts were dehusked by hand, dried and cracked by hand. Each treatment was evaluated by determining the percentages whole and half kernel. Figure 2 shows that in addition to whole and half kernels, there were a number of kernels where the two cotyledons had separated over most of the adaxial surfaces but still remained joined near the embryonic axis. These “split” kernels are rare to non-existent in the final packages at cracking plants – probably

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Burgershall</th>
<th>Leuvubu</th>
<th>Merensky</th>
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</tr>
<tr>
<td>N2</td>
<td>18</td>
<td>11</td>
<td>26</td>
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</table>

Source of data: Sippel et al., 2002

Figure 1. Impact damage to the husk of macadamia nuts dropped 5.85 m onto a concrete surface.

Figure 2. In addition to whole and half kernel, hand cracking results in numerous split kernels with the cotyledons joined weakly at the embryonic axis.

Figure 3. Effect of various NIH treatments on the recovery of whole kernel.
because they are separated in the cracking and sorting processes. Since the aim of the trial is to determine the extent of whole kernel, these split kernels were evaluated with the half kernel in the data analysis.

As shown in Figure 3, the various handling treatments had no significant effect on the extent of the whole kernel. Even the 5.85 m drop onto a concrete surface, which caused considerable damage to the husk, appears to have had little effect on kernel breakage.

In the NIS trial, nuts were harvested from the ground and dehusked by hand. Immediately after dehusking, nuts at full moisture (wet in shell = WIS) of around 20% were dropped either once from 0.5 m or 1 m or dropped twice from 1 m. They were then dried to 1% moisture prior to cracking and evaluating. Separate batches of nuts were first dried to 10% moisture content before being dropped once from either 1 m or 2 m or dropped twice from 2 m. These nuts were then dried to 1% moisture before cracking and evaluating. Two final batches of nuts were first dried to 1% moisture before being dropped from either 0.5 m or 1 m. They were then cracked and evaluated. All dropping was done by hand. All drops were onto a hard surface. Drop heights were selected to simulate the heights that nuts are typically dropped under farm and factory conditions at the selected moisture contents. Each treatment comprised three replicates of forty nuts each. Figure 4 shows the effect of the various treatments on the proportion of whole kernel. It can be seen that there were no significant differences in whole kernel between treatments.

It would appear that the rough handling of both NIH and NIS has little effect on the recovery of whole kernel. This is in agreement with the findings of Wallace et al. (2000) and Walton and Wallace (2008). These authors did find, however, that rough handling led to increased shoulder damage and more dusty and oily kernel. The kernel in these trials has yet to be evaluated for these parameters.

**Effect of dehusking and curing on kernel breakage**

A number of dehusking and curing trials were carried out in the current season, also using the Beaumont cultivar. The first of these trials compared hand dehusking to machine dehusking with a Shaw type dehusker. The mechanically dehusked nuts were split into two sub-treatments, with one being cured at room temperature and one at 35°C in a drying oven. Once dry, the nuts were all hand cracked and evaluated for the percentage whole and half kernel. Each treatment comprised three replicates of 60 nuts each.

As is shown in Figure 5, machine dehusking had very little influence on the percentage whole kernel relative to hand dehusking, when the nuts were dried at room temperature (RT). However, when machine dehusked nuts were dried at 35°C, whole kernel increased by 54% rela-
tive to machine dehusked nuts dried at room temperature. Nuts dried at higher temperatures appear to yield more whole kernel – either due to the temperature itself or due to a faster drying rate.

The second trial examined dehusking using machines at several farms. There were two different types of dehusker available – a Shaw type with spring loaded fingers working against a scrolled roller (denoted S in Figure 6) and a newer type with a heavy chain working against a scrolled roller (denoted C). At farm/dehusker 1, two types of nut were used – one with the husk fully hydrated (denoted W) and one in which the husk was dehydrated enough to have split but still be green (denoted D). For farms/dehuskers 2, 3, 4 and 5 the nuts were all fully hydrated. For each dehusker, sufficient nuts were used to allow two drying treatments – one at room temperature and one at 34°C. Each treatment was replicated three times with an average of 135 nuts per replicate for hydrated husks and 175 nuts per replicate for dehydrated husks (sampling was done by weight in this trial rather than by number of nuts). The most obvious trend seen in Figure 6, is the greater percentage whole kernel when nuts were dried at 34°C rather than at room temperature. Amongst the nuts dried at room temperature, those with a slightly dehydrated husk produced significantly more whole kernel than many of the treatments using nuts with fully hydrated husks. This difference was not seen in nuts dried at 34°C. However, this should not be seen as a reason to leave nuts to dehydrate on the orchard floor for extended periods. Walton and Wallace (2009) have shown that this practice may lead to reduced whole kernel and increased shoulder damage as well as severe after roast darkening of kernel. It may also

![Figure 6](image1.png)

Figure 6. Drying temperature and moisture content of the husk appear to play a greater role in kernel breakage than the type of dehusker used.

S = Shaw type dehusker, C = chain type dehusker, W = wet husk, D = partly dehydrated husk, RT = room temperature, (1, 2, 3, 4, 5) = dehusker number

![Figure 7](image2.png)

Figure 7. The effect of various drying treatments on the extent of whole kernel recovery.
reduce kernel shelf life. There were also differences between dehuskers in terms of whole kernel. However, many of these were differences between dehuskers of the same design and manufactured by the same supplier. Since both the Shaw and chain type dehuskers are adjustable in terms of the pressure applied to the NIH, it appears as if some machines are not being properly adjusted and that this leads to more breakage on some farms.

The aim of the final curing trial was to determine the effect of differing drying regimes on the percentage whole kernel. In the first treatment, nuts were dried at room temperature for 1, 2, 3 or 4 days, followed by final drying to 1% moisture at 35°C. In the second treatment, nuts were initially dried at 40°C for 5, 10, 20 or 40 minutes, followed by drying to 1% moisture at 35°C. In the third treatment nuts were dried at 50°C for 5, 10, 20 or 40 minutes followed by drying to 1% moisture at 35°C. In the final treatment, nuts were packed in silica gel at room temperature until they reached 1% moisture. At 1% moisture all nuts were hand cracked and the percentage whole kernel evaluated. As seen in Figure 7, the nuts initially dried at room temperature produced the lowest amount of whole kernel. Despite part of the drying taking place at 35°C, this produced less wholes than the previous trial where nuts were dried only at room temperature (refer to Figures 8 and 9). This is possibly due to the nuts for the two trials being sourced in different growing areas. The nuts dried initially at 40°C and 50°C tended to produce more whole kernel than those dried initially at room temperature, although not all of these recoveries were significantly higher. Where 50°C was the initial drying temperature there was a trend towards higher whole kernel recoveries as the time at 50°C increased. This trend was not apparent at 40°C. Again, it must be noted that these findings may not be applicable commercially as high temperatures can cause damage to kernels, promoting rancidity and a shorter shelf life. Further studies will have to determine the maximum time nuts can be exposed to higher temperatures without the kernel quality being compromised. In the final treatment, nuts were dried at room temperature in silica gel. This compound efficiently absorbs water from the shell, increasing the drying rate without the need to apply heat to the nuts. This treatment produced as much whole kernel as the best heat treatment, and shows that the increase in whole kernel in all of the curing trials is most likely due to increased drying rate rather than exposure to higher temperatures.

In general, it should also be noted that all of the trials conducted achieved percentages of whole kernel equal to or significantly higher than the industry averages for this cultivar. This is possibly attributable to the use of hand crackers. Further trials are being conducted to determine the effect of mechanical crackers on whole kernel.

CONCLUSIONS
As in the Australian industry, there are considerable differences between cultivars in terms of the amount of whole kernel produced. This is an indication that growers planning new orchards (or replanting) should give consideration to factors other than yields when selecting cultivars. There is no evidence arising from these trials that rough handling of NIH or NIS (at any moisture content) will significantly affect the extent of whole kernel recovery. However, as shown by Wallace et al. (2000) and Walton and Wallace (2008), such practices will cause shoulder damage, surface damage, chipping and increase the extent of oily kernel – all of which reduces kernel quality and may negatively influence shelf life. From the data collected, there is no evidence that properly adjusted mechanical dehuskers reduce whole kernel. This is in agreement with the findings of Walton and Wallace (2005). However, differences in whole kernel between similar dehuskers (on different farms) indicates that not all dehuskers are being properly adjusted. Finally, there are clear indications that higher drying rates increase the proportion of whole kernel recovered. In practice this is achieved by higher drying temperatures which have the potential to negatively affect kernel quality and shelf life. This aspect needs further investigation.

ACKNOWLEDGEMENTS
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LITERATURE CITED