RESEARCH PAPER

Maturation studies of pecan nuts grown in Queensland

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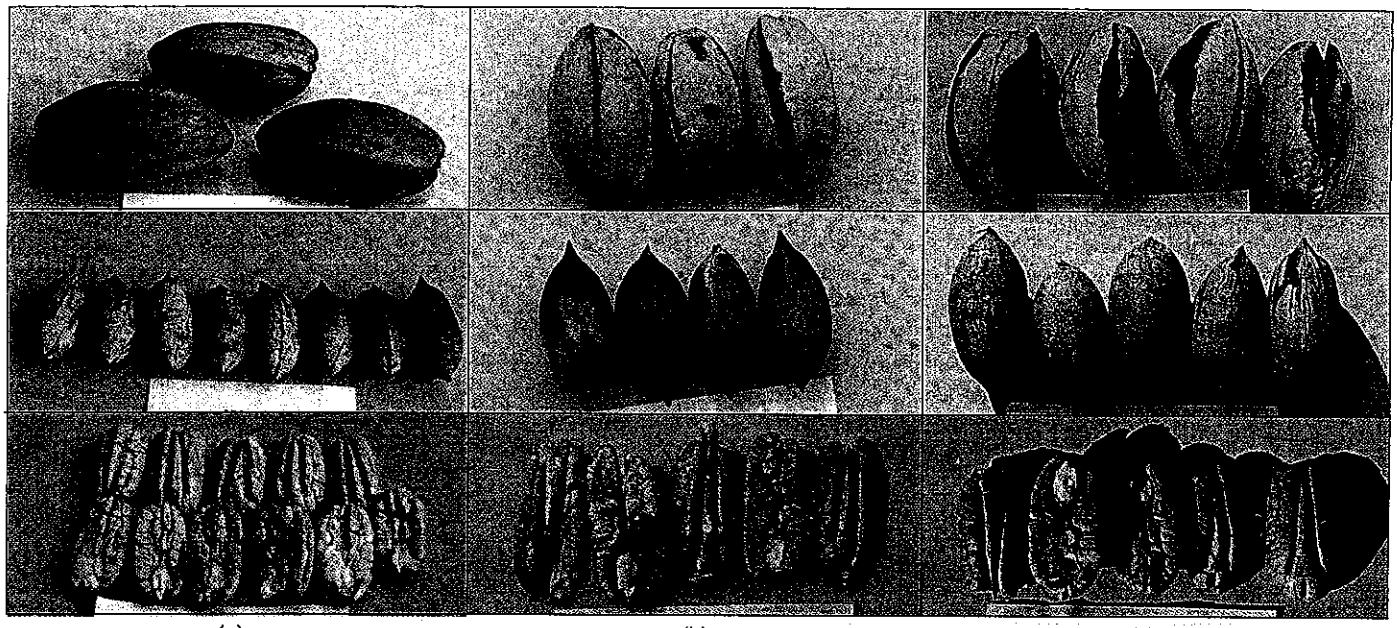
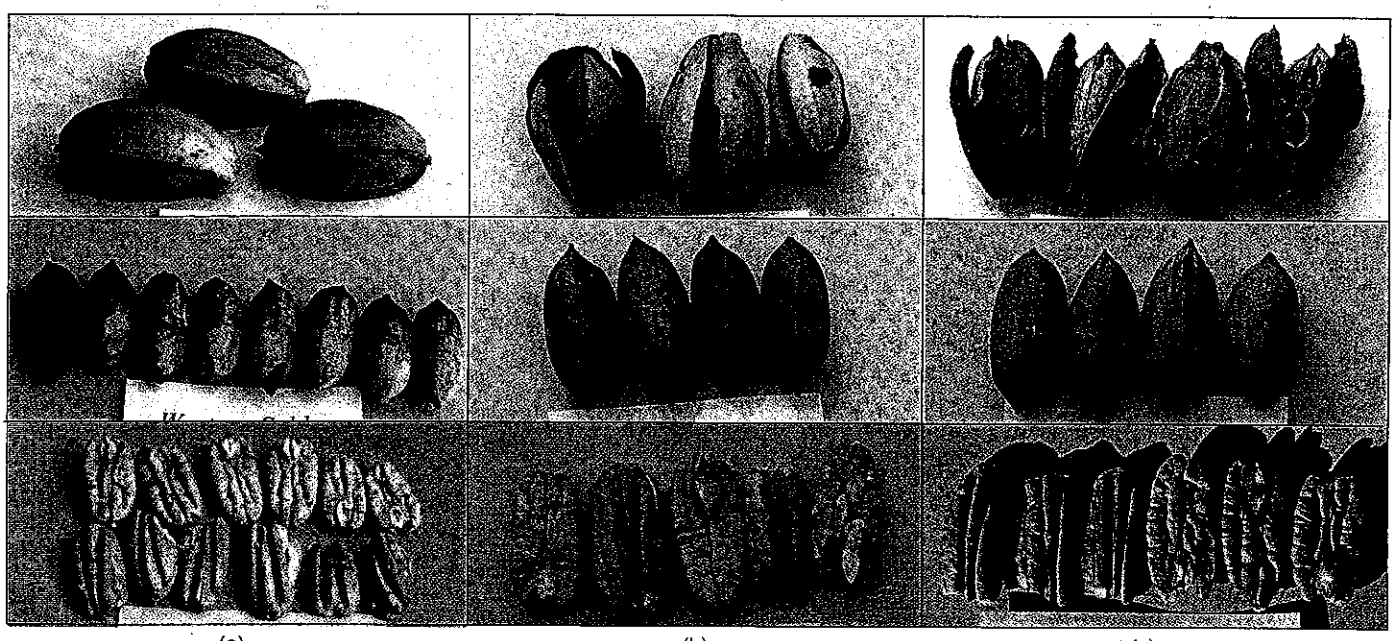
Changes in chemical composition, physical and sensory characteristics were followed in two pecan cultivars Wichita and Western Schley harvested from a commercial orchard at Gatton in Queensland seven times during 1996. Testa colour of both pecan cultivars darkened and opalescence decreased as the nuts matured. Bitterness of Western Schley pecans decreased with maturity. Colour of shuck, shell and kernel of both cultivars developed as the nuts matured. Wichita pecans were larger than Western Schley at all harvest times. Both nut-in-shell and kernel moisture decreased with maturity, whereas oil and sucrose contents increased. Both pecan cultivars had reached advanced maturation by the first harvest on March 18.



(a) (b) (c)

Figure 1. Fruit, nuts in shell and kernels of Wichita pecans harvested at (a) March 18, (b) April 9, (c) April 29



(a) (b) (c)

Figure 2. Fruit, nuts in shell and kernels of Western Schley pecans harvested at (a) March 18, (b) April 9, (c) April 29

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The pecan [*Carya illinoinensis* (Wangenh.) K. Koch] is a native north American plant and an important agricultural crop (Wood & others 1994). In the USA, the pecan became commercially significant in the 1930s and production increased steadily (Heaton & others 1977) reaching 184 369 t in 1999 and 95 059 t in 2000 (Anon 2001).

In Australia, Stahmann Farms Inc. is the only major commercial pecan producer and currently markets 80% of the total Australian production from its orchards at Moree in New South Wales and Gatton in Queensland. The Moree orchard has 700 ha with 68 800 trees (Dodd & others 1995), whereas the Gatton orchard has only 32 ha with 1128 trees (Osborn 1996 personal communication). The main cultivars grown in both orchards are Wichita and Western Schley (Cullen 1995, Dodd & others 1995). A number of small orchards account for the remaining Australian production of pecans.

Pecan quality is usually determined by colour, flavour and texture (Woodroof & Heaton 1967, Kays 1987), filling of kernel and shelling (Woodroof & Heaton 1967) and absence of insect and disease damage (Kays 1987, Herrera 1994). Harvest time (Heaton & others 1975, Kays 1987, Smith & Loustalot 1994), moisture content (Heaton & Beuchat 1980, Kays 1987) and oil content (Kays 1987) are the main factors that affect pecan flavour.

Changes in kernel composition can affect pecan quality. Various researchers have investigated factors such as oil content (Heaton & others 1977), sugar content (Wood & McMeans 1982, Rawash & others 1984, Fourie & Basson 1990), protein content (Hammer & Hunter 1946, Wood & Reilly 1984, Santerre 1994), moisture content (Heaton & others 1977, Heaton & Beuchat 1980, Chinnan 1984), micronutrients (Senter 1976) and phenolic compounds (Senter & others 1980, 1983, Santerre 1994).

Maturity of the pecan nuts can be defined according to whether the nuts are harvested early or late (Sparks 1989). In the USA, pecans are harvested at two stages of maturity. Nuts from early harvests are considered to be mature after the shuck dehisces and the shell turns brown with full development of natural markings. At this stage, the shuck is still green, the nut contains about 30% moisture and the kernel has not developed its full flavour (Thor & Smith 1935, Smith & Loustalot 1944, Sparks 1989, Herrera 1994). Nuts from the late harvest are left on the tree until they dry naturally. At this stage, the shuck dries out and turns brown (Sparks 1989). Flavour, colour and texture usually improve as the nuts mature (Heaton & others 1975, Kays 1987).

Early harvest and subsequent artificial drying have become more common because of the high profitability associated with access to early markets (Kays 1987, Eddy & Storey 1988, Sparks 1989, Herrera 1994, Herrera & others 1994). This practice also reduces exposure of the nuts to birds, insects and pests (Worley 1994) and weight loss (Herrera & others 1994), avoids unfavourable weather and contributes to improved colour and flavour stability (Heaton & others 1975). Whether harvesting of pecans is early or late, Resurreccion & Heaton (1987) stated that pecans tend to mature over a prolonged period of time, making the optimum time to harvest difficult to determine.

In Australia, the nuts are commercially harvested from late April to early July (Durack 1996 personal communication). Currently there is no objective measure of pecan maturity and both the American and Australian industries rely on testa colour to determine harvest time.

While extensive information has been published in the USA on the relationship between chemical composition and changes in maturity, there is no published information on this aspect for pecans grown in Australia. As growing conditions and horticultural practices are different between the two countries, this study aimed to investigate the maturation of Australian grown pecans with particular emphasis on changes in chemical, physical and sensory characteristics. A reliable indication of kernel maturity would also assist the Australian industry in determining the optimum harvest time in order to maximise pecan quality.

Materials and methods

Experimental design

Pecan nuts from the cultivars Wichita and Western Schley were harvested by hand from the Stahmann Farms Gatton, Queensland orchard at weekly intervals between March and April 1996. At each harvest, 200 nuts from each cultivar were collected from the same four trees, with two locations within the orchard considered as blocks. The 200 nuts were taken from all positions on the trees to ensure a representative sample at each harvest.

No attempt was made to compare cultivars in this study because the industry is already aware that there are differences in quality between the two cultivars and in fact processes each cultivar separately.

Physical characteristics

At each harvest, samples of the unshucked pecans, nut-in-shell (NIS) and kernels were visually described and photographed in order to simulate the current commercial practice used to determine maturity and harvest time. NIS (5-10 nuts) were randomly selected and their dimensions (length and diameter) measured using a micrometer. Samples of NIS (10-25 g) and kernel (2 g) were then randomly selected for moisture determination. The remaining NIS were dried at 30°C in a dehumidified dryer to a moisture content of 2%, sealed in lacquered metal cans and held at 4°C. As an indication of nut size, the number of nuts per kg was calculated by weighing the nuts after drying.

Chemical determinations

Duplicate samples (15-20 kernels) of nuts from each treatment were used for all chemical determinations, except for sugar analyses that were performed on single samples. Moisture content and oil content were determined using methods 40.1.04 and 40.1.05 (AOAC 1995) respectively. Oil was expressed as total lipid content on a dry basis. Sucrose content was determined using the procedure of Wills & others (1980), using 85% ethanol/water by volume instead of 85% methanol/water and an amine bonded phase column ("Water" Carbohydrate) instead of a Bondapak/Carbohydrate column; and 83% acetonitrile/water as the mobile phase instead of 80%.

Sensory evaluation

Panellists (12) trained in the evaluation of pecans assessed sensory characteristics of the pecan kernels, in individual booths illuminated with white light (day light

equivalent). Data were collected directly into computers using an integrated software package, *Compusense*® Five Ver 2.4 (Compusense Inc., Canada).

Weekly samples were sealed in lacquered cans and stored at 4°C until all harvests were completed, then presented to the panel according to an incomplete block design. A commercial sample obtained from Stahmann Farms Inc. was included to satisfy the incomplete block design and there were four testing sessions with four treatments tasted per session. The order of presentation of samples to each panellist was randomised at each session.

The kernels were assessed using a standard rating test, AS2542.2.3, Method 2.3 (Standards Association of Australia 1988) for appearance, texture, flavour and overall quality. Appearance attributes included skin colour (0-pale; 100-dark), thickness (0-thin; 100-plump), physical damage (0-none; 100-severe) and opalescence (0-none; 100-total). Opalescence is a visual characteristic associated with oil cell rupture that is evident as bruising around the interior of the pecan kernel (Wakeling & others 2000). Texture was assessed through hardness (0-soft; 100-hard). Flavour was assessed in terms of sweetness, bitterness, astringency, other flavours and total flavour based on all the flavour characteristics. All flavour ratings were made on a 0-100 scale in which 0-none and 100-strong. Finally, overall quality (0-dislike extremely; 100-like extremely) based on all the sensory characteristics was also assessed in order to obtain an indication of preference for each sample.

Statistical methods

Data from physical and chemical measurements from each harvest were compared using a randomised block design and results were analysed by analysis of variance (ANOVA). Mean panellist scores from the sensory evaluation were also analysed using ANOVA according to the incomplete block design. For all variables where significant F-values ($P<0.05$) were found, comparisons of means were then determined using Fisher's least significant difference (LSD) procedure.

Results and discussion

Pecan colour

The shuck, shell and kernel colours of pecans from the early, mid and late harvests are shown in Figure 1 for Wichita and Figure 2 for Western Schley (p 562). Over the experimental period, the shuck colour for Wichita changed from green to yellow and then to yellow-black, whereas Western Schley changed from deep green to yellow and then to dark brown. The shuck of Western Schley changed to black and dried out earlier than that of Wichita. The shell colour of Wichita changed from light yellow to brown with markings developing over time and dense dots apparent at the base of the nuts. Western Schley also changed from light yellow to brown, but dots and markings developed across the whole nut. The kernel colour of Wichita changed from light yellow to brown while Western Schley changed to dark brown. These changes may indicate that Western Schley matured earlier than Wichita. Pecan colour may be a valid practical indicator of harvest time depending on the outcome of the other quality assessments.

Nut dimensions

The physical characteristics of nuts from each of the seven harvests are shown in Table 1. With regard to nut size (NIS/kg) Wichita nuts harvested on March 18 were significantly smaller ($P<0.05$) than nuts harvested on April 22. However, there were no other significant differences ($P>0.05$) in the size of nuts at any other harvests. No significant differences ($P>0.05$) were found between the mean nut size of Western Schley as harvest date advanced.

The length and diameter of nuts from both cultivars changed very little as the harvest time advanced, suggesting that both Wichita and Western Schley may have ceased physiological growth at the first harvest. However, as indicated previously, changes were still occurring in the appearance of the nuts, which may be indicative of compositional and quality changes. Wichita nuts are generally larger than Western Schley.

Moisture content

Wichita nuts harvested in the first four harvests between March 18 and April 9 were significantly higher ($P<0.05$) in NIS moisture than nuts from the final two harvests (Table 2). For Western Schley there was a continual decrease in NIS moisture content as harvest time was delayed (Table 3).

The mean kernel moisture content of Wichita pecans harvested on March 18 was significantly higher ($P<0.05$) than that of nuts from all other harvests and there were no significant differences ($P>0.05$) in the kernel moisture of nuts harvested at the later dates (Table 2). The moisture contents of kernels from Western Schley harvested on March 18 and March 25 were significantly higher ($P<0.05$) than those from all other harvests. The trend was for kernel moisture content to decrease as harvesting was delayed (Table 3).

These results indicate that as harvest date was delayed, both the NIS and kernel moisture content decreased. Even though the nuts seemed to have fully developed in terms of physical size, internal changes were still occurring which may be due to either physical or chemical changes associated with the maturation process.

Oil content

For both cultivars, oil content increased as harvest was delayed. Wichita increased from 42.3 to 62.8% and then remained relatively constant, while Western Schley increased from 44.1 to 68.7% (Tables 2 and 3). Resurreccion & Heaton (1987) found that the oil content of American pecans from early harvests was 72.8%, while at the traditional harvest, the oil content was 70.3%. The oil contents of pecans from this work were lower than that of American pecans for both early and traditional harvests. This may be due to differences in geographic and growing conditions. Thor & Smith (1935) discovered that the amount of oil per nut increased from filling until harvest and remained relatively constant thereafter. Wichita nuts in the current study seemed to follow this trend while the oil content of Western Schley was still increasing at the last harvest. The cultivars evidently reach maturity at different rates (Herrera & Goff 1989, Sparks 1992, Rice 1994), Wichita nuts reaching maturity earlier than nuts from Western Schley.

Sugar content

Sucrose, the only sugar found in detectable quantities, increased over the entire harvest period in both cultivars (Tables 2 and 3).

Wood & McMeans (1982) stated that pecan kernels contain fructose, glucose, sucrose and inositol during

development and that the concentrations decrease as kernels mature. However, Smith & Loustalot (1944) found that total sugars increased in kernels as date of harvest advanced and this finding is supported by the results presented here. However, the sensory panel did not detect any changes in sweetness associated with the increase in sucrose content.

Skin colour

The skin colour (Table 4) of Wichita pecans harvested on March 25 and April 1 was significantly lighter ($P<0.05$) than that of pecans from other harvests, except those harvested on March 18. There was no significant difference ($P>0.05$) in skin colour between pecans harvested on April 9 and April 29. The skin colour (Table 5) of Western Schley pecans harvested on March 25 and April 1 was significantly lighter ($P<0.05$) than that of pecans from other harvests. There was no difference in the skin colour of nuts from these two harvests nor between that of any of the other harvests.

These results indicate that the skin colour of both cultivars darkened slightly as harvest date was delayed. However, as changes in other sensory characteristics were minimal there does not appear to be any justification for using this as an index of eating quality.

Opalescence

The mean opalescence scores (Table 4) of Wichita pecans from the first two harvests were significantly higher ($P<0.05$) than those for all other samples. The

Table 1. Physical characteristics of Wichita and Western Schley pecans at seven stages of maturity

Harvest date	Nut size (NIS/kg)		Length (mm)		Diameter (mm)	
	Wichita	Western Schley	Wichita	Western Schley	Wichita	Western Schley
18.03.1996	177 a	227	46.5 ab	45.2 ab	20.6 a	18.2 b
25.03.1996	162 ab	211	48.4 a	45.9 b	20.5 a	18.6 b
01.04.1996	164 ab	210	48.6 ab	44.5 b	19.9 ab	18.0 b
09.04.1996	159 ab	210	49.8 a	46.4 ab	21.3 a	19.3 ab
15.04.1996	152 ab	217	47.0 ab	45.7 ab	21.1 a	18.0 b
22.04.1996	146 b	223	47.1 ab	43.7 b	20.7 a	18.7 b
29.04.1996	162 ab	215	47.2 ab	44.6 b	20.4 a	18.5 b
LSD (5%)	24.8	NS	3.3	3.3	1.5	1.5

Means followed by a common letter are not significantly different ($P > 0.05$)
NS means not significantly different in ANOVA

Table 2. Moisture, oil and sucrose contents of Wichita pecans

Harvest Date	NIS moisture (%)	Kernel moisture (%)	Oil content (% dry wt)	Sucrose content (% dry wt)
18.03.1996	34.6 a	42.1 a	42.3 a	0.78 a
25.03.1996	32.6 a	24.1 b	55.6 b	1.21 b
01.04.1996	31.2 a	21.4 b	56.6 bc	1.38 b
09.04.1996	29.0 a	25.5 b	53.9 b	1.51 b
15.04.1996	20.3 b	14.7 b	62.8 e	1.88 c
22.04.1996	15.5 b	13.6 b	61.8 de	2.18 cd
29.04.1996	20.2 b	18.2 b	59.2 cd	2.37 d
LSD (5%)	7.8	12.6	3.08	0.350

Means followed by a common letter are not significantly different ($P>0.05$)

Table 3. Moisture, oil and sucrose contents of Western Schley pecans

Harvest Date	NIS moisture (%)	Kernel moisture (%)	Oil content (% dry wt)	Sucrose content (% dry wt)
18.03.1996	41.0 a	36.9 a	44.1 a	1.13 a
25.03.1996	35.6 a	32.3 ab	47.9 b	1.26 ab
01.04.1996	25.1 b	15.1 cd	60.4 d	1.83 bc
09.04.1996	27.5 b	20.8 bc	56.0 c	2.24 cde
15.04.1996	26.7 b	15.0 cd	60.0 d	2.05 cd
22.04.1996	9.1 c	5.8 d	65.4 e	2.83 e
29.04.1996	13.8 c	4.9 d	68.7 f	2.48 de
LSD (5%)	7.8	12.6	1.65	0.625

Means followed by a common letter are not significantly different ($P > 0.05$)

mean opalescence scores of nuts harvested on April 9 was significantly lower (P<0.05) than those of nuts from all other harvests, except those harvested on April 15 and April 29.

The mean opalescence scores (Table 5) of Western Schley nuts harvested on March 25 were significantly higher (P<0.05) than those of nuts from all other harvests, except those harvested on March 18. Pecans harvested on April 15 had significantly lower (P<0.05) opalescence scores than nuts from all other harvests, except those harvested on April 9 and April 29. The level of opalescence of Western Schley pecans was generally lower than that of Wichita, especially in the early harvests.

The commercial samples had significantly higher (P<0.05) opalescence scores than all other samples from the trial.

Overall, opalescence appeared to decrease as harvest time advanced. However, levels of opalescence in this work were low compared to the commercial samples probably because the experimental nuts were hand, not mechanically, cracked.

Hardness

Nuts from the commercial samples were significantly softer (P<0.05) than any samples from the trial. There was no significant difference (P>0.05) in hardness for either pecan cultivar harvested from March 18 to April 29 (Tables 4 and 5). Harvest date has no affect on the texture of either pecan cultivar.

Flavour

There were no significant differences (P>0.05) in flavour attributes between any of the harvest dates for the cultivar Wichita (Table 6).

There were no significant differences (P>0.05) in total flavour, sweetness, astringency and other flavours for the cultivar Western Schley over the experimental period (Table 7). While there were some significant differences (P<0.05) in the bitterness scores, the differences were small and unlikely to be of any practical importance.

Results from this work are not consistent with those of Smith & Loustalot (1944) and Kays (1987) who stated that late harvested pecans can be rancid and bitter. This inconsistency may be because of the different geographical origins of the pecans in this research or because the American nuts were harvested well past the normal harvest time.

Overall quality

There were no significant differences (P>0.05) in overall quality of pecans between any of the harvest dates for both cultivors (Tables 4 and 5).

Conclusion

Results from this investigation indicate that both pecan cultivars had reached an advanced stage of maturation by the first harvest on March 18. However, changes in physical, chemical and sensory characteristics still occurred during the following six weeks. Further experimentation is required to fully understand the maturation of Australian grown pecans and to identify those factors that determine optimum harvest time.

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Table 4. Skin colour, opalescence, hardness and overall quality of Wichita and commercial pecans

Harvest Date	Skin colour*	Opalescence**	Hardness+	Overall quality++
18.03.1996	34 cd	48 b	51 a	50
25.03.1996	29 d	48 b	51 a	48
01.04.1996	30 d	29 c	51 a	52
09.04.1996	44 bc	9 d	54 a	63
15.04.1996	43 bc	15 cd	53 a	67
22.04.1996	48 ab	26 c	55 a	55
29.04.1996	54 ab	15 cd	55 a	67
Commercial	58 a	63 a	45 b	64
LSD (5%)	11.6	14.2	4.3	NS

Means followed by a common letter are not significantly different (P>0.05)
* Line scale (0-pale; 100-dark)
** Line scale (0-none; 100-total)
+ Line scale (0-soft; 100-hard)
++ Line scale (0-dislike extremely; 100-like extremely
NS means not significantly different in ANOVA

Table 5. Skin colour, opalescence, hardness and overall quality of Western Schley and commercial pecans

Harvest Date	Skin colour*	Opalescence**	Hardness+	Overall quality++
18.03.1996	51 a	20 bc	55 a	58
25.03.1996	26 b	29 b	53 a	50
01.04.1996	33 b	19 c	56 a	56
09.04.1996	44 a	10 de	52 a	61
15.04.1996	51 a	7 e	52 a	63
22.04.1996	51 a	16 cd	52 a	62
29.04.1996	50 a	14 cde	52 a	60
Commercial	49 a	75 a	42 b	57
LSD (5%)	7.8	8.8	5.9	NS

Means followed by a common letter are not significantly different (P>0.05)
* Line scale (0-pale; 100-dark)
** Line scale (0-none; 100-total)
+ Line scale (0-soft; 100-hard)
++ Line scale (0-dislike extremely; 100-like extremely
NS means not significantly different in ANOVA

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Table 6. Flavour scores of Wichita and commercial pecans

Harvest date	Flavour*				
	Total flavour	Sweetness	Bitterness	Astringency	Other flavour
18.03.1996	52	17	24	37	7
25.03.1996	53	18	23	31	10
01.04.1996	50	20	23	34	5
09.04.1996	56	23	20	28	4
15.04.1996	54	28	19	28	4
22.04.1996	50	22	21	29	5
29.04.1996	58	28	15	27	3
Commercial	58	28	19	31	6
LSD (5%)	NS	NS	NS	NS	NS

* Line scales (0-none; 100-strong)
NS means not significantly different in ANOVA

Table 7. Flavour scores of Western Schley and commercial pecans

Harvest date	Flavour*				
	Total flavour	Sweetness	Bitterness	Astringency	Other flavour
18.03.1996	58	24	29 a	41	5
25.03.1996	54	22	23 bc	34	4
01.04.1996	55	21	26 ab	38	7
09.04.1996	56	27	24 bc	33	3
15.04.1996	57	26	25 bc	33	6
22.04.1996	57	27	23 bc	32	5
29.04.1996	59	29	22 c	34	3
Commercial	57	27	24 bc	34	4
LSD (5%)	NS	NS	3.2	NS	NS

Means followed by a common letter are not significantly different (P>0.05)
* Line scales (0-none; 100-strong)
NS means not significantly different in ANOVA