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Effect of nitrogen on the skin colour and other quality attributes of ripe 'Kensington Pride' mango (*Mangifera indica* L.) fruit

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SUMMARY
Near-ripe 'Kensington Pride' mango (*Mangifera indica* L.) fruit with green skin colour generally return lower wholesale and retail prices. Pre-harvest management, especially nitrogen (N) nutrition, appears to be a major causal factor. To obtain an understanding of the extent of the problem in the Burdekin district (dry tropics; the major production area in Australia), green mature 'Kensington Pride' mango fruit were harvested from ten orchards and ripened at 20 ± 0.5 ° C. Of these orchards, 70% produced fruit with more than 25% of the skin surface area green when ripe. The following year, the effect of N application on skin colour and other quality attributes was investigated on three orchards, one with a high green (HG) skin problem and two with a low green (LG) skin problem. N was applied at pre-flowering and at panicle emergence at the rate of 0, 75, 150, 300 g per tree (soil applied) or 50 g per tree as foliar N for the HG orchard, and 0, 150, 300, 450 g per tree (soil applied) or 50 g per tree (foliar) for the LG orchards. In all orchards the proportion of green colour on the ripe fruit was significantly ($P<0.05$) higher with soil applications of 150 g N or more per tree. Foliar sprays resulted in a higher proportion of green colour than the highest soil treatment in the HG orchard, but not in the LG orchards. Anthracnose disease severity was significantly ($P<0.05$) higher with 300 g of N per tree or foliar treatment in the HG orchard, compared with no additional N. Thus, N can reduce mango fruit quality by increasing green colour and anthracnose disease in ripe fruit.

Skin colour is an important quality parameter for 'Kensington Pride' mango (*Mangifera indica* L.). During typical ripening, its skin colour changes from green to yellow, often with a pink to red blush on the sun-exposed side of the fruit. Ripening also results in flesh softening, conversion of starch to sugars, loss of acidity and development of ripe flavours and aromas (Hofman *et al*; 1997 a). However, in some fruit, loss of green colour occurs more slowly than the other ripening changes, resulting in green soft fruit (Hofman *et al.*, 1997a). These fruit sell more slowly on wholesale and retail markets and often at a lower price. Green ripe fruit is one of the major quality problems with 'Kensington Pride' mangoes on the Australian market.

Several factors can affect fruit skin colour. McKenzie (1994) reported that 'Heidi', 'Haden' and 'Tommy Atkins' mango had little green skin colour when soft. However, ripe 'Sensation', 'Keitt' and especially 'Kent' fruit often retained significant green skin colour. Higher rates of pre-harvest nitrogen (N) fertilizer can significantly increase the amount of green colour on apple fruit at harvest and after storage (Neilsen *et al.*, 1984; Fallahi *et al.*, 1985; and Raese and Drake, 1997). A survey of mango grower fertilizer practices in South Africa suggested a link between the green skin colour of ripe 'Sensation' mangoes and the amount of pre-harvest N application (Oosthuyse, 1993; McKenzie, 1994). Fruit from orchards with a low soil N status de-greened completely when ripe, while those from orchards with moderate or high soil N either failed to de-green appreciably or did not de-green at all. These results suggest that N fertilizer regimes can be manipulated to improve the skin colour of ripe 'Kensington Pride' mango on the retail shelf. In addition to influencing fruit colour, high N rates have also been reported to increase fruit rots in avocado (Abou Aziz *et al.*, 1975), nectarine (Daane *et al.*, 1995), and tomato (Segall *et al.*, 1977; Bartz *et al.*, 1979). Other factors such as light exposure, position in the canopy and fruit maturity at harvest can also affect skin colour (Seymour *et al.*, 1990; Hofman *et al.*, 1995, 1997b).

The objectives of the present study were to gain understanding of the extent of the green fruit colour problem in the major production region in Australia and investigate whether N fertilizer practices affected skin colour. In the first year a small survey of ten representative orchards was conducted to confirm that green skin on ripe fruit was a problem in the region. The survey was also anticipated to suggest causal factors and potential sites for further research. In the following year, a more detailed investigation was conducted on fruit responses

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TABLE I

Survey. Soil type, nitrogen status, the proportion of green colour on the skin (%green skin area), the severity of anthracnose (% of the skin area affected) and stem-end rots (% of the flesh volume affected), days to ripe (DTR) and the flesh total soluble solids (TSS) and acidity of ripe 'Kensington Pride' mangoes from ten commercial orchards and ripened at 20 ±0.5°C

Orchard	Soil type	N status[1] (g N/ tree)	Green colour (%)		Anthracnose (%)		SER (%)		DTR (days)	TSS (°Brix)	Acidity (%)
1	SL	L (0)	12.7^{a}	(4.8)	0.0^{a}	(0.0)	2.8^{a}	(0.2)	17.2^{a}	13.4^{e}	0.14^{c}
2	SL	H[2] (160)	42.1^{f}	(44.9)	0.5^{ab}	(0.0)	4.7^{ab}	(0.7)	18.6^{b}	11.9^{bcd}	0.11^{a}
3	HCL	H (305)	32.2^{de}	(28.3)	0.2^{ab}	(0.0)	15.8^{de}	(7.4)	19.0^{b}	10.9^{a}	0.12^{ab}
4	HCL	M (89)	32.4^{de}	(28.7)	0.8^{abc}	(0.0)	12.8^{cd}	(4.9)	18.9^{b}	12.7^{de}	0.11^{a}
5	HCL	H (392)	36.1^{e}	(34.8)	3.2^{e}	(0.3)	35^{f}	(34.4)	19.4^{b}	11.5^{abc}	0.11^{a}
6	HCL	H (347)	31.8^{de}	(27.8)	1.4^{bcd}	(0.1)	9.7^{abcd}	(2.9)	16.4^{a}	13.2^{e}	0.13^{bc}
7	HCL	M (143)	29.9^{cd}	(24.9)	0.8^{abc}	(0.0)	7.1^{abc}	(1.5)	16.5^{a}	11.9^{bcd}	0.14^{c}
8	HCL	L (0)	29.9^{cd}	(24.9)	2.3^{de}	(0.2)	21.0^{e}	(12.8)	19.5^{b}	12.2^{cd}	0.11^{a}
9	HCL	L (0)	26.3^{c}	(19.6)	2.1^{cde}	(0.1)	11.3^{bcd}	(3.8)	19.1^{b}	11.3^{ab}	0.13^{bc}
10	SL	M (0)	18.8^{b}	(10.4)	0.0^{a}	(0.0)	3.0^{a}	(0.3)	18.9^{b}	12.6^{de}	0.13^{bc}
LSD			4.6		1.3		7.1		1.0	0.8	0.01

[1]N status was based on N fertilizer history as supplied by the growers. The values in brackets are the pre-harvest N applications per tree applied in the current season. L, M and H are classified as low, moderate and high N status.

[2]Orchard 2 is classified as high N status because of heavy N applied in previous years (with indication of high leaf N).

SL = sandy loam, HCL = heavy clay loam.

The percentage data for diseases are degrees angular transformed, with back transformed means presented in brackets. Means followed by the same letter in the each column are not significantly different based on LSD at $P<0.05$.

to soil and foliar N applied near flowering time. Three orchards with differing green skin severity were used in the one season, since soil and cultural factors are more likely to influence the interaction between N and fruit quality than seasonal factors.

MATERIALS AND METHODS

Survey (1999/2000)

Ten orchards in the Burdekin district of north Queensland, Australia (dry tropics; latitude 19°-21°S) with a range of soil types and history of green ripe fruit were selected for the survey. The soil type was recorded for each orchard and the N status described as low, medium or high based on pre-harvest N fertilizer history (Table I). Ten green mature 'Kensington Pride' fruit were harvested from the northern, outer canopy sector from each of six representative trees in each orchard in late November 1999 (commercial maturity). The fruit were packaged in commercial trays and transported by air to the laboratory in Nambour, SE Queensland within 24 h of harvest.

Nitrogen trial (2000/2001)

From the survey, one orchard on a sandy loam soil producing green ripe fruit (high green or HG) and two orchards, one on sandy loam soil and the other on heavy clay loam soil producing ripe fruit with little green skin colour (low green or LG1 and LG2, respectively) were used in fertilizer trails. The N concentrations in leaves (n = 30) just before treatment were 1.37 (± 0.02)%, 1.07 (± 0.02)%)% and 1.12 (± 0.01)% for HG, LG1 and LG2 orchards, respectively. Soil N as nitrate, measured in pooled samples from each orchard, was 3.4, 1.4 and 1.3 mg kg^{-1}, respectively (see *Mineral analysis* section for sampling methods).

Six single-tree replicates per treatment were randomly assigned within five rows in each orchard with a guard tree in between each tree. No N was applied to the guard trees. The 8 m spacing between the rows and the small size of the trees resulted in minimal root or canopy overlap of trees between or within rows. Nitrogen as ammonium nitrate was applied at pre-flowering on 4 July 2000 and at panicle emergence on 28 August 2000 at 0, 75, 150, 300 g per tree or foliar sprays for the HG orchard, and 0, 150, 300, 450 g per tree or foliar sprays for the LG orchards (Table II). Soil applications were spread evenly under the canopy of each tree. The foliar treatments were applied as four sprays of 0.75% ammonium nitrate by spraying trees with a low-pressure backpack spray with 12.5 g N per tree per spray. Foliar sprays were applied in the absence of wind to eliminate spray drift. Trees were irrigated by under tree sprinklers immediately after soil application and then regularly thereafter based on standard commercial practice. Other macro- and micro-elements were applied according to standard commercial practice to all trees (Kernot *et al*, 1998).

At commercial maturity on 24 November 2000 for HG and LG1 orchards and 30 November 2000 for the LG2 orchard, 12 green mature 'Kensington Pride' fruit were

TABLE II

Nitrogen trials. Nitrogen treatments (g of elemental N per tree) applied at pre-flowering on 04/07/00 and panicle emergence on 28/08/00 for 'Kensington Pride' mango trees. The N was applied as ammonium nitrate within the drip zone of each datum tree

Treatment, (total g N/tree)	pre-flowering, (g/tree)	panicle emergence, (g/tree)
HG orchard		
0	0	0
75	50	25
150	100	50
300	200	100
Foliar[1]	50	-
LG orchards		
0	0	0
150	100	50
300	200	100
450	300	150
Foliar[1]	50	-

[1]Four foliar sprays. Total of 50 g N (0.75% ammonium nitrate/5 l containing 12.5 g N per tree) on 04/07, 18/07, 14/08 and 28/08/00.

harvested from the northern outer canopy sector of each tree. A total of 72 fruit per treatment were transported to the Nambour postharvest laboratory. Fruit were dipped in hot Spin Flo® (carbendazim 50% a.i) ($1gl^{-1}$) at 52°C for 5 min within 24 h of harvest.

The total fruit weight and fruit number per datum tree were recorded for the HG and LG2 orchards. Average fruit weight per tree was calculated by dividing the total fruit weight by the fruit number per tree.

Fruit quality assessment

The fruit were ripened at 20 ± 0.5 ° C and 80-90% relative humidity without added ethylene. Fruit firmness was assessed by gentle hand squeezing using a 1-6 rating scale where 1 = hard, 2 = rubbery, 3 = sprung, 4 = softening, 5 = eating soft (ripe) and 6 = over soft (over ripe). Firmness rating 5 was equivalent to approximately 4 Newtons (N) force required to push an 8 mm hemispherical probe 2 mm into the fruit (skin not removed) using an Instron Universal Testing Machine model 1122 (Instron Ltd, UK). Regular checking was made with the Instron to ensure consistency of the hand firmness assessment. The number of days to ripe (DTR) was recorded as the number of days from harvest for each fruit to reach a firmness rating of 5.

When ripe, fruit were visually assessed for skin colour by estimating the percentage of the skin surface area with green colour (proportion green colour). Colour intensity of the greenest part of the skin was measured with a Minolta Colourmeter (Model CR-200/CR-210, Japan). The results were expressed as hue angle (Voss, 1992).

Anthracnose and stem-end rots (SER) were characterized based on the appearance of the lesions as described by Coates *et al.* (1995). Anthracnose severity was rated as the percentage of skin surface area affected and SER severity as the percentage flesh volume affected.

Flesh samples excluding skin were taken from the middle equatorial section of each fruit. All fruit samples from each tree were pooled and blended to provide one representative sample per tree. Total soluble solids (TSS) expressed as °Brix was measured on the blended sample with an Atago (Model 3T, Japan) bench refractometer. Titratable acidity (expressed as % citric acid) was measured on 10 g of blended fruit pulp diluted with 10 ml water by titrating with 0.1 M sodium hydroxide to pH 8.2 using a Titrino Model 719S autotitrator (Metrohm, Herisau, Switzerland).

Total skin chlorophylls and carotenoids concentrations were determined on a 12 mm diameter skin disc taken from the greenest part of the skin of each of three ripe fruit from each tree. The flesh was removed from under each disc for a disc thickness of less than 1 mm. The discs were homogenized with 2 ml of 80% acetone and centrifuged at 2000 **g** for 5 min. The residue was washed with another 2 ml of 80% acetone and centrifuged again. The combined supernatants were made up to 5 ml with 80% acetone. Total chlorophylls (*a* and *b*) and carotenoids (xanthophylls and ß-carotene) were determined by measuring the absorbance at 663, 646 and 470 nm. The concentrations (expressed by µg, cm^{-2}) were calculated according to the method of Lichtenthaler (1987): $C_a = 12.5\ A_{663} - 2.79\ A_{646}$, $C_b = 21.50\ A_{646} - 5.10\ A_{663}$, $C_{x+c} = (1000\ A_{470} - 1.82\ C_a - 85.02\ C_b)/198$; where C_a, C_b are chlorophyll a and b. Total chlorophylls (a + b) = $C_a + C_b$, C_{x+c} is total carotenoids (xanthophylls and ß-carotene), and A663, A646 and A470 are absorbance at 663, 646, and 470 nm.

Minerals analysis

Leaf samples were collected before N application at pre-flowering in early July, at panicle emergence in late August and at harvest in late November. Twenty most recently mature leaves from randomly selected branches around each tree were picked, washed with deionized water and dried at 60°C for 2 d in a forced-draught oven (Catchpoole and Bally, 1996). After drying, the N concentration was determined by the Dumas total-combustion method using a Leco CHN-1000 elemental analyser (Leco Inc., St. Joseph, MI, USA). The results were expressed as percentage dry weight N in the leaf. Soil samples were taken from four positions under the canopy of each tree at pre-flowering, and the samples pooled for each orchard. The samples were dried at 60°C for 2 d and then analysed at a commercial laboratory (Incitec Ltd, Brisbane).

Statistical analysis

Data were analysed with Genstat® 5 version 4.2 (Lawes Agricultural Trust, UK). The general analysis of variance model with a completely randomized design and a treatment^x tree structure was used. Six replications (trees) per treatment were used, with 10 and 12 fruit per replication for the survey and the nitrogen trials, respectively. Skin colour, anthracnose and stem-end rot ratings with percentage data were angular transformed in degrees prior to analysis. The back-transformed means are shown in brackets in the tables.

RESULTS

Survey (1999/2000)

Skin colour and pigments: The proportion of skin green colour was significantly different ($P<0.05$) between orchards. Fruit from orchards 2 and 5, both with a high N fertilizer history, had more green colour than fruit from orchards 1 (low N) and 10 (medium N) (Table I). Seven orchards had fruit with more than 25% of the ripe fruit skin coloured green.

Significant differences ($P<0.05$) in hue angle and chlorophylls concentration between orchards were recorded and were similar to those for proportional green colour (data not presented). Regression analyses revealed that there were significant positive relationships between the proportion of green colour and hue angle ($y = 75.5 + 0.38x$, $r = 0.87$, $P = 0.001$, $n = 60$) and the proportion of green colour and skin chlorophylls concentration ($y = 1.71 + 0.17x$, $r = 0.78$, $P = 0.001$, $n = 60$). Thus, fruit with a higher proportion of the skin area with green colour also had more intense green colour in the greenest part of the skin. The pattern of skin carotenoids concentrations between the orchards was not similar to the pattern of chlorophylls concentrations (data not presented). Nonetheless, there was still a significant relationship between the proportion of green colour and carotenoids concentration ($y = 2.95 + 0.05x$, $r = 0.65$, $P = 0.001$, $n = 60$).

Diseases: Anthracnose severity was generally low in all ten orchards while SER severity was high in five orchards (Table I). Anthracnose severity was significant-

ly ($P< 0.05$) lower in fruit from orchards 1, 2 and 10 on sandy loam compared with fruit from orchards 5, 8 and 9 on heavy clay loam soil. Fruit from orchards 1, 2 and 10 also had significantly ($P< 0.05$) lower SER severity than fruit from orchards 3, 4, 5 and 8 on heavy clay loam.

Other quality attributes: Fruit from orchards 1, 6 and 7 ripened significantly ($P< 0.05$) more rapidly than those from the other orchards (Table I). There was a significantly positive relationship between SER and DTR ($y = -47.1 + 3.2x$, $r = 0.42$, $P = 0.01$, $n = 60$), but no significant relationship between anthracnose and DTR ($r = 0.28$, $P>0.05$). TSS was significantly ($P<0.05$) higher in fruit from orchards 1, 4 and 6 and lower in fruit from orchards 3, 5 and 9. Acidity was significantly ($P<0.05$) higher in fruit from orchards 1, 7 and 9 and lower in fruit from orchards 2, 4, 5 and 8.

Nitrogen trial (2000/2001)

Leaf nitrogen: In the HG orchard there was no effect of N application on leaf N either at panicle emergence or at harvest (Table III). In contrast, the % leaf N in the LG orchards was significantly ($P<0.05$) higher in the 450 g N treatment compared with untreated trees. A significant relationship ($y = 0.88 + 0.004x$, $r = 0.44$, $P = 0.05$, $n = 30$) between leaf N at panicle emergence and the proportion of fruit skin green colour was only observed in the LG1 orchard, but not with leaf N at other time in any orchards.

Fruit yield: Yield was not significantly ($P>0.05$) affected by treatment in the HG orchard (Table III). In the LG2 orchard, the foliar treatment plants had a lower fruit yield than those of the 300 and 450 g N per tree treatment. However, there was no significant ($P>0.05$) difference between the control and the soil treatments. The average fruit weight was also not affected by treatment in both orchards (data not presented).

TABLE III

Nitrogen trials. The effects of N application to soil or foliar treatment on 'Kensington Pride' leaf nitrogen concentration at pre-flowering on 04/07/00, panicle emergence on 28/08/00 and harvest on 24 & 30/11/00, and fruit yield per tree

Treatment (g N/tree)	Leaf N (%)	Panicle emergence	Yield (kg/tree)
HG orchard 2			
0	1.19	1.12	72.0
75	1.19	1.16	82.5
150	1.19	1.12	77.2
300	1.22	1.12	85.6
Foliar	1.22	1.12	70.1
LSD	n.s	n.s	n.s
LG1 orchard			
0	0.87^{a}	0.92^{a}	-
150	0.93^{ab}	1.04^{ab}	-
300	0.96^{ab}	0.98^{ab}	-
450	0.97^{b}	1.05^{b}	-
Foliar	0.96^{ab}	0.94^{ab}	-
LSD	0.10	0.12	-
LG2 orchard			
0	1.04^{a}	0.96^{a}	39.7^{ab}
150	1.11^{b}	1.06^{ab}	35.9^{ab}
300	1.14^{b}	1.10^{ab}	49.4^{b}
450	1.12^{b}	1.14^{b}	40.7^{b}
Foliar	1.12^{b}	1.05^{ab}	23.3^{a}
LSD	0.07	0.16	17.1

Means followed by the same letter in each column are not significantly different at $P<0.05$. n.s = not significant.

Skin colour and pigments: In the HG orchard, fruit from trees treated with 150 g N per tree and above or with foliar sprays had significantly ($P<0.05$) higher proportion of green colour than fruit from trees treated with 0 or 75 g (Table IV). There was no significant ($P>0.05$) difference in the proportion of green colour between 150 and 300 g.

TABLE IV

Nitrogen trials. The effects of N application to soil or foliar treatment (50 g N per tree) on the proportion of green colour on the skin, the severity of anthracnose (% of the skin area affected) and stem-end rots (% of the flesh volumes affected), days to ripe (DTR) and total chlorophylls of the greenes part of the skin of ripe 'Kensington Pride' mangoes ripened at 20°C ±0.5

Treatment (g N/tree)	Green colour (%)		Anthracnose (%)		SER (%)	DTR (days)	Total chlorophylls (μg cm^{-2})	
HG orchard								
0	15.8^{a}	(7.4)	11.7^{a}	(4.1)	8.2	(2.1)	21.6	6.8^{a}
75	18.1^{a}	(9.7)	13.2^{ab}	(5.2)	9.8	(2.9)	21.9	7.5^{a}
150	25.7^{b}	(18.8)	13.1^{ab}	(5.1)	7.7	(1.8)	21.0	9.7^{b}
300	26.9^{b}	(20.5)	15.5^{b}	(6.9)	9.7	(2.8)	21.1	10.8^{b}
Foliar	32.1^{c}	(28.3)	20.2^{c}	(11.9)	13.3	(5.3)	20.9	11.0^{b}
LSD	4.2		3.7		n.s		n.s	1.5
LG1 orchard								
0	4.5^{a}	(0.7)	11.1	(3.7)	3.1	(0.3)	23.0^{ab}	--
150	8.5^{b}	(2.2)	14.2	(6.0)	3.4	(0.4)	24.1^{bc}	--
300	21.7^{d}	(13.7)	14.8	(6.5)	5.5	(0.9)	24.5^{c}	--
450	26.0^{e}	(19.2)	12.2	(4.5)	3.5	(0.4)	22.7^{a}	--
Foliar	12.4^{c}	(4.6)	13.2	(5.2)	5.8	(1.0)	22.8^{ab}	--
LSD	3.7		n.s		n.s	1.3		
LG2 orchard								
0	7.1^{a}	(1.6)	24.0	(16.6)	6.8	(1.4)	22.0^{c}	--
150	12.2^{b}	(4.5)	25.2	(18.1)	2.7	(0.2)	21.6^{c}	--
300	22.8^{d}	(15.0)	22.7	(14.9)	2.8	(0.3)	21.4^{c}	--
450	30.7^{e}	(26.0)	26.0	(19.2)	2.7	(0.2)	20.4^{b}	--
Foliar	17.8^{c}	(9.3)	22.5	(14.7)	4.3	(0.6)	19.4^{a}	--
LSD	4.5		n.s		n.s	0.8		

The percentage data are degrees angular transformed, with back-transformed means presented in brackets. Means followed by the same letter in each column are not significantly different based on LSD at $P<0.05$. n.s = not significant.

In both LG orchards, the proportion of green colour from the 0 g N treatment was low, while all soil applications resulted in significantly ($P<0.05$) higher proportions in both orchards (Table IV). In contrast to the HG orchard, fruit from the foliar N treatment had significantly ($P<0.05$) lower proportion of green colour than fruit from the 300 or 450 g soil N treatments. N treatment effects on hue angle were similar to those on the proportion of green colour (data not presented).

Skin chlorophyll concentrations in the greenest part of the skin (HG orchard only) were significantly ($P<0.05$) higher in fruit from trees treated with 150 g N per tree and above and with foliar sprays, compared with the trees treated with 0 g or 75 g per tree (Table IV). There was no significant ($P>0.05$) difference in fruit skin chlorophylls concentrations between the 150 or 300 g N per tree or foliar spray treatments (data not presented). Significant positive relationships were noted between skin chlorophylls concentration and soil N application ($y = 7.1 + 0.0Ix$, $r = 0.72$, $P = 0.01$, $n = 24$). Nitrogen application did not significantly ($P>0.05$) affect the carotenoids concentration.

Diseases: Anthracnose severity was significantly ($P<0.05$) higher with 300 g N per tree and the foliar treatment in the HG orchard, but there were no treatment effects on anthracnose severity in the two LG orchards (Table IV). SER was not significantly ($P>0.05$) affected by N treatments (data not presented).

Other quality attributes: There was no treatment effect on DTR in the HG orchard (Table IV). In the LG2 orchard, the DTR was significantly ($P<0.05$) shorter with 450 g N and foliar N compared with 0, 150 or 300 g N treatments, but there were no consistent treatment effects in LG1. DTR was positively correlated to anthracnose ($y = -22.8 + 1.5x$, $r = 0.67$, $P = 0.001$, $n = 30$) and SER ($y = -16.4 + 0.9x$, $r = 0.44$, $P = 0.05$, $n = 30$) in the LG1 orchard only. The flesh TSS and acidity were not significantly ($P>0.05$) affected by N application in all three orchards (data not presented).

DISCUSSION

The results from the orchard survey confirm that soil type and N supply can affect 'Kensington Pride' mango quality, skin colour, fruit ripening rate (DTR), TSS and acidity and disease. The results support observations that retention of green colour on ripening fruit at the wholesale markets is an important quality issue (Ledger, 1996). Trees on sandy loam soil were more likely to produce fruit with less green colour than those on clay soils. However, N history was also a interacting factor since orchard 2 on sandy loam, which was classified as a high N orchard based on past fertilizer history and soil analysis, produced fruit with a high proportion of green colour. Other factors may also be involved, given that orchard 8 had a low N status classification, but produced ripe fruit with more than 25% green colour.

The link between pre-harvest N and skin colour was confirmed by the nitrogen trials. In all three orchards, high N application rates resulted in greener coloured ripe fruit. Oosthuyse (1993) also found that fruit from 'Sensation' mango trees fertilized with more N had a lesser ability to de-green during ripening than fruit from trees fertilized with less N. Similar results have also been obtained for apples (Neilsen *et al.*, 1984; Fallahi *et al.*, 1985) and in a second season's trial using different N application rates and time of application for 'Kensington Pride' mango (data not presented).

The effect of N fertilization on enhancing the chlorophylls concentration in fruit skin is supported by the known roles of N in plants. There is a direct correlation between increased N nutrition and increased photosynthetic activity in leaves (Evans, 1989). Nitrogen is either partitioned into CO_2 fixing enzymes such as ribulose 1,5-bisphosphate (RuBP) or proteins associated with chloroplast thylakoid membranes. Visually, increased N fertilization can be seen as increased green colour. Strong positive relationships between chlorophylls and N concentration exist because a large proportion of leaf N is bound up in proteins that complex the chlorophyll pigments (Evans, 1989). Fruit are strong sinks for N in perennial plants, often drawing N from leaves and other reserves (Lea, 1993). Therefore, excess N applied to fruit trees is likely to be partly partitioned into fruit skin because of their photosynthetic capability for all or part of their development. Foliar sprays of urea significantly increased the chlorophylls concentrations in apple fruit skin (Reay *et al.*, 1998). Our data indicate that chlorophylls concentration in the skin of 'Kensington Pride' mangoes was closely related to green skin colour and that both were promoted by N fertilization.

Ripening in many fruit involves degradation of some pigments and synthesis of others (Goldschmidt, 1980). The change in colour from green to yellow during mango ripening is influenced by the rates of chlorophylls breakdown and of carotenoids synthesis (Medlicott *et al.*, 1986). The current results suggest that chlorophylls play a greater role in skin colour changes in ripening 'Kensington Pride' than carotenoids, since the proportion of green colour showed a stronger relationship to chlorophylls concentrations than to carotenoids concentrations. In addition, N treatments that increased the proportion of green skin colour also increased chlorophylls concentration. In contrast, there was little effect on carotenoids concentration.

Our results indicate that previous N fertilizer regime and a history of green ripe fruit need to be considered when deciding N application rates. A high proportion of green colour in the fruit from HG control trees compared to the LG control trees was evidently due to higher soil and leaf N in the HG trees. In addition, the response to N application varied in accordance with the initial soil and leaf N and history of green fruit. For example, both LG orchards had a greater response to 300 g per tree N application rates than the HG trees. In contrast to N application to the soil, foliar treatment increased the proportion of green colour in the HG orchard but not in the LG orchards. In apples, foliar N treatment was found to increase fruit green colour more than soil N application (Meheriuk *et al.*, 1996). The smaller response to foliar sprays in the LG orchards may be partly explained by the lower leaf N concentration in these orchards compared with HG.

Fertilizer history also affects other aspects of fruit quality. The orchard survey results suggested that soil type may influence diseases since anthracnose and SER

severity were both lower from orchards on sandy loam soils. Additionally, in the N trial, high N rates increased anthracnose severity on one orchard, despite the fact that the fruit were treated with hot fungicide after harvest. Similar effects of N increasing fruit diseases have been reported for other fruits (Abou Aziz *et al.*, 1975; Segall *et al.*, 1977; Bartz *et al.*, 1979; Daane *et al.*, 1995). Such N effects could occur through reduced concentrations of phenolics, lignin and silicon in plant tissues (Matsuyama and Dimond, 1973; Menzies *et al.*, 1991). High N rates can also increase susceptibility to the physiological disorders of 'soft nose' (Young *et al.*, 1965) and 'necrosis' (Ram *et al.*, 1988) in mangoes. The form of N applied also needs to be considered. It is possible that the ammonium ion could be antagonistic to the absorption of Ca (Pill *et al.*, 1978; Witney *et al.*, 1990), leading to reduced Ca uptake and transport into fruit with associated increased physiological disorders. In addition, the positive relationship between DTR and disease severity in the LG1 orchard and between SER and DTR in the survey, indicates that fruit that take longer to ripen are likely to have a higher disease severity. A similar result was reported on avocado (Hopkirk *et al.*, 1994). However, there is a need for further research since the links between DTR and disease were variable in this experiment.

The present results clearly demonstrate that increased N application can increase the green ripe fruit problem in 'Kensington Pride' mangoes as well as possibly increase anthracnose disease. Small effects on yield and other quality attributes, such as flesh TSS and acidity, suggest that soil N could be reduced to improve skin colour in these orchards without a pronounced negative yield response. However, the balance between yield and quality needs to be investigated over several seasons because of the large effect of seasonal and tree effect on yield. Nevertheless, it was clear that N applications had a stronger effect on mango fruit skin colour than on yield in these orchards.

The poor regression between leaf N and the proportion of green colour on ripe fruit suggests that using leaf N to predict fruit colour, as used on apples (Raese and Williams, 1974), may not be practical in 'Kensington Pride' mangoes since only one orchard showed a significant relationship. An estimate of green skin colour intensity would better indicate the proportion of green colour in the ripe skin, as indicated by the regressions between the proportion of green colour, and chlorophyll concentration and hue angle. N application could be adjusted during fruit growth or after harvest as required. Further research in several seasons would be required to confirm this approach.

Pre-harvest measures to reduce green colour in ripe fruit need to be considered in conjunction with postharvest ripening and storage practices. Ripening temperature and the use of ethylene can affect the skin colour (Nguyen *et al.*, 2002), indicating that an integrated approach to reducing green ripe fruit is required.

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