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Artigo/Article

Influence of late nitrogen soil applications on mandarin fruit quality

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SUMMARY

Nitrogen (N) application influences tree growth, yield, as well as appearance and internal quality of Citrus fruit. Adequate availability of N during flower initiation and fruit development is important to support optimal yield, however, over-application could negatively influence rind quality. The objective of this study was to determine the influence of N application during the later stages II and III of Nules Clementine and Nadorcott mandarin (*Citrus reticulata* Blanco) fruit development. Late N was soil-applied at 20 and 40 $kg^{-1}\cdot ha$ at 140 and 170 days after full bloom (DAFB) as well as 1% urea at 180 DAFB on 10 trees per treatment in two orchards, in addition to 250-300 $kg^{-1}\cdot ha$ N applied commercially. These cultivars are harvested in May and August, respectively, in South Africa, and are susceptible to postharvest rind disorders. Fruit from the N-treated trees were stored at -0.6°C or 4°C for 30 days to determine the impact of postharvest stress on the external and internal quality. For both cultivars, in all the orchards, no significant differences due to N-application, with respect to fruit coloration or rind disorders were recorded. The results suggest a possible advantage of later N application in mandarin cultivars, without negatively affecting external or internal fruit quality.

Index terms: rind condition, physiological disorder, mineral nutrition.

Influência da aplicação tardia de nitrogênio no solo na qualidade dos frutos de tangerinas

RESUMO

A aplicação de nitrogênio (N) influencia o crescimento das plantas, o rendimento, bem como a aparência e a qualidade interna dos citros. A disponibilidade adequada de N durante o início da flor e o desenvolvimento do fruto é importante para suportar um rendimento ótimo, no entanto, a aplicação excessiva de N pode afetar negativamente a qualidade da casca. O objetivo foi determinar a influência da aplicação de N nos estágios posteriores II e III do desenvolvimento de frutas de clementina "Nules" e tangerina "Nadorcott" (*Citrus reticulata* Blanco). O N foi aplicado tardiamente em 20 e 40 kg ha-1 aos 140 e 170 dias após a floração total (DAFB), bem como 1% de ureia a 180 DAFB em 10 árvores por tratamento em dois pomares, além de 250-300 kg ha-1 de N aplicado comercialmente. Essas cultivares são colhidas em maio e agosto, respectivamente, na África do Sul, e são suscetíveis a distúrbios na casca na pós-colheita. Os frutos das árvores tratadas com N foram armazenados a -0,6 °C ou 4,0 °C durante 30 dias para determinar o impacto

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do estresse pós-colheita na qualidade externa e interna. Para ambas as cultivares, em todos os pomares, não foram registradas diferenças significativas devido à aplicação de N, em relação à coloração do fruto ou distúrbios da casca. Os resultados sugerem uma possível vantagem da aplicação posterior de N em cultivares de tangerina, sem afetar negativamente a qualidade da fruta externa ou interna.

Termos de indexação: distúrbios na casca, desordens fisiológicas, nutrição mineral.

INTRODUCTION

Central to the sustainable production of high quality citrus fruit of commercial adequate yield is the understanding of soil and nutrient requirements and optimising thereof. Nitrogen (N) is a key component of enzymes, vitamins, chlorophyll and other cell constituents and therefore one of the most important macro-nutrients required in leaves, flowers and fruit to collectively ensure regular high citrus crop yields (Iglesias et al., 2007). Nitrogen fertilisation is critical to ensure tree growth and citrus fruit development compared to any other single mineral nutrient, as this nutrient is often deficient in soils. In citrus trees adequate supply of N is needed to promote rapid growth and development of young non-bearing trees as well as to promote flower initiation, development as well as fruit set (Lovatt, 1999). Therefore, it is a standard practice in citriculture to adjust or augment N levels during each new cropping cycle, either as foliar or soil applications. However excessive leaf N concentration has resulted in a decrease in fruit yield due to the effect of luxurious consumption of N (Alva et al., 2006). In citriculture the emphasis is often placed in mineral nutrition programs to achieve optimum pre-harvest fruit quality i.e. sugar content and fruit size, with less focus placed on the physiological condition of the rind as an indicator for cold storage potential and susceptibility to disorders. One of the most practical parameters available to discern rind quality is the use the degree of colour development, as low carotenoid content often translate into high susceptibility to physiological disorders (Cronjé et al., 2011a, 2011b; Lado et al., 2014).

The main mineral nutrients affecting rind pigment composition and concentration are N, P and K, of which N has the greatest effect (Koo & Reese, 1977; Reitz & Embleton, 1986) where high N levels in the leaves and rind is shown to be a strong inhibitor of rind colour development (Iglesias et al., 2001). Reuther & Smith (1952) found that high leaf N (2.5%) at colour break in Washington Navel and Valencia orange retarded colour development and in addition resulted in a greener rind. The timing of the N applications, specifically later in summer, is also thought to be problematic by Jones & Embleton (1959). Contradictor, application of N during the summer to induce retardation of rind colour in Satsuma mandarin Mudau et al. (2004) could not affect this negative change, possibly due to leaf N concentration never exceeding 2.2%. It is thus possible that it is not N-application as a standalone treatment influencing rind colour. Coggins et al. (1981) reported that high levels of N under warm and humid environmental conditions, being favourable for plant growth, increased the degree of re-greening of late maturing oranges. Therefore, a generally recommendation in citriculture is that lower N levels in the citrus tree resulted in more orange-coloured fruit (Ritenour et al., 2003; Coetzee, 2007). Excessive application of N is known to have several adverse effects in addition to reduced colour development and may include increased rind thickness and toughness, a decreased sugar:acid ratio, and increased susceptibility of new foliage to winter frost damage (Chapman, 1968).

Development of physiological disorders during postharvest ripening and storage of fruit depends on a range of pre-harvest factors (Ferguson et al., 1999). The factors affecting susceptibility are mostly associated with either positional effects on the tree affecting fruit-to-fruit variation (Cronjé et al., 2011a, 2011b) or the environmental variation affecting susceptibility between seasons. The canopy position which affects the allocation of nutrients and carbohydrates to sinks could lead to a predisposed susceptibility in a fruit, which would then respond to environmental changes or extremes (temperature or relative humidity) (Ferguson et al., 1999), leading to the development of a disorder. Few studies in citriculture, with the exception of those indicating the impact of low calcium status on crease, has correlated a nutrient - especially at excessive levels - with an increase in rind susceptibility to a disorders. Reuther et al. (1989) suggested Valencia orange fruit from trees exhibiting a high foliar N content were more susceptible to rind staining than fruit from trees with a normal or subnormal content.

In South Africa, as in the rest of the citrus producing countries, a large increase in plantings of so-called late maturing mandarin culitvar have taken place over the last decade. However, the existing citricultural practises, such as regimes for nutrition and crop management, has not been fully evaluated for its impact on postharvest quality aspects such as colour and susceptibly to rind disorders. Nadorcott mandarin, the most widely planted cultivar, have shown to be susceptible to postharvest rind disorders not previously associated with mandarins in South Africa (Cronje, 2013). The objective of this study was to ascertain whether additional N applied later than the standard practice of application during the first fruit development phase, could negatively impact on rind colour and increase susceptibility to rind disorders of Nules Clementine and Nadorcott mandarin.

MATERIALS AND METHODS

One orchard of Nules Clementine and Nadorcott mandarin each, both grafted on Carrizo citrange {[*Poncirus trifoliate* (L.) Raf.] X [*Citrus sinensis* (L.) Osb.]}, were selected for treatments and sampling in Riebeeck Kasteel (Wynkeldershoek) in the Western Cape Province, South Africa. The Nules Clementine orchard was established in 1993 at 4.5 x 2 m row spacing whilst the Nadorcott mandarin orchard was planted in 2007 at a spacing of 5.0 x 2.4 m.

To both experimental sites soil were applied at 20 $kg{\cdot}ha^{-1}$ (90 g limestone ammonium nitrate per tree (LAN; 28% N) and 40 $kg{\cdot}ha^{-1}$ as limestone ammonium nitrate (LAN; 28% N), in addition to a standard commercial recommended N-fertigation regime of approximately 250-300 $kg{\cdot}ha^{-1}$ used by the producer (Coetzee, 2007). These two treatments were applied, both as an early application i.e. 140 days after full bloom (DAFB) as well as a later application treatment, at 170 DAFB. A foliar application of 1% urea was sprayed on untreated single trees on 180 DAFB. These six treatments (including the control) were applied in a complete randomised block design on ten tree replications (n=10), with one buffer tree between treated trees.

Twenty fruit per replicate tree were harvested based on uniformity of size and colour and lack of visual rind injuries from the outside 20-25cm of the canopy on a height of approximately 1-1.5 m from soil level. Ten fruit per replicate were used for to record harvest data with respect to external and internal quality parameters and the remaining fruit were allocated to cold storage treatments. Rind colour was measured using a Minolta chroma meter (Model CR200; Minolta Camera Osaka, Japan) and the data were expressed as hue angle (Hue°) where a higher hue angle value represents a more green colour whereas a lower hue value would represent a more orange rind colour (0 red to purple; 90º yellow and 150º green). Colour measurements were taken at two opposite sides of the fruit to include both the lighter and darker rind colour of the fruit where after an average value was used. Visual rind colour was assessed using a No. 36 Citrus Research International (CRI, 2004) colour chart from 1 to 8, with 1 responding to being well coloured and 8 being fully green for mandarins. Internal quality was determined by cutting fruit in half on the equatorial line, where after the flesh was juiced using a citrus juicer (Sunkist®, Chicago, USA). The juice was strained through a muslin cloth to remove any solid particles. Juice percentage was calculated by dividing the weight of the juice by the total weight of the fruit. Total soluble solids (°Brix) content of the juice was determined by using an electronic refractometer (PR-32 Palette, Atago Co, Tokyo, Japan) and titratable acidity (TA) was determined by titrating 20 ml of juice against 0.1562 N sodium hydroxide. Phenolphthalein was used as indicator and titration was complete when the liquid turned pink in colour. Acid was expressed as citric acid content. The °Brix:TA ratio was determined by dividing the °Brix values by the TA values.

To increase the likeliness of postharvest disorders all the fruit were subjected after harvesting at commercial maturity, to a dehydration/rehydration protocol (Alférez et al., 2003). On the fifth day following harvest, after being subjected to the dehydration/re-hydration stress fruit were waxed in a simulated commercial pack line with natural based wax (18% solids) consisting of carnauba-shellac based formulations (875 High Shine, John Bean Technologies, Brackenfell, South Africa). No fungicide or plant growth regulators were included in the postharvest treatments and the fruit were stored at either -0.6°C or 4°C for 30 days prior to a 7-day storage period at room temperature to simulate shelf life, where after the fruit were evaluated for rind disorders and colour development. The incidence of rind disorders (chilling and non-chilling related) was determined by visually inspecting fruit. A scoring rind disorder incidence on a rating scale from 0 (no disorders noted) to 3 (severe disorder incidence) based on the extent and intensity of the symptom was used. The rating values were used to calculate the rind disorder index (RDI) according to the following Formula 1:

$$RDI = \Sigma \frac{\left[\text{Rind disorder scale}(0-3) \times \text{number of fruit within each category}\right]}{\text{Total number of fruit in replicate}(n=10)} \quad (1)$$

Prior to N-application as well as at harvest, the fresh rind (containing the flavedo and albedo), pulp and leaves of ten replicates of all treatments were collected for mineral analysis to be conducted at a commercial analytical laboratory (Bemlab (Pty) Ltd., Strand, South Africa) according to the following protocol. A volume of 50 ml in solution was analysed on the Nitric / Hydrochloric total Acid digestion, ICP–OES (Inductively Coupled Plasma–Optical Emission spectrometer) (Varian PRX–OEX, Varian, Inc. Corporate, Palo Alto, CA, USA) against suitable standards. For the N analysis, 0.15 g of the sample was combusted (Total combustion method) at 850 °C and analysed on a LECO Nitrogen analyser by thermal conductivity (LECO FP528 Nitrogen analyser, LECO cooperation, St. Joseph, MI, USA) [W.A.G. Kotzé, Bemlab (Pty), Ltd., Strand, South Africa; personal communication] (Cronje et al., 2011a). The results of the mineral analysis of the leaves are expressed as a percentage (%), whereas the rinds and pulp are expressed as $mg.100g^{-1}$ fresh weight, later to be converted to a percentage (%) value. All macro and microelements (including % water) were analysed, but only the N, K and Mg data are presented.

Data were analysed with each N and time combination as a treatment, but cultivars were not statistically compared. Statistical analyses of fruit physico-chemical properties were carried out using the statistical software package *SAS Enterpise Guide* (*SAS EG* v.5.1; SAS Institute, Cary, VC, USA). Ranked data were subjected to one-way ANOVA analysis, where possible interactions could be detected. Means of treatments were separated by Fisher's least significant difference (LSD; $p = 0.05$). A p-value <0.05 is interpreted as a significant difference between treatments.

RESULTS

At harvest the late application of N at $20\ kg{\cdot}ha^{-1}$ on 170 DAFB reduced the Nules Clementine mandarin rind colour on the colour chart significantly between the different N treatments (Table 1). The 1% urea applied 180 DAFB and $40\ kg{\cdot}ha^{-1}$ LAN at 140 and 170 DAFB did not reduce rind colour compared to the control. When colour was estimated by Hue° the late application of LAN at 170 DAFB significantly reduced rind colour, compared to the control and other LAN and urea treatments (Table 1). However, evaluation after cold storage resulted in no significant differences between treatments and no consistent pattern was established that would correlate or predict a decrease in rind colour with an increase in N application, irrespective of application rate or timing. Nadorcott mandarin showed no significant colour differences between treatments; irrespective of quantification method (colour chart or Hue°) or whether the colour was recorded at harvest or following long-term cold storage (Table 1; Figure 1). A comparison of colour measurements between the two cultivars indicate the difference in rind colour potential, with Nadorcott mandarin in general developing in a more vivid orange colour compared to Nules Clementine.

The internal quality indices of Nules Clementine mandarin showed significant differences between the different N applications at harvest as well as after storage (Table 2). The juice % was the highest in fruit harvested from trees treated with the $40kg{\cdot}ha^{-1}$ N application at 140 DAFB and the $20\ kg{\cdot}ha^{-1}$ N application at 170 DAFB. For % TA at harvest, treatments and the control were comparable, except for fruit from the 140 DAFB $20\ kg{\cdot}ha^{-1}$ N application, which were significantly higher in %TA than fruit from the higher application rate of $40\ kg{\cdot}ha^{-1}$ N, applied during the same period. Fruit stored at 4 °C for 30 days did not differ

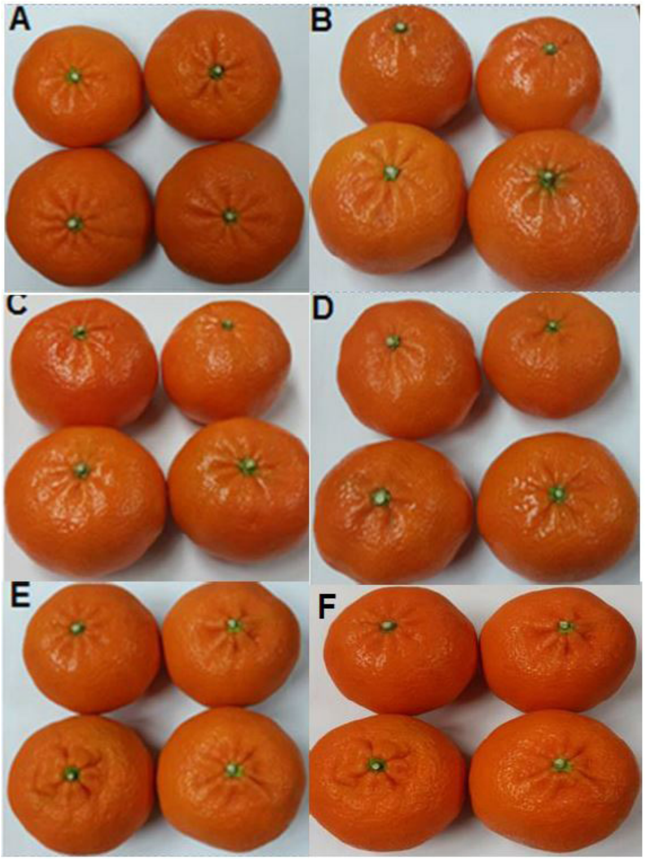

Figure 1. Nadorcott mandarin fruit shown at harvest following the application of a range of soil LAN (limestone ammonium nitrate) and foliar urea (1%) nitrogen treatments ($kg{\cdot}ha^{-1}$), either on 140, 170 or 180 days after full bloom (DAFB). (A) Control, (B) $20\ kg{\cdot}ha^{-1}$ Early, (C) $40\ kg{\cdot}ha^{-1}$ Early, (D) $20\ kg{\cdot}ha^{-1}$ Late, (E) $40\ kg{\cdot}ha^{-1}$ Late and (F) 1% Urea.

Table 1. Effect of additional late nitrogen application on external fruit quality of Nules Clementine and Nadorcott mandarin at harvest and after cold storage at -0.6 °C or 4 °C for 30 days, following a range of additional nitrogen soil application as well as foliar urea (%) treatments, applied either early 140 days after full bloom (DAFB) or late 170/180 DAFB

Nitrogen treatment	Nules Clementine						Nadorcott					
	Colour Chart (1-6)*			Hue°**			Colour Chart (1-6)			Hue°		
	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C
Control	2.7ab[y]	1.0[ns]	1.0[ns]	77.3b	73.4[ns]	72.6[ns]	1.4[ns]	1.0[ns]	1.0[ns]	55.2[ns]	55.9[ns]	55.5[ns]
20 kg·ha^{-1} Early (140 DAFB)	2.8ab	1.0	1.0	78.1b	74.7	72.1	1.5	1.0	1.0	55.4	55.8	55.8
40 kg·ha^{-1} Early (140 DAFB)	2.1b	1.0	1.0	77.2b	73.2	72.6	1.6	1.0	1.0	55.9	56.1	56.1
20 kg·ha^{-1} Late (170 DAFB)	3.1a	1.0	1.0	78.3b	74.2	73.6	1.4	1.0	1.0	54.9	55.6	55.4
40 kg·ha^{-1} Late (170 DAFB)	2.6ab	1.0	1.0	83.3a	78.6	76.9	1.8	1.0	1.0	57.3	57.4	56.9
1% Urea (180 DAFB)	2.0b	1.0	1.0	80.4ab	76.4	74.4	2.1	1.0	1.0	56.0	56.4	56.2
p-value	*0.006*	*0.11*	*0.09*	*0.031*	*0.097*	*0.064*	*0.298*	*0.08*	*0.07*	*0.167*	*0.734*	*0.621*

[ns]No significant differences. [y]Means with a different letter within a column differ significantly at the 5% level (LSD). *Colour chart values indicate the degree of fruit colour development: 1 being complete orange and 6 completely green. **Hue° as quantitative measurement of colour with higher values denoting a less intense orange colour.

Table 2. Effect of additional late nitrogen application on internal fruit quality of Nules Clementine mandarin at harvest and after cold storage at -0.6 °C or 4 °C for 30 days, following a range of additional soil LAN (limestone ammonium nitrate) nitrogen treatments as well as foliar urea (%) treatments, applied either early 140 days after full bloom (DAFB) or late 170/180 DAFB

Nitrogen treatment: [N (kg.ha^{-1}) or Urea (%)]	Juice content (%)	Titratable acidity (TA) (%)			Total soluble solids (°Brix)			°Brix:TA		
	Harvest	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C
Control	54.5b[y]	1.0ab	0.9ab	0.9[ns]	12.4ab	13.5abc	13.9ab	13.0ab	14.9[ns]	15.5[ns]
20 kg·ha^{-1} Early (140 DAFB)	53.4b	1.1a	0.9ab	0.9	12.9a	14.2a	14.1a	12.3b	15.5	15.3
40 kg·ha^{-1} Early (140 DAFB)	59.4a	0.9b	0.9ab	0.9	12.8a	13.2bc	13.7ab	14.3a	14.7	15.6
20 kg·ha^{-1} Late (170 DAFB)	60.1a	1.0ab	1.0a	1.0	11.9a	13.8ab	14.0ab	12.1b	14.0	14.2
40 kg·ha^{-1} Late (170 DAFB)	52.0b	1.0ab	0.9b	0.9	12.3ab	12.9c	13.0b	12.7b	15.1	14.9
1% Urea (180 DAFB)	54.5b	1.0ab	1.0ab	1.9	12.8a	13.4abc	13.6ab	12.9b	13.9	13.9
p-value	*<.0001*	*0.022*	*0.034*	*0.065*	*0.004*	*0.001*	*0.019*	*0.001*	*0.126*	*0.127*

[ns]No significant differences; [y]Means with a different letter within a column differ significantly at the 5% level (LSD).

significantly among the various N-treatments with respect %TA. Differences in °Brix for fruit associated with the various N treatments were recorded at harvest and following cold storage at both temperatures. However, none of these values differed significantly from that of control fruit. A significant difference in °Brix:TA ratio was measured at harvest. However, the difference was not retained after the storage of fruit at either of the storage temperatures.

No significant differences occurred in the Nadorcott mandarin juice content (%), TA (%) and °Brix:TA ratio at harvest for the various N-treatments (Table 3). A significant difference in the °Brix at harvest was detected where fruit from the 1% urea treatment at 180 DAFB resulted in significantly lower °Brix values compared to the control and other N-treatments. Following cold storage at both -0.6 °C and 4 °C a decrease in TA (%) was observed in comparison to fruit freshly harvested. After storage at -0.6 °C the significant difference in °Brix at harvest described above was not evident anymore. However, °Brix differed significantly for fruit stored at 4 °C and also resulted in the °Brix:TA ratio to be significantly higher at this temperature regime. In general, no consistent pattern exerted by the N-applications on the internal quality emerged.

No consistent, significant differences were detected for any of the minerals discussed (N, K and Mg) in either the leaves or fruit from both cultivars (Table 4). The leaf N content were higher in all treatments compared to the commercial recommendation for mandarins in South Africa at 2.1-2.3% (Coetzee, 2007). The pulp N in Nadorcott mandarins was also significantly reduced in all late N applications compared to the control. The K and Mg content of the pulp was not influenced by the treatments, in either of the cultivars (Table 4). The rind N in Nules Clementine were affected by the treatments with a general numerical increase compared to the control as well as significantly for the 20 $kg \cdot ha^{-1}$ N at 170 DAFB treatment. The Mg content in Nules Clementine differ between N treatments but not from the control.

The incidence of rind disorders, chilling and non-chilling, were evaluated but a too low incidence occurred to result in any meaningful analysis and data is therefore not shown.

DISCUSSION

The results from this study showed that later N applications i.e. after the late summer/early autumn flush, additional to a commercial N program, did not increase the susceptibility of the two mandarin cultivars to either chilling or non-chilling rind disorders. In addition, the rind colour development as well as the internal quality was not negatively affected by these treatments. Fruit colour change is of particular economic importance since the external colour of citrus fruit are considered a critical quality parameter for the fresh market (Alós et al., 2006). The colour break in citrus rind results from the differentiation of chloroplasts to chromoplasts, a process that in citrus is influenced by environmental conditions, in particular temperature, mineral and carbohydrate nutrient availability and the phyto-hormones ethylene and gibberellic acid (Alós et al., 2006).

Nutrient imbalances and the effect of inadequate fertilization have been the focus in various studies to link nutrition with rind colour and disorder susceptibility. Nitrogen, phosphate and potassium mostly affect changes in rind pigments, although N has the greatest effect (Reitz & Embleton, 1986). The role of other macronutrients has been reported in that the outer tree canopy fruit, which exhibits a more vivid orange colour, contains higher Mg and Ca levels and is less prone to rind disorders than the pale fruit located inside the tree canopy (Cronje et al., 2011a). Nevertheless, nitrogenous fertilisation is one of the modifiable factors that can influences rind colour of *Citrus* (Sala et al., 1992). Early studies on citrus reported high N applications, at approximately 1.1 kg per tree per year, to delay fruit maturity, colour break and reduce colour development at harvest as well as promote re-greening (Reuther & Smith, 1952; Reitz & Koo, 1960; Coggins et al., 1981). In this current study, additional later soil and foliar N-applications produced contradictory results to previous studies on the impact on fruit rind colour of mandarins. In this study, the expected pattern of increased N concentration and decreased rind colour was not observed. However, numerical increase in the Hue° values in some instances by the late application of higher N rates of 40 $kg \cdot ha^{-1}$ at 170 DAFB and 1% urea at 180 DAFP may indicate some detrimental effects with respect to rind colour if higher levels of N are applied. However, none of the N treatments did result in new growth flushes and therefore it could be reasoned that Gibberellic acid production which is know to inhibit colour development, was not stimulated.

The relationship between N content application and the susceptibility to physiological rind disorders remains unclarified. Rind pitting, which may be morphologically similar to rind breakdown of Nules Clementine mandarin, have been associated with nutritional imbalances. Zaragoza et al. (1996) demonstrated that the application of $Ca(NO_3)_2$ to Fortune mandarin fruit at colour-break

Table 3. Effect of additional late nitrogen application on internal fruit quality of Nadorcott mandarin at harvest and after cold storage at -0.6 °C or 4 °C for 30 days, following a range of additional soil LAN (limestone ammonium nitrate) nitrogen treatments as well as foliar urea (%) treatments, applied either early 140 days after full bloom (DAFB) or late 170/180 DAFB

Nitrogen treatment: [N ($kg.ha^{-1}$) or Urea (%)]	Juice content (%)	Titratable acidity (TA) (%)			Total soluble solids (°Brix)			°Brix:TA		
	Harvest	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C	Harvest	-0.6 °C	4 °C
Control	58.1^{ns}	1.3^{ns}	1.1ab^{y}	1.0ab	12.2a	12.5^{ns}	12.8a	9.4^{ns}	11.3^{ns}	13.2ab
20 $kg·ha^{-1}$ Early (140 DAFB)	57.1	1.3	1.2a	1.2a	12.0a	12.6	12.7a	9.1	10.6	10.9b
40 $kg·ha^{-1}$ Early (140 DAFB)	57.5	1.4	1.1ab	1.1ab	12.1a	12.4	12.2ab	9.9	11.5	11.5ab
20 $kg·ha^{-1}$ Late (170 DAFB)	58.6	1.2	1.1ab	1.0ab	11.9a	12.5	12.8a	9.8	11.5	13.5a
40 $kg·ha^{-1}$ Late (170 DAFB)	54.1	1.3	1.1ab	1.1ab	11.8a	12.5	12.4ab	9.3	11.7	11.9ab
1% Urea (180 DAFB)	57.7	1.1	0.9b	0.9b	10.6b	11.8	11.7b	9.6	12.7	13.3ab
p-value	*0.057*	*0.059*	*0.035*	*0.007*	*0.001*	*0.360*	*0.031*	*0.603*	*0.115*	*0.007*

^{ns}No significant differences. ^{y}Means with a different letter within a column differ significantly at the 5% level (LSD).

Table 4. The macronutrient content of Nadorcott and Nules Clementine mandarin expressed as % N, K and Mg of leaf, pulp and rind (n=10) prior to any additional N application and at harvest, following the application of a range of soil LAN (limestone ammonium nitrate) and foliar urea (1%) nitrogen treatments (kg·ha^{-1}), either on 140, 170 or 180 days after full bloom (DAFB). The average values of the mineral nutrients the day prior to the first applications are supplied as a reference and not used in the statistical analysis

Treatment	N (g kg^{-1})	Nules K (g kg^{-1})	Mg (g kg^{-1})	N (g kg^{-1})	Nadorcott K (g kg^{-1})	Mg (g kg^{-1})
Leaf analysis						
Prior to treatment	***0.217***	***0.112***	***0.043***	***0.193***	***0.088***	***0.062***
Control	0.237^{ns}	0.132^{ns}	0.047^{ns}	0.270^{ns}	0.079^{ns}	0.062^{ns}
20 kg·ha^{-1} Early (140 DAFB)	0.223	0.134	0.049	0.272	0.081	0.064
40 kg·ha^{-1} Early (140 DAFB)	0.219	0.155	0.044	0.258	0.078	0.060
20 kg·ha^{-1} Late (170 DAFB)	0.229	0.142	0.046	0.270	0.088	0.061
40 kg·ha^{-1} Late (170 DAFB)	0.237	0.136	0.047	0.278	0.098	0.057
1% Urea (180 DAFB)	0.235	0.139	0.044	0.264	0.075	0.067
p-value	*0.503*	*0.890*	*0.434*	*0.320*	*0.128*	*0.121*
Pulp analysis						
Prior to treatment	***0.033***	***0.033***	***0.003***	***0.024***	***0.028***	***0.003***
Control	0.140^{ns}	0.181^{ns}	0.011^{ns}	0.235a^{y}	0.155^{ns}	0.015^{ns}
20 kg·ha^{-1} Early (140 DAFB)	0.151	0.169	0.011	0.173b	0.162	0.015
40 kg·ha^{-1} Early (140 DAFB)	0.182	0.173	0.011	0.156b	0.159	0.015
20 kg·ha^{-1} Late (170 DAFB)	0.166	0.170	0.011	0.162b	0.155	0.014
40 kg·ha^{-1} Late (170 DAFB)	0.188	0.184	0.010	0.145b	0.150	0.014
1% Urea (180 DAFB)	0.20	0.176	0.010	0.151b	0.153	0.014
p-value	*0.081*	*0.415*	*0.048*	*<0.0001*	*0.586*	*0.487*
Rind analysis						
Prior to treatment	***0.041***	***0.043***	***0.008***	***0.031***	***0.031***	***0.012***
Control	0.196b	0.277^{ns}	0.025ab	0.177^{ns}	0.165^{ns}	0.035^{ns}
20 kg·ha^{-1} Early (140 DAFB)	0.236ab	0.251	0.027a	0.192	0.183	0.033
40 kg·ha^{-1} Early (140 DAFB)	0.215b	0.242	0.022ab	0.202	0.167	0.034
20 kg·ha^{-1} Late (170 DAFB)	0.277a	0.278	0.020ab	0.191	0.178	0.030
40 kg·ha^{-1} Late (170 DAFB)	0.223ab	0.244	0.017ab	0.187	0.172	0.026
1% Urea (180 DAFB)	0.198b	0.262	0.015b	0.195	0.160	0.029
p-value	*0.002*	*0.351*	*0.028*	*0.364*	*0.673*	*0.274*

^{ns}No significant differences. ^{y}Means with a different letter within a column differ significantly at the 5% level (LSD).

significantly reduced rind pitting incidence at harvest. In contrast fruit from trees exposed to high nitrogen levels, as indicated by leaf analysis, was found to be more susceptible to rind staining than fruit from trees with normal or subnormal levels of N (Reuther et al., 1989). In this current study, the incidence of chilling and non-chilling rind disorders was recorded, but levels were too low for all treatments and therefore could not be correlated with N levels of leaves or fruit.

Increased N supplied to Valencia orange trees can increase soluble solids, acid and juice percentage, along with promoting the percentage of green fruit, whilst reducing individual fruit weight and the percentage of export quality fruit. In the sweet orange cv. Mosambi, higher doses at 800-1200 $g \cdot tree^{-1}$ N reduced storage decay and accelerated fruit weight loss compared to fruit from trees subjected to lower or no applications of N (Govind & Prasad, 1981). Despite inconsistency in literature, it is recognized that high nitrogen application, as a rule, decreases storage potential of fruit (Ladaniya, 2008). However, contradictory to views held by Ladaniya (2008) and others our results indicated the internal fruit quality of mandarin, at harvest, for both cultivars, did not differ significantly when additional N was applied either as LAN in the soil or as urea in the leaves, early or late in the growing season and at two different rates.

CONCLUSION

The late application of nitrogen in this study had no negative effect on the fruit rind condition i.e. colour or susceptibility to rind disorders in addition to internal quality. These negative results provides evidence for the South African citrus industry on the possible use of N at different timings to affect physiological changes in late mandarins. For instance, the late N application, following the summer flush, could be considered as an option to increase tree N content in late mandarin cultivars. These lucrative cultivars flower within a month from harvest, resulting in a limited opportunity to apply adequate N to facilitate flower development. Further research on the possible impact of additional late N applications on flower and fruit set in the subsequent season is required. In addition, more studies which focus on the influence of N-status on the citrus rind and its disorders as pertaining to other climatic areas i.e. summer rainfall in comparison to Mediterranean/winter rainfall areas, as was used in this study, as well as the influence of irrigation. Comparisons between different cultivars would be valuable to provide an understanding on how, if at all, cultural practise such as N-application could induce an inherent sensitivity towards rind disorders.

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