Scientia Horticulturae 226 (2017) 316–321

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Research Paper

Manipulation of mango fruit dry matter content to improve eating quality

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ARTICLE INFO

Keywords:
Mangifera indica
Yield
Mango quality
Water denial
Water stress

ABSTRACT

A near infrared spectroscopic method was used to non-invasively assess dry matter (DM) of fruit on tree with a $R^2_p = 0.82$ and RMSEP = 0.52% across fruit from a range of water denied treatments. A variety of techniques for manipulating tree fruit carbohydrates (fruit thinning, girdling, nitrogen and water manipulation) were implemented on six mango farms in 2013. Fruit thinning and water denial treatments resulted in increased DM. Water denial for periods as short as 2 weeks before harvest resulted in increased DM (17.6 cf. 16.5% in control) and ripened fruit Brix (14.3 cf. 13.3° in control) without decrease in fruit size associated with long periods of water denial.

1. Introduction

Mango (*Mangifera indica L.*), the 'king of fruits', is a climacteric tropical fruit with a short shelf life, and thus a volatile market value. Attempts to maximize profits by supplying fruit while market prices are high can lead to the placement of under or over mature fruit to the market. Earlier harvest fruit will have a longer shelf life but will have lower dry matter content (DM). DM is the weight of all tissue components except water, but as constitutional components such as cell walls and membranes are relatively constant with fruit maturation, DM is a useful index of soluble and insoluble carbohydrate content, i.e. sugars and starch in mango fruit. DM at fruit harvest is well correlated with ripened fruit Brix (°B) and eating quality (Whiley et al., 2006). Lower DM fruit can cause customer dissatisfaction and reduce the rate of repurchase. For this reason the Australian Mango Industry Association has recommended minimum DM levels by cultivar, and major retailers are adopting these specifications (AMIA, 2016). Therefore there is a need for agronomic 'tools' to manipulate fruit to meet market DM specifications.

Several agronomic treatments can be employed to alter fruit DM, by altering photosynthate or water allocation to the fruit. For example, manual thinning (to one/two fruit per panicle and removal of 50% of panicles) and chemical (Corasil E) fruit thinning of 'Sensation' mangoes was undertaken by Yeshitela et al. (2004). Manual thinning treatments resulted in increased Brix in ripened fruit (15.1–16.3° cf. control 13.7°), with yields comparable to the control (25.8–27.9 cf. 26.1 t/ha) due to increased fruit size. A chemical thinning treatment resulted in increased Brix but reduced yield (21.6 c.f. 25.7 t/ha for control).

An alternative technique to increase photosynthate partitioning to fruit is girdling. Trunk girdling is sometimes practiced pre-flowering, to induce flowering (Jose 1996). Simmons et al. (1998) report on girdling of mango branches and manipulation of leaf: fruit ratios, leaving a single fruit per girdled branch with either 30, 60 or 120 leaves from eight weeks after flowering. The treatments impacted both fruit weight (441, 363, 533 and 697 g/fruit for control, 30, 60 and 120 leaves/fruit treatments, respectively) and fruit DM (14.4, 16.4, 16.3, 14.6 g, respectively).

Fruit bagging has also been reported to result in increased fruit carbohydrate content. Zhao et al. (2013) reported increased fructose, glucose, sucrose and total sugars in bagged fruit compared to the control for all four varieties considered (Chinhuang 121.6 cf. 115.7, Guifei 108.3 cf. 98.5, Baixiangya 114.6 cf. 99.5, and Hongyu 123.5 cf. 112.2 mg/g FW, total sugars).

Application of fertilisers ahead of flowering can result in increased vegetative growth and a change in source-sink balance. Pre-flowering soil applied nitrogen (4 and 8 gN m^{-2}) resulted in increased yield, relative to control, of 'Calypso™' mango (43.1, 47.4 and 28.9 kg/tree, respectively) (Whiley et al., 2006). The effect on fruit carbohydrate load was not documented.

The effect of deficit irrigation (DI), partial root-zone drying (PRD) and regulated deficit irrigation (RDI) on fruit size, yield and fruit quality parameters is well documented for many tree fruit. For example, water denial applied in the early season (7–10 days after fruit set) of kiwi fruit resulted in 25% smaller fruit than the control and late season treated fruit (Miller et al., 1998). Late season water denial (~70 days before harvest) resulted in fruit with significantly higher ripened Brix than the control (15.3° cf. 14.4°B), and fruit ripened 6 weeks sooner than the control fruit. Fruit weight was not impacted. A DI treatment

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http://dx.doi.org/10.1016/j.scienta.2017.09.001
Received 22 February 2017; Received in revised form 30 August 2017; Accepted 1 September 2017
Available online 11 September 2017
0304-4238/

(~40% of control irrigation) applied to 'Braeburn' apple Trees 72 days before harvest resulted in lower yield compared to the control (10.8 cf. 11.5 kg/tree) but higher Brix (13.0° cf. 11.8°) (Mpelasoka et al., 2001). Water stress applied to muskmelon a week before harvest increased fruit Brix (11.2 cf. 8.8°B) (Long et al., 2006). In general, water deficit early in the fruit development period can impact fruit size while water deficit in the later development period increases the concentration of storage reserves.

A number of reports have also been made of the effect of water stress on mango yield and quality. Simmons et al. (1998) report on water denial treatments of 'Kensington Pride' mango. Irrigation water was denied for 56 days following panicle emergence ('early' treatment), 56 days before harvest ('late'), and 14 days before harvest ('pre-harvest') and compared to a continuously watered treatment. DM was significantly higher in 'late' treatment fruit compared to the 'pre-harvest' and control treatments (17.4, 14.4 and 13.9%) while the 'early' treatment had the lowest DM (12.7%). Fruit size was compromised in 'early' and 'late' treated fruit (344, 350 g) compared to the control and 'pre-harvest' treatments (513, 479 g).

Spreer et al. (2007) reported on PRD, RDI at 50% evapotranspiration (ETc) and nil irrigation (applied after fruit set) treatments of 'Chok Anan' mango. Higher yield was obtained in the control treatment than the nil irrigation treatment (8.00 cf. to 3.62 t/ha in 2004, a year of no rainfall, and 15.1 cf. 11.1 t/ha in 2005, a year with 71 mm rainfall during fruit development). Ripened fruit Brix was similar for all treatments. Srikasetsarakul et al. (2011) reported on PRD (50% ETc applied after flowering) of 'Nam Dokmai' mango, noting that water stress resulted in a non-significant decrease of yield compared to the control (e.g. 19.3 cf. 25.7 kg/tree in 2010). Dos Santos et al. (2015) reported PRD treatments (100, 80, 60 and 40% of ETc,) applied from flowering on 'Tommy Atkins' mango were associated with a decrease in yield in the more severe treatments (PRD 40–100 of 15.4–26.4, cf. control 24.0 t/ha). Nagle et al. (2010) reported higher DM and harvest Brix (24.6% and 9.1°B respectively) when irrigation denial was implemented from flowering, compared to the control (21.4% and 7.6°B). Thus mango fruit weight and carbohydrate content can be manipulated by water stress, although consideration must be given to timing and severity of treatment.

DM of intact mango fruit on tree can be measured non-invasively using near-infrared (NIR) spectroscopy to acceptable levels of accuracy. Guthrie and Walsh (1997) reported use of a multiple linear regression (MLR) model in prediction of DM of a single cultivar of hard green mango fruit (R^2 = 0.96, and RMSEP = 0.79), while Saranwong et al. (2004) reported use of a partial least squares regression model (PLSR) (R^2 = 0.92, SEP = 0.41, bias = 0.07). A multi cultivar mango DM PLSR model developed by Subedi et al. (2007) was used in prediction of independent populations of fruit with acceptable accuracy (R^2 = 0.79, RMSEP = 0.97). Lineal dimensions of fruit (length, width and thickness) can also be assessed non-destructively, and can be related to fruit weight (R^2 = 0.96, accuracy of 0.1 g) (Spreer and Müller, 2011). These non-invasive techniques allow for repeated monitoring of individual fruit on tree, eliminating the sampling error associated with destructive sampling over a time series. However, Nagle et al. (2010) have reported that a SWNIR model gave poor calibration results with fruit under water deficits (R_c^2 = 0.35, RMSEC = 4.6% DM), with the suggestion made that changes in intercellular spacing could result in a change in light scattering properties, upsetting the Nir-DM measurement (as noted in other applications, Dahm and Dahm, 2001).

The current study employed non-invasive measurements of fruit DM and size to assess the effect of various agronomic treatments on these attributes during fruit development, with the aim of developing recommendations on crop management procedures to increase fruit DM. The robustness of a Nir-DM estimation of fruit from different seasons and production (water status) conditions was also documented.

2. Materials and methods

2.1. Plant material

Treatments were imposed with commercial mango orchards, in which each tree was equipped with a ~55 L/h sprinkler. Normal practice involved irregular irrigation through the fruiting period, typically involving 2 h sessions every 2–3 days, dependent on rainfall or grower's discretion based on soil moisture.

In 2013, treatments were imposed on five mango (*Mangifera indica*, var. B74/'Calypso™') orchards located in the Northern Territory (NT) (in Acacia Hills, Darwin, Katherine and Mataranka) and on one farm located in Dimbulah, Queensland (QLD). In 2015 and 2016, treatments were imposed on 9–10 year old (mature) mango trees (B74/'Calypso™' grafted on 'Kensington Pride' root stock) with 3 m spacing, at the Acacia Hills site.

2.2. Treatments

At each site, each treatment was imposed on five trees, and an additional five trees maintained under commercial farm practices were monitored as the control treatment. The harvest time was based on farm commercial practice, which involved a minimum 15% DM and a level of yellow coloration of fruit flesh.

At the Dimbulah site, fruit were enclosed in paper bags eight weeks before harvest. At the Mataranka site, 46 g nitrogen (NH_4SO_4) per tree was surface broadcast within the tree drip line six weeks before harvest. In Darwin, trees were (i) girdled (shallow chainsaw cut around base of tree), (ii) thinned of all fruit but tagged/monitored fruit, and (iii) supplied 46 g N, six weeks before harvest. In Acacia Hills, (i) 23 or (ii) 46 g soil applied nitrogen per tree was administered within the tree drip line six weeks before harvest. In Katherine, trees were denied irrigation water (i) 4 and (ii) 8 weeks before harvest, and (iii) supplied 46 g N, 6 weeks before harvest. Plastic tarpaulins were pinned to the ground to shed rainwater. In each of the 2015 and 2016 seasons, three water denial treatments and a control (normal practice) were imposed at Acacia Hills, with five trees per treatment. In 2015, trees were denied water 4, 6 and 8 weeks before harvest, with the same trees used in 2016 for 2, 4 and 6 week water denial treatments. In the 2016 season, ground tarpaulins were used.

On each tree, six fruit were tagged. For the 2013 trials, one fruit selected from each of the upper and lower canopy of the north and south sides, and two fruit were selected from the inner canopy (shaded). In the 2015 season, an additional random outside fruit was selected to replace one of the internal fruit, to better represent the proportion of fruit inside and outside the canopy. In 2016, a small sized fruit was selected on the outside of the canopy as the sixth fruit. This fruit was assumed to be from a delayed flowering event, however many of these fruit never reached commercial size (< 225 g) and thus were removed from the experiment.

Twenty fruit from each of the four treatments (n = 80) were harvested for use in a NIR calibration/validation exercise. Tagged fruit were measured for Brix (°B) and oven-DM after ripening in 2015 and 2016 (n = 120, n = 100). Fruit were ripened at 20 °C without exogenous ethylene. At the end of the 2016 trial, 10 fruit per tree (n = 200) were left after commercial harvest and followed until fully ripe or fallen; to determine "hanging time".

2.3. Measurements

DM was assessed of tagged fruit at weekly intervals until harvest using a F750 (Felix, WA, USA), a handheld short-wavelength NIR spectrometer based on the monolithic miniature spectrometer (Zeiss, Oberkochen, Germany) which has a ca. 3 nm pixel resolution across the range 300–1050 nm. Hereafter the terms Nir-DM and oven-DM are used to distinguish between DM assessed by NIRS and by oven dehydration.