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Effects of fruit canopy position on chemical composition and fruit colour development of starfruit cultivated under netted structure

(Kesan kedudukan buah pada pelbagai posisi kanopi terhadap perkembangan kandungan kimia dan warna buah belimbing di bawah struktur pelindung jaring kalis serangga)

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Abstract

The effects of fruit canopy position on chemical composition (SSC, ascorbic acid, carotenoid concentrations) and colour development of starfruit (*Averrhoa carambola*) under netted structure, were determined. The treatments consisted of three canopy positions: fruits facing the morning sun, fruits facing the evening sun and fruits under the canopy. The fruit canopy position did not significantly (p <0.05) influence the fruit SSC. Exposure to irradiance increased the ascorbic acid concentration of starfruit. The carotenoid concentration increased with heat units and exposure to irradiance (PAR) indicating that irradiance might play an important role in the synthesis of carotenoid. Excessive irradiance (exposed fruits) resulted in lower L* value, and darker green fruits with less shine. Fruits protected under the plant canopy had better cosmetic appearance and are suitable for export market.

Introduction

When starfruits are grown under netted structure, they are not individually wrapped and thus subjected to exposure to the sun which in turn influenced the fruit surface temperature and irradiance impinging on the fruits. Microenvironment such as fruit surface temperature and irradiance have pronounced effects on fruit quality such as texture, chemical composition, skin colour and postharvest keeping quality (Blanpied et al. 1978). Fruit temperature is inversely correlated to firmness (Rose et al. 1934; Unrath 1972).

Besides firmness, fruit temperature also influences fruit chemical properties such as vitamin C concentration (Lee and Kader 2000) and soluble solid concentration (Wang and Camp 2000). Exposure to high irradiance reduces the soluble solid concentration of strawberry and Valencia orange (Reitz and Sites 1948; Wang and Camp 2000). Strawberries receiving high irradiative condition have higher ascorbic acid concentration while those exposed to wet cloudy weather have lower values (Hansen and Waldo 1994). Both the irradiance and fruit temperature impinging

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on the fruit also influence fruit colour (Blakenship 1987; Tyas et al. 1998).

The fruit microenvironment may also influence the fruit nutrient concentration and other qualities such as fruit firmness. Thus, the objective of this study was to understand the effect of the fruit microenvironment (irradiance and heat units) on fruit chemical composition such as ascorbic acid, soluble solid concentration, carotenoid concentration and fruit colour development, when cultivated under netted structure (as fruits are not wrapped).

Materials and methods

The study was conducted on 12-year-old starfruit cv. B10, cultivated under netted structure at MARDI starfruit farm in Serdang, Selangor. The treatments consisted of three canopy positions: fruits exposed to the morning sun, fruits exposed to the evening sun and fruits under canopy. The crop load was 400–450 fruits per tree.

There was no temperature gradient within the structure (Zabedah et al. 1999). The irradiance and temperature sensors were randomly placed at the various canopy positions. The experimental design was a randomized complete block design (RCBD) with 12 replications. When treatments were sampled for analysis, composite samples were taken for at least three replicates.

Crop maintenance

Fertilizer, at the rate of 720 g N: 315 g P: 1,440 g K, was applied in three split application. All trees were irrigated with approximately 20–25 litres of water daily using a low sprinkler irrigation system. Benomyl (2 g per 4.5 litres) was applied at full bloom to control anthracnose fruit spot, while cypermethrin (6 ml per 4.5 litres) was applied to control flower moth *(Diocrotricha fasciola)*.

Fruit microenvironment: Irradiance and heat unit

The microenvironment data recorded were irradiance (PAR) impinging on the fruits, fruit surface temperature for calculation of heat units and rainfall. Irradiance (PAR m. m^{-2}) was measured using the Single Channel Light Sensor (SKP215-PAR Quantum, Skye Instrument Ltd. U.K). The temperature was measured using thermocouple temperature probes (STTS 200 Series, Skye Instrument Ltd. UK) appressed to the fruits surface. The data was logged at 10 min interval.

Soluble solid and ascorbic acid concentrations

The fruits of three samples from each treatment were homogenized in a warring blender. These samples were analysed for soluble solid concentration (SSC) and ascorbic acid (vitamin C). Juice from the homogenate was measured for total soluble solid using a digital refractometer. Results were expressed as degrees Brix.

Ascorbic acid was based on the reduction of 2, 6-dichlorophenol indophenol by ascorbic acid. Ten grammes of sample was blended with 3% metaphosporic acid (HPO_3) and made up to 100 ml with HPO_3, and then filtered. An aliquot of the HPO_3 extract of the sample was titrated with the standard dye (Ranganna 1986).

Carotenoid concentration

The total fruit carotenoid concentration was determined at maturity stage 2, 3 and 4 of the fruit development.

A 25 ml aliquot of the blended starfruit juice was homogenized in a homogenizer with 50 ml of extracting solvent (hexane-acetone-ethanol; 50:25:25, v/v), and centrifuged (SIGMA 3K 30, Germany) for 5 min at 6,500 rpm at 5 °C.

The supernatant was transferred to a 25 ml volumetric flask. The volume was then adjusted to 25 ml with hexane. Then 1.75 ml of the mixture was placed in a cuvette (2 ml) and the total carotenoid concentration was determined by measuring the absorbance at 450 nm in a dual beam spectrophotometer (UV 1600, Shimadzu, Japan). Total carotenoid concentration was calculated according to De Ritter and Purcell

(1981) using an extinction coefficient of ß-carotene,

$$E^{1\%} = 2505$$

Fruit colour

Fruit colour was determined using a reflectance colorimeter, CR-200 (Minolta, Japan). Fruit surface colour was measured individually and recorded in terms of co-ordinates L*C*h° (CIELAB system). The L* value indicates shine or darkness, C* is chroma and h° is the hue angle. The mean values of L*C*h° for the fruits were averaged from individual fruit.

Statistical analysis

Data was analysed using Statistical Analysis Systems package. The effects of treatments at various fruit maturity index on fruit chemical properties and colour was compared by Duncan Multiple Range Test (DMRT). Stepwise regression analysis was used to determine factors influencing fruit chemical properties (soluble solid concentration, ascorbic acid and carotenoid concentration), fruit colour development and their relation to the fruit microenvironment.

Results and discussion

Irradiance and heat units

The fruit canopy position significantly influenced the daily irradiance. The difference in irradiance received by the various treatments in turn resulted in significant differences in cumulative irradiance (*Table 1*) impinging on the fruits.

Similarly fruit surface temperature and heat units were significantly influenced by the fruit canopy position. The difference in fruit temperature at the various canopy position in turn resulted in difference in cumulative heat units received by the fruits from 20 days after anthesis. The highest cumulative heat units were received by fruits facing the morning and evening sun followed by fruits under the tree canopy ($p \leq 0.05$) (*Table 1*).

The data on the fruit irradiance and heat units were used for the stepwise regression analysis to determine the effects of microenvironment on fruit chemical properties and fruit colour development.

Soluble solid concentration

The soluble solid concentration (SSC) at various canopy positions were low at maturity index 1 (5.0–5.9%) and increased significantly at stage 4 (7.0–7.4%) (*Figure 1*). However, differences between treatments were not significant at the four stages of maturity index.

To understand the factors affecting SSC, a stepwise regression analysis was conducted. The SSC (%) was significantly influenced by two parameters, fruit dry weight and heat units (°C) ($R^2 = 0.94^{***}$). The relationship between SSC, fruit dry

Table 1. The cumulative irradiance values and heat units impinging on the fruits at various canopy position

Days after anthesis	Cumulative irradiance (PAR m.m^{-2})			Heat units (ºC)		
	Morning sun	Evening sun	Under canopy	Morning sun	Evening sun	Under canopy
10	92.03a	62.72b	4.43c	204.3a	207.8a	199.2a
20	199.72a	144.47b	9.43c	412.8a	414.6a	396.44b
30	302.37a	266.43b	18.70c	625.1a	626.6a	593.1b
40	383.88a	383.31a	24.97b	836.7a	834.5a	789.2b
50	672.59a	556.02b	30.24c	1051.2a	1046.4a	979.2b
60	786.52a	630.46b	33.46c	1269.4a	1261.4a	1174.8b
70	912.34a	683.85b	36.24c	1490.2a	1474.0a	1373.4b
80	1017.43a	749.01b	43.72c	1709.6a	1689.3a	1585.5b

Means followed by different letters in the same row are significantly different at $p \leq 0.05$

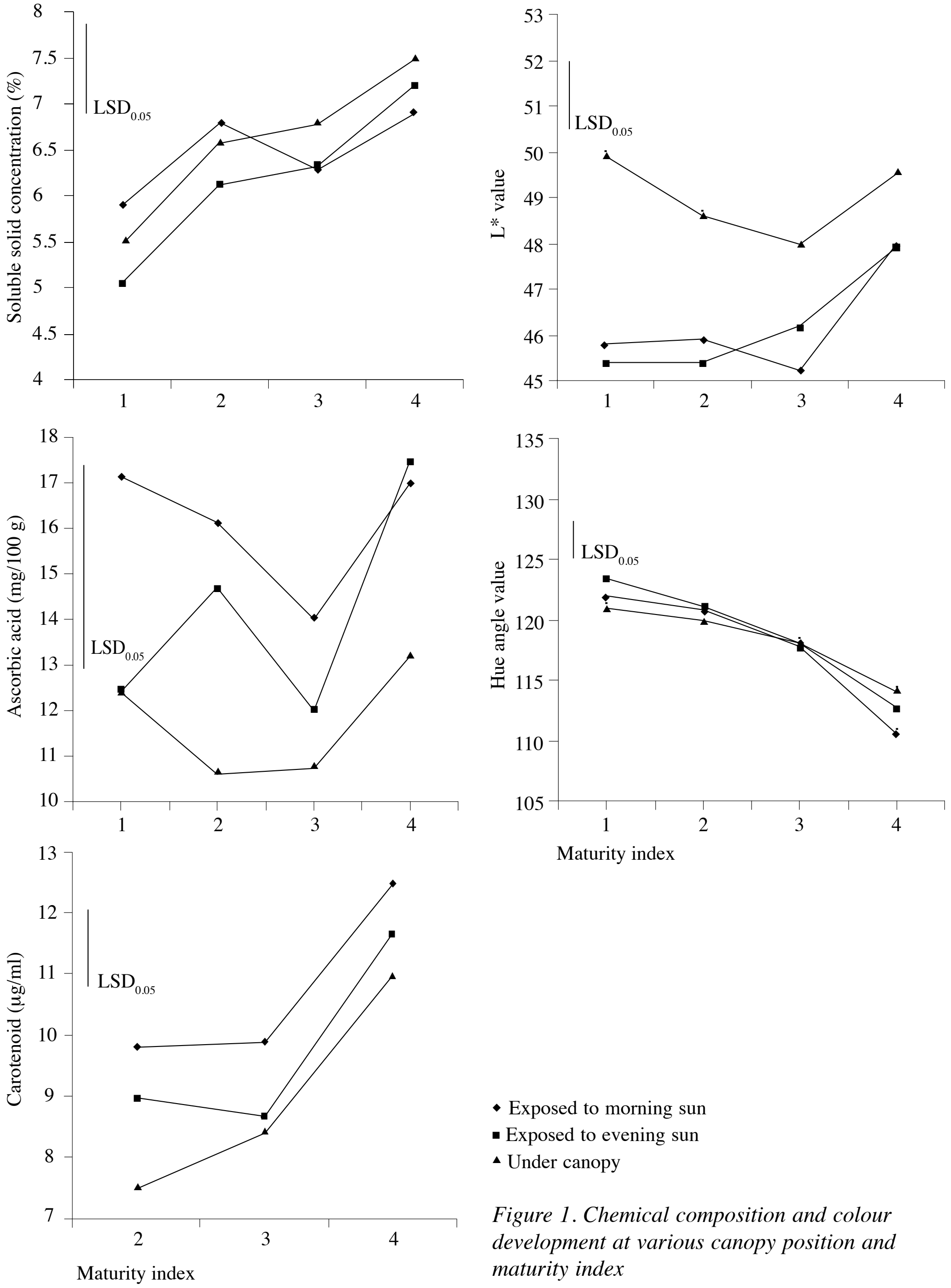

Figure 1. Chemical composition and colour development at various canopy position and maturity index

weight (DW), and heat units (HEAT) is:

$$SSC = 3.32 + 0.22\ DW + 0.0011\ HEAT$$

The equation showed that SSC is positively related to fruit dry weight and heat units. As fruits matured, SSC increased. The insignificant effect of fruit canopy position on SSC was probably due to the inherently low SSC of starfruit cultivar B10 used in this study. The inherently low SSC of cv. B10 was also reported by Abd. Rahman and Johari (1992), where SSC of cv. B10 reaches a maximum of 10–11% at maturity index 4–5. The result is also supported by the work of Marler et al. (1994) who reported that the SSC of starfruit is independent of temperature and irradiance. They observed that there was no significant difference in SSC of starfruit grown in a wide range of tropical and subtropical environment in Australia.

Ascorbic acid concentration

The ascorbic acid concentration of fruits under canopy was always the lowest, however only at maturity index 2, it was significantly lower than fruits facing the morning sun (*Figure 1*).

Result of the stepwise regression analysis showed that the ascorbic acid concentration in the fruit was significantly influenced by irradiance (PAR) ($R^2 = 0.47^{***}$). The relationship between ascorbic acid and PAR is:

$$\text{Ascorbic acid} = 10.46 + 0.007\ PAR$$

The above equation confirmed that exposure to irradiance (PAR) could increase the fruit ascorbic acid concentration, thus explained for the lower ascorbic acid concentration of the fruits under the canopy compared to the fruits exposed to the morning sun. It is believed that irradiance is important in the biosynthesis of ascorbic acid.

Similar trend was observed by Harris (1975), that is outside fruits exposed to maximum sunlight contain higher amount of ascorbic acid than inside and shaded fruits on the same plant. Recent work by Pateraki et al. (2004) on molecular characteristic and expression study on melon showed that irradiance might regulate ascorbic acid biosynthesis.

Carotenoid concentration

The fruit canopy positions significantly influenced the carotenoid concentration at maturity index 2 and 3 (*Figure 1*). At maturity index 2, the carotenoid concentration of fruits exposed to the morning sun and evening sun were significantly higher than fruits under the canopy. As fruits matured from maturity index 2 to 3, there was no significant increase or decrease in carotenoid concentration for the various canopy position.

The carotenoid concentration at maturity index 3 of fruits exposed to the morning sun was significantly higher than fruits under the canopy. For each treatment, the increase was significant as fruits matured from index 3 to 4. However at maturity index 4, the difference in carotenoid concentration between fruit canopy positions was not significant.

Result of the stepwise regression analysis showed that the fruit carotenoid concentration was significantly influenced by heat units and irradiance (PAR) ($R^2 = 0.5^*$). The relationship between fruit carotenoid, heat units and irradiance (PAR) is as follows:

$$\text{Carotenoid} = 4.3032 + 0.0034\ HEAT + 0.0015\ PAR$$

The above stepwise regression equation confirmed that fruit carotenoid concentration increased with heat units (fruit maturity) and exposure to irradiance (PAR). Thus this indicated that irradiance (PAR) might play an important role in the synthesis of carotenoid of starfruit which gives the yellow colour of the fruit. Similar observation was made by Cheng and Ma (2004). They associated this to the higher xantophyll cycle dependent thermal dissipation and antioxidants of the ascorbate – glutathione pathway of sun-exposed peel than shaded apples.

Fruit colour

At stage 1, 2, and 3 of fruit maturity index, fruits exposed to the morning and evening sun had significantly lower L* value (*Figure 1*). On the other hand, fruits protected under the canopy had significantly higher L* value. At stage 4 where the fruits have started to turn yellow, the L* values were not significantly different.

A stepwise regression analysis showed that fruit L* value was significantly influenced by irradiance (PAR) ($R^2 = 0.48^*$). The relationship between L* and PAR is:

$$L^* = 48.22 - 0.003\ \text{PAR}$$

The above relationship indicated that fruit colour L* was negatively influenced by irradiance (PAR) hence the lower L* values of the fruits exposed to the morning and evening sun.

Higher L* value of fruits indicated that fruits were lighter in colour with shines. The stepwise regression analysis confirmed that irradiance significantly reduced the L* value of the fruits. Thus excessive irradiance (exposed fruits) resulted in lower L*, darker green, dull starfruit with less shine.

The hue values reduced significantly as the fruits matured (*Figure 1*). The bigger hue angle showed that the fruits were green, while the smaller hue angle indicated that fruits have turned yellow. At stage 4 of the maturity index, fruits exposed to the morning and evening sun were pale yellow with a tinge of green, while fruits under the canopy were greener with a tinge of yellow.

A stepwise regression analysis showed that only the heat units significantly influenced the hue angle ($R^2 = 0.95^{***}$). The relationship between hue angle values and heat units is:

$$\text{Hue} = 147.58 - 0.02\ \text{HEAT}$$

The above equation confirmed that hue angle significantly reduced with heat units. The exposed fruits turned yellow faster at stage 4 of the maturity index.

The result of the stepwise regression analysis showed that chroma value (C*) was not significantly influenced by either heat units or irradiance (PAR). This is further illustrated in *Table 2* where C* value seemed to decrease or increase with no clear relation to either heat units or irradiance.

As starfruit matured, the fruit became yellow as chlorophyll gradually disappeared and the carotenoid was unmasked. This is illustrated in both the hue angle values and the carotenoid concentration at stage 4, where fruits exposed to the morning sun were pale yellow with a tinge of green with high carotenoid concentration (more than 12 µg/ml). The colour index indicated that fruits exposed to the morning sun were in advanced stage 4 while fruits exposed to the evening sun and fruits under canopy were in stage 4 of the maturity index.

It is believed that exposure to high temperature and irradiance might influence some steps prior to the ripening process of starfruit, which may cause the fruit exposed to the morning sun to be in slightly

Table 2. The effects of fruit canopy position on fruit colour Chroma (C*) values at various fruit maturity index

Fruit maturity index	Fruit canopy position	C*
1	Morning sun	25.27a
	Evening sun	23.50a
	Under canopy	24.74a
2	Morning sun	23.79a
	Evening sun	27.57a
	Under canopy	27.92a
3	Morning sun	23.77a
	Evening sun	23.71a
	Under canopy	24.49a
4	Morning sun	26.05a
	Evening sun	25.03a
	Under canopy	25.00a

Means with the same letter within the maturity index are not significantly different at $p \leq 0.05$

advanced stage 4 compared to fruit exposed to the evening sun and fruit under canopy.

Conclusion

The soluble solid concentration of starfruit was not significantly influenced by the irradiance impinging on the fruits. On the other hand, the ascorbic acid and carotenoid concentrations increased with irradiance (PAR). Fruits protected under canopy at stage 3 had better cosmetic appearance and are suitable for export to Europe. To ensure more fruits are protected under the plant canopy, it is thus recommended that during pruning, the branches should be bent down. Fruits exposed to the morning and evening sun should also be removed when small as they are bleached, lacked lustre and thus not marketable.

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Abstrak

Kesan kedudukan buah pada pelbagai posisi kanopi terhadap komposisi kimia buah (kandungan pepejal larut, asid askorbik, kandungan karotenoid) dan perkembangan warna buah belimbing di bawah struktur jaring telah dikaji dan dikenal pasti. Kajian terdiri daripada tiga posisi buah pada kanopi pokok: buah terdedah kepada cahaya matahari pagi, buah terdedah kepada cahaya matahari petang dan buah terlindung di bawah kanopi. Kedudukan buah pada pelbagai posisi kanopi tidak memberi kesan ketara kepada kandungan pepejal larut ($p < 0.05$). Pendedahan kepada iradians (PAR) telah menambahkan kandungan asid askorbik belimbing. Kandungan karotenoid bertambah apabila unit haba dan pendedahan kepada iradians bertambah. Hal ini menunjukkan bahawa iradians memainkan peranan penting dalam sintesis karotenoid. Iradians berlebihan (buah yang terdedah kepada matahari) menghasilkan buah berwarna hijau gelap, kurang berkilat dengan nilai L* yang rendah. Buah yang terlindung di bawah kanopi kelihatan lebih menarik dan sesuai untuk pasaran eksport.

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