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Research Articles

Canopy management to improve fruit quality of Coe Red Fuji, Granny Smith and Spartan varieties of apple (*Malus domestica*)

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ABSTRACT

Light management within apple (*Malus domestica* Borkh.) canopies has been an invariable rationale of fruit tree architecture strategy during the development of training systems. This paper attempts to compare fruit quality characteristics of three apple cultivars Coe Red Fuji, Granny Smith and Spartan trained on three canopy architectural engineering (training) system, viz. Espalier, Vertical axis and Cordon were grafted on M 9 rootstock. The maximum fruit weight (210.11g) was observed in Granny Smith and maximum yield per tree (32.11 kg/cm^2) and yield efficiency (0.69 kg/cm^2) in Coe Red Fuji which may be due to higher crop density. Among training systems, maximum fruit weight (200.12 g), highest yield per tree (36.36 kg) and maximum yield efficiency (0.72 kg/cm^2) was observed in espalier training system. The interaction study displayed maximum fruit weight in Granny Smith (210.55g), highest yield per tree in Coe Red Fuji (32.16 kg) and maximum yield efficiency in Spartan on Espalier system. Light interception demonstrated maximum photon flux density (237 µmolm^{-2} s^{-1}) across the canopy of Spartan with minimum leaf area index (0.30) and among training systems maximum PPFD (221 µmolm^{-2}s^{-1}) was observed in Espalier system with minimum LAI (0.21). Fruit size, TSS and colour parameters of fruits in all varieties were significantly influenced by light intensity. Higher the light intensity, higher was the TSS and colour development in coloured varieties like Spartan and Coe Red Fuji. Therefore, espalier training system was found the best canopy management system allowing maximum PAR penetration and diffusion leading better fruit quality and productivity.

Key words: Light interception, Yield efficiency, Photon flux, Training system

The productivity of apple (*Malus domestica* Borkh.) and its fruit quality are determined through optimisation of sunlight spectrum and synchronization of cultural practices such as training system and orchard design directed towards the improvement of quantity of light (i.e. the amount of photosynthetically active radiation, PAR) intercepted and distributed by orchards (Hampson *et al.* 2002, Peck *et al.* 2006, Bastias and Corelli 2012). These various factors required to be investigated to augment the production efficiency and fruit quality of this important crop and subsequently its competitiveness in diverse cultivation environments. The type of training systems also affect plant blooming, fruit ripening time and total fruit production (Palmer 1989, Robinson 1997), as well as the plant adaptation to specific conditions (Robinson 2004a, Robinson 2004b, Robinson 2006). Furthermore, the associative effect of training system and photosynthetic photon flux density are also determining factors for fruit quality (Wunsche and Lakso 2000, Willaume *et al.* 2004, Zhang *et al.* 2016). The yield of well-cultivated trees depends mainly on the total light interception for each part of the canopy structure that is produced by the different training systems (Palmer 1989, Robinson 1997). Improvement of light penetration within tree canopies has been a constant objective of fruit tree architecture manipulation through the setting up of training systems. This significant effect of light can be explained through imperative role of radiation spectrum in photosynthetic carbon fixation and fruit quality. In the intra-tree canopy, the fruit quality changes in response to orchard architecture. Significant variations in fruit quality are specifically affected by the irregular distribution of light across canopy (Robinson and Lakso 1988, Wagenmakers and Callesen 1995) and the light quality; e.g. red light (600–700 nm) enhances anthocyanin synthesis in fruit peel (Awad

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et al. 2012, Bastias and Corelli 2012). Incorrect training system can cause canopy shading, which will then reduce the qualitative parameters of the fruit, such as size, colour, sugar content, and secondary metabolite concentrations. However, little is known of the effects of the different types of canopies on fruit nutritional quality. Nowadays, a systemic approach based on the study of the main tree vegetative (trunk area, summer pruning), productive (yield, fruit size) and PAR factors along with main fruit sensorial (soluble sugars, total acidity) and nutritional (total polyphenols content, TSS and acidity) parameters is seen as an important option. This can provide a better overview of the light/canopy interactions, and subsequently of the effects on fruit yield efficiency and nutritional quality. The present study was conducted to: (a) compare the effects of three training systems on three apple cultivars in terms of yield efficiency and fruit quality; (b) to describe the effects of different PAR availability for the training systems (c) to determine the relationship between colour variation and fruit quality according to the different training system and (d) to determine interactive effect of training system and apple cultivar on changes in the fruit quality and yield efficiency.

MATERIALS AND METHODS

Three apple varieties grafted on M 9 clonal rootstock were evaluated across three training system, viz. Espalier, Vertical axis and Cordon during 2014-15 and 2015-16. The varieties were planted during 2008-09 and are maintained at ICAR-Central Institute of Temperate Horticulture, Rangreth, Srinagar (J & K), India. Their irrigation and nutritional requirement is met through drip and fertigation system. Yearly dormant pruning in December was combined with summer pruning in June to form and maintain three training systems. At the end of each of the two production cycles at seventh and eight years after grafting, the trunk circumferences were measured at 15 cm above grafted point. The trunk circumferences converted into trunk cross sectional area (TCSA cm^2). The crop density was estimated for each plant under different apple cultivars and training system. Upper, middle and lower leaves were randomly selected and the leaf area index (LAI) was measured using UV Meter Model -3414F. For the two years, the measurements of the PAR for each layer were made using Light Scout Solar/Electric Quantum Meter – External Sensor Model - 3415FXSE with the PAR expressed as the photosynthetic photon flux density (PPFD; $\mu molm^{-2}s^{-}1$). The PAR measurements were made two weeks before fruit harvest, over three consecutive days. The instrument was placed perpendicular to the plant height in for each layer and per training system/cultivar combination (5 random points per repetition). The measurements were carried out on a sunny day from 11:00 am to 12:00 noon. For each of the two years, the fruits were harvested for both of the training and cultivar combinations. The fruit weight, yield per plant and yield efficiency were measured for both years, and the plant yield efficiency (PYE) was calculated as the total yield/TCSA ratio (Milosevic *et al*. 2013). For both of the cultivar/training combinations, the fruit were sampled at the end of the two production cycles. At harvest time, the four layers of each cultivar/training combinations were identified and fruits were randomly selected from upper, lower and middle portions and they were immediately used to determine colour parameters and total soluble sugar in each cultivar/training system. Apple colour was measured and expressed as L, a, b and Tint using Chroma meter. All of the data were analysed using one-way ANOVA tests for means comparisons using Duncan's mean range test method (SAS 2000).

RESULTS AND DISCUSSION

There was more vigorous plant growth observed among the different interactions including varieties and training systems. This difference was seen in the diameter of the trunk cross sections during 7th and 8th year. For the seventh year of cultivation, Granny Smith trained on Cordon exhibited 23.89% thinner trunk cross section followed by Spartan/Vertical axis (31.12cm^2). In the seventh year of cultivation, the maximum trunk cross section area (46.33 cm^2) was measured for Coe Red Fuji among on Espalier training system with maximum TCSA (50.31 cm^2). Following interactions, Coe Red Fuji/Espalier combination exhibited maximum trunk cross section area (48cm^2) while as minimum trunk cross section area (28.15 cm^2) was observed Granny Smith/Cordon combination (Table 1). In both years, the PPFD intercepted by the orchard

Table 1 Performance of apple varieties on different training system in apple

Treatment	TCSA (cm^2)	Fruit wt (g)	Yield (kg/tree)	YE (kg/ cm^2)
Variety				
Coe Red Fuji (V_1)	43.89 ^{B}	181.44^{A}	32.93^{B}	0.69 ^{A}
Granny Smith (V_2)	40.91^{AB}	210.26^{C}	25.54^{A}	0.63 ^{A}
Spartan (V_3)	36.88^{A}	189.22^{B}	24.47^{A}	0.66 ^{A}
Training system				
Espalier (T_1)	49.99^{C}	200.0^{C}	35.70^{B}	0.72 ^{A}
Vertical axis (T_2)	40.70^{B}	188.4^{B}	27.35^{A}	0.69 ^{A}
Cordon (T_3)	36.26^{A}	180.7^{A}	24.46^{A}	0.66 ^{A}
Interaction				
V1T1	47.66^{f}	185.37^{d}	32.31^{d}	0.6667^{d}
V1T2	40.88^{cd}	175.95^{c}	21.04^{b}	0.5200^{b}
V1T3	41.66^{cde}	170.54^{b}	23.52^{b}	0.5567^{b}
V2T1	45.30^{ef}	210.58^{g}	28.46^{c}	0.6100^{c}
V2T2	38.25^{c}	200.51^{f}	17.56^{a}	0.4500^{a}
V2T3	28.25a	197.18^{f}	15.39^{a}	0.5467^{b}
V3T1	42.92^{de}	192.73^{e}	**30.17^{cd}**	0.7167^{e}
V3T2	31.11^{ab}	165.60^{a}	17.39^{a}	0.5467^{b}
V3T3	32.39^{b}	174.43^{c}	14.80^{a}	0.4467^{a}

Means followed by the same letter within the columns are not significantly different (P=0.05) using Duncan's multiple range test was altered by cultivar to training combinations, while the variation across the two years among interaction was insignificant. For individual varieties, training system and cultivar to training combinations, the PPFD values were recorded as the means over the two years (Table 2). The maximum PPFD (237 $\mu molm^{-2}s^{-1}$) was measured for Spartan among varieties and in Espalier system (221 $\mu molm^{-2}s^{-1}$) among training systems. Following interactions, Spartan/ Espalier combination exhibited maximum PPFD (227 $\mu molm^{-2}s^{-1}$), while as minimum PPFD (172.6 $\mu molm^{-2}s^{-1}$) was observed in Coe Red Fuji/Cordon combination (Table 2). The effective management of plant architecture can modulate light interception thereby affecting yield efficiency, fruit colour and nutritional quality (Losciale *et al.* 2010, Demotes-Mainard *et al.* 2016). The current study illustrated the influence of three training system, viz. Espalier, Vertical axis and Cordon used in three apple cultivars Granny Smith, Coe Red Fuji and Spartan. The interaction of Spartan/ Espalier modulates PAR distribution with lower LAI in orchard design. Due to these parameters, the light entered more easily across all of the orchard rows, as verified by the shift in the comparative magnitude of the PPFD classes to those with the higher ranges 237 $\mu molm^{-2}s^{-1}$ and the positive effects on the yield per plant and fruit quality parameters. The correlation between training system and PPFD range has exhibited positive response particularly for the Spartan/Espalier combination considered as the most significant effect of the light efficiency in terms of fruit attributes (Campbell and Marini 1992, Wagenmakers and Callesen 1995, Cheng *et al.* 2000, Han *et al.* 2012). The better distribution of light inside the apple orchard depends on the optimal leaf density, as expressed by the LAI. Among varieties, Spartan exhibited minimum LAI (0.30) and among training systems Espaliar exhibited minimum LAI (0.22). Following interaction, Granny Smith/Vertical axis exhibited maximum LAI (0.55), while as minimum LAI (0.27) was displayed by Coe Red Fuji/espalier interactions. The relationship displayed between PPFD and LAI is quite complex among the cultivars/training systems interactions. Though cultivar and training system independently exhibited usual response but the interaction among cultivars and training systems exhibited hermetic response. This can be attributed to different mode of not only light interception by individual cultivars depending on their respective LAI but also by differential PPFD distribution by training system. The more uniform horizontal PPFD distribution contribute significantly to fruit quality and colour development and a more uniform vertical PPFD distribution contribute more to crop photosynthesis than did higher values of LAI.

The effects on the yield per tree and yield efficiency were paralleled by strong positive effects on vegetative growth manifested as enhancement in trunk cross section area in Espalier training system (Clayton-Greene 1993, Lauri *et al.* 2005). Spartan is an important cultivar for early fruit maturation and the results achieved with these plants grafted onto M 9 rootstock demonstrate that Spartan with Espalier training system is better adapted to induce higher productive performances along with superior fruit quality as

Table 2 Influence of light intensity on different quality parameters in apple

Cultivar/Training system	Light parameters			LAI	Color parameters				TSS °B
	PPFD $\mu molm^{-2}s^{-1}$	PPFD (%)	DLI (Mol/ m^2day)	LAI	L	a	b	Tint	
Cultivars									
Coe Red Fuji (V1)	172.33^{a}	29.6^{a}	8.60^{a}	0.33^{ab}	54.76^{a}	10.30^{b}	22.17^{a}	-57.47^{b}	14.55^{b}
Granny Smith (V2)	192.00^{b}	38.4^{b}	9.67^{b}	0.37^{c}	71.34^{b}	-10.28^{a}	32.70^{b}	10.33^{c}	10.76^{a}
Spartan (V3)	237.33^{c}	45.5^{c}	11.9^{c}	0.30^{a}	51.76^{a}	24.28^{c}	20.62^{a}	-88.24^{a}	12.57^{ab}
Training system									
Vertical axis (T1)	196.33^{a}	22.80^{a}	9.66^{a}	0.45^{b}	65.30^{c}	6.53^{a}	24.74^{a}	-30.70^{a}	12.70^{ab}
Espalier (T2)	221.00^{b}	37.06^{c}	11.44^{a}	0.22^{a}	42.61^{a}	14.86^{b}	34.69^{b}	-20.36^{b}	14.55^{b}
Cordon (T3)	201.33^{a}	26.06^{b}	10.51^{a}	0.26^{a}	55.20^{b}	8.70^{a}	22.66^{a}	-33.38^{a}	12.70^{a}
Interaction									
V1T1	172.50^{a}	19.88^{a}	8.63^{a}	0.45^{b}	65.06^{c}	8.70^{b}	20.16^{a}	-58.94^{c}	13.36^{bcd}
V1T2	194.00^{c}	23.58^{b}	9.70^{ab}	0.27^{a}	50.39^{a}	11.72^{c}	26.73^{b}	-60.43^{c}	15.50^{d}
V1T3	179.27^{b}	19.97^{a}	9.03^{a}	0.29^{a}	56.85^{b}	10.39^{bc}	22.70^{a}	-58.20^{c}	14.77^{cd}
V2T1	182.78^{b}	22.36^{ab}	9.77^{ab}	0.55^{c}	78.07e	-10.80^{a}	30.51^{c}	10.70^{d}	9.85^{a}
V2T2	198.10^{d}	24.21^{bc}	10.34^{ab}	0.34^{a}	65.10^{c}	-10.94^{a}	34.83^{d}	11.21^{d}	11.53^{ab}
V2T3	180.46^{b}	21.35^{ab}	9.49^{a}	0.34^{a}	71.22^{d}	-9.00^{a}	33.08^{cd}	9.60^{d}	10.46^{a}
V3T1	207.77^{e}	27.00^{cd}	10.70^{ab}	0.44^{b}	54.55^{ab}	23.86^{d}	21.44^{a}	-86.45^{b}	11.63^{ab}
V3T2	227.33^{f}	29.43^{d}	11.62^{a}	0.32^{a}	50.18^{a}	26.56^{e}	20.00^{a}	-90.70^{a}	13.59^{bcd}
V3T3	200.63^{d}	24.61^{bc}	10.58^{ab}	0.34^{a}	51.34^{a}	24.69^{de}	20.58^{a}	-87.88^{ab}	12.98^{bc}

Means followed by the same letter within the columns are not significantly different (P=0.05) using Duncan's multiple range test demonstrated by prominent colour development (Grossman and DeJong 1995, Sansavini and Corelli-Grappadelli 1996). The increases in the plant yields (36.36 kg) induced by Espalier training system were stringently correlated to the increase in the fruit size (200.12 g). Robinson *et al.* (2013) established the functional significance of high quantity of light penetrating the orchard, to induce the development of larger fruit, with a greater final size as in observed in our study in Granny Smith/espalier interaction (210.55 g). Coe Red Fuji exhibited comparatively higher yield per tree (32.11 kg) and 0.69 yield efficiency as compared to Spartan displaying 24.55 yield per tree and Granny Smith exhibit minimum yield efficiency (0.63 kg/cm^2). Among training system, espalier system was most substantial in terms of yield per tree (36.36 kg) and yield efficiency (0.72 kg/cm^2). Following the interaction between cultivar/training system Coe Red Fuji/espalier system exhibited maximum yield per tree (32.16 kg) followed by Spartan/espalier system (30.12 kg). The maximum yield efficiency (0.72 kg/cm^2) was also observed in Spartan/espalier combination (Table 1).

Influence of training system greatly affects the fruit qualitative parameters (size, total soluble sugar and colour), and these differences were substantially significant across the two years of observation. The training system had a statistically significant effect on fruit size among three cultivars. The highest fruit weight was recorded for the Granny Smith (210.11 g/fruit) among varieties and 36.36 g across espalier system while as in interaction Granny Smith/espalier exhibited maximum fruit weight.

The lusture index (L) among varieties, viz. Granny Smith, Coe Red Fuji and Spartan was 71.14, 54.78 and 51.66 respectively (Table 2). The values for 'L' ranged from 50-72 among varieties. The Spartan had dark purple skin exhibiting lower 'L' values. Among training systems Espalier demonstrated maximum lustre index (65.20). Following interactions, Granny Smith/espalier exhibited maximum lustre index (78.12) while as minimum L index (50.12) was displayed in Coe Red Fuji/vertical axis. The saturation of red colour as the index of chromaticity or "a" range from 10.3 to 24.60 for the varieties tested. Granny Smith apples which are green in colour gave -10.02 to -10.31 trained on espalier system. Spartan apples were saturated with red colour that passed through purple. The values of the index "b" for Granny Smith apples were close to 60 signifying that the skin of the Granny Smith was practically pure green in colour. The maximum total soluble sugar content among apple cultivars was found in Coe Red Fuji (14.10^{o}B) followed by Spartan (12.50 ^{o}B). Among training system espalier system showed maximum total soluble sugar content (16.24 ^{o}B), while as Coe Red Fuji/espalier interaction exhibited maximum total soluble sugar (15.40 ^{o}B). Minimum soluble sugar was exhibited in Granny Smith/vertical axis interaction.

The better distribution of light inside the canopy depends on the optimal leaf density, as expressed by the LAI (Tustin *et al.* 1998). This situation has a positive effect on the light use. It improves the productive efficiency and yield per plant; the quality indices, such as fruit size and skin overcolour, which represent an important source of antioxidant substances (phenols, vitamin C, carotenoids); and the uniformity of the fruit for some specific parameters (e.g. redness of the skin), which contribute to the fruit ripening. Relationship between orchard density, LAI, light interception and fruit yield has been studied (Palmer *et al.* 1992). The training system and PPFD has strong effects on the fruit nutritional quality parameters. As compared to the Granny Smith/vertical axis trees, the fruit harvested from the Coe Red Fuji/espalier exhibited improved nutritional quality such as higher total soluble sugar (15.40 ^{o}B) and moderately advanced colour development. However, PPFD exhibited maximum value in Spartan/espalier interaction which consequently leads to higher colour development with highest "a" value (26.20) as an indicator of early maturation. Also, this response was perhaps due to the change in the microclimate inside the espalier canopy, which can result in early ripening of the fruit across espalier training that has better light conditions. The redness of the fruit skin, which in apple is generally determined by the diffusion, intensity and type of overcolour, is one of the main important commercial traits to attract the consumer. The colour of the fruit results from the presence of chlorophyll, carotenoid and anthocyanin pigments (Lancaster *et al.* 1997). The anthocyanins are compounds that are characterised by having light-dependent metabolism and their biosynthesis and accumulation are increased by enhanced PAR, as has also been demonstrated for other fruit species (Bakhashi and Arakawa 2006). The plant architecture immensely affects light interception and consequently influence the nutritional quality of the apple fruit. Conditions that provide better light penetration inside the canopy promoted an increase in fruit overcolour, due to the higher accumulation of polyphenols. Indeed, from our study, the intensity of the over colour correlates with the PAR intensity, Spartan/espalier combination, the PPFD and the skin over colour are already high which induces greater homogeneity of the fruit over colour.

Conclusions

This study investigated the effects of apple varieties-training system interaction on the total yield of a plant, yield efficiency and fruit nutritional quality. The differences in the total production induced with three training system demonstrate that under Coe Red Fuji/espalier interaction could lead to considerable improvements in production in terms of vegetative growth, yield per plant and yield efficiency. However, for advancement in fruit colour and nutritional quality developed as result of maximum light interception was exhibited by Spartan/Espalier training system. Thus our study recommends espeliar plant architecture for improving light interception as well as higher yield efficiency in apple orchard. Although total productivity under espalier system is lower than cordon and vertical axis system. But quality and size of fruits in espalier system is better than the fruits from cordon and vertical axis system. Hence present study recommends espalier canopy management system for obtaining higher grade apples with better commercial value and acceptance.

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