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Early fruit thinning improves yield and quality of three low chill apples (*M. domestica* Borkh) cultivars in Central highlands of Ethiopia

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Abstract

Three low chill apple cultivars grafted on MM-106 semi dwarf rootstock were evaluated for fruit yield and quality attributes. The trial was carried out in a five years old orchard in central highlands of Ethiopia at Debrebirhan. Trees were treated as crop loads with 0 (unthinned) to 2, 3 and 4 fruits per spur to evaluate the influence of crop load on tree growth, fruit yield and quality. For the three cultivars tested, tree growth was reduced with an increasing crop load while total fruit yield per tree (kg) increased with high crop load. Average fruit weight and diameter differed significantly in all the tested cultivars, for which the highest value was recorded with the low crop load (2 fruits per spur). The mean values for fruit growth and yield indicate that fruits with marketable quality i.e. greater than 60 mm in diameter were recorded at low crop load (2 fruits per spur); for Anna, (76%), Dorsette golden, (50%) and Princesa, (64%). Similar analysis for fruit quality showed that at higher crop loads (more than three fruits per spur in cm^2 TCSA); total soluble sugar concentration, titratable acidity, starch content, ripening index (RI) and red color were decreased significantly for all the tested cultivars. For lower crop load treatment, (2fruits per spur) in cm^2 of trunk cross-sectional area (cm^2 TCSA); fruit weight, soluble sugar contents (SSC) and red color values were significantly higher ($P \leq 0.05$) in all cultivars. Relationships between crop loads with fruit growth and yield variables revealed that fruit weight increases with low crop load (2 fruits per spur); for cultivar Anna ($R^2 = 0.79$), Dorsette golden ($R^2 = 0.72$) and Princesa ($R^2 = 0.85$) were recorded. Our study also confirmed the relationships between different crop loads with quality parameters showed that trees under the heavier crop load (un thinned trees) expressed the lower percentage of soluble sugars, titratable acidity, starch contents, firmness and red color, whereas trees with lower crop loads (2 fruits per spur) showed a significant increments in these characteristics.

Keywords: Ethiopian highland; fruit thinning; crop load; fruit quality; fruit yield; *Malus domestica*.
Abbreviations: TCSA_ trunk cross sectional area in cm^2; SP_ spurs per tree; NF_ number of fruits per tree; YD_ yield per tree at harvest (kg); FW_ average fruit weight at harvest (g); FD_ average fruit diameter at harvest (mm); FD > 60 mm_ average fruit diameter greater than 60 mm in percentage (marketable fruit); FDR_ fruit drop in percent; TSS_ total soluble solids (^{O}Brix); TA_ titratable acidity; PA_ percent acid; SA_ sugar acid ration; ST_ starch content; FF_ fruit flesh firmness (N); RC_ red color (%); RY_ red over yellow color (%); SP_ splash color (%); RI_ ripening index.

Introduction

Ethiopia is believed to be one of the most important apple growing areas in east Africa with suitable agro-ecology that endowed with adequate chilling temperatures, mosaic of soils and water resources (German *et al.,* 2006). To date, apple cultivation was rapidly expanding in most of the highlands in the country as a source of nutrition and household income for the majority of small holder farmers. Though apple is a recent introduction to Ethiopia, many efforts have been made to improve the limited knowledge and experience in cultivar-rootstock selection, nursery management and orchard management practices such as pruning, tree training and crop load managements which are the key for final quality harvest. and commercial farmers for apple cultivation to meet successful export (Byerlee et al., 2007). Crop load of the fruit tree is a measure of the fruiting density expressed by the number of fruits per cm^2 of trunk cross-sectional area (TCSA) (Wunsche and Ferguson, 2005; Stover et al., 2004). Crop load can directly affect fruit quality and requires careful management for achieving commercial requirements for fruit size and other consumer-based quality attributes (Treder et al., 2010; Wunsche et al., 2005). High crop load would result in a large number of small, poor-quality fruits and have a negative effect on the next season's cropping potential and tree survival (Schmidt et al., 2009; Wright et al., 2006). In commercial apple production, thinning is used to increase fruit quality, enhance return bloom, lessen biennial bearing and avoid limb breakage (Ferree 1996; Byers et al., 1990; Williams, 1979). Accordingly, fruit size, appearance, flavor, firmness, and storability are very important quality attributes for the fresh market and mainly enhanced by crop load regulation. Forshey and Elfving (1989) stated that fruit quality attributes like soluble solids content, dry matter, fruit color, firmness and starch content can be affected by crop load in un thinned (heavily cropped trees) that produce small-sized and inferior quality fruits. Also, flower bud production for the following season can be negatively affected by an increase in the current season fruit load (Dennis, 2000; Palmer, 1992).

In respect of the present consumers demand for organic products, manual thinning of fruit at early stage is environmentally friendly and therefore employed to improve fruit size, quality, and regulate cropping when compared to chemical thinning. Because chemical thinning always carries some risk, as the practice must be completed very early in the season, before the grower can accurately judge crop size and before the danger of frost has passed. It may sometimes cause adverse effects such as reduced yield (Link, 1998; Marini, 1996; McArtney et al., 1995; Elfving and Cline, 1993a; Byers and Carbaugh, 1991), reduced fruit growth (Jones et al., 1983), fruit russeting (Bound et al., 1993; Pavirie and Paulie, 1989), fruit deformation (Rogers and Williams, 1977), poor fruit colour (Byers and Carbaugh, 1991), and lower calcium concentration in fruit (Elfving and Cline, 1993b).

Forshey and Elfving (1997) states that crop load should be limited to the minimum number of fruits on a tree that will ensure acceptable fruit quality and adequate return bloom for a full crop in the subsequent growing season. The following season's flower buds are initiated early in the fruit development of the current growing season and these two processes are competitive where excessive fruit will inhibit flower bud formation for the next season (Koutinas et al., 2010). Information on crop load manipulation and fruit quality are of particular importance to optimize fruits loads per tree for achieving the desired fruit qualities. Therefore, the objective of this experiment was to investigate the most appropriate crop load for these mostly cultivated low chill apple cultivars (Anna, Dorsette Golden and Prencisa) grown at Ethiopian highland conditions in order to achieve standard fruit quality for domestic and export markets.

Results

Crop load, growth and yield characteristics

Different crop loads in all the tested cultivars did not significantly influence the trunk cross sectional area (TCSA) (Table1). A significant difference was observed for the number of spurs per tree which significantly affected fruit yield and number of fruits per tree depending on crop load treatments (Table 1). It indicates that at heavy cropping (zero or un thinned plants) and trees with 4 fruits per spurs, there was a higher number of small sized fruits which increased the total absolute fruit number of trees (Table 1) and lower the average weight and diameter of fruits of marketable quality (60 mm diameter or above). The result also indicates that the heavier crop load (un-thinned trees) in cultivar Anna lowered fruit weight by (11.92%), which in turn affects fruit diameter of marketable quality (> 60 mm diameter) by (12%), when compared to that of the trees carrying lower crop load (2 fruits per spur) (Table 1). Heavier cropping also showed similar effect on Dorsette golden and princesa cultivars. As observed in

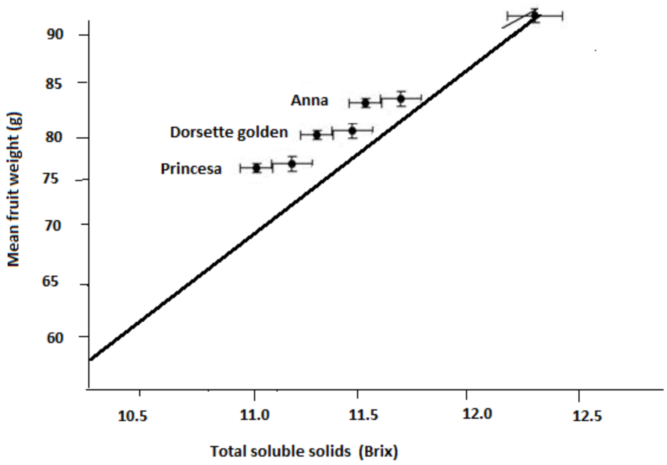

Fig 1. Relationship between fruit weight and sugar contents of the three low chill apples cultivar.

all the tested cultivars, fruit weight and diameter decreased with increasing crop load. More number of fruits exists on the tree would result in large number of undersized fruits with lower quality due to high competition for photo assimilates to satisfy the sink demand. Percentage fruit drop was not significant for all the tested crop loads in the season; because this may depends on synchronization in pollination among cultivars, tree canopy management and fertilizer use of the orchards.

Fruit quality characteristics affected by crop load

No significant differences were observed in total soluble solid (TSS) and titratable acidity (TA) contents among the treatments in all investigated cultivars. However, sugar acid ratio was significant with all crop load treatments for the tested cultivars (Table 2). Also, fruit firmness and starch content increased significantly with lower crop load in all the tested cultivars (Table 2), which indicates that lower crop loads contributed to the improvement of internal and external fruit quality characteristics; such as early ripening, increased soluble solid contents, more starch contents, firmness, color and often have a higher levels of dry matter.

Moreover, the red color percentage was higher in all the tested cultivars for trees with lower crop load (2 fruits per spur) (Table 2). No differences were observed for red over yellow color (red color on yellow ground) among crop load treatments. Conversely, for splash color (yellow color on red ground) a significant difference was observed for all crop load treatments with the values higher for heavier crop load (Table 2). Ripening index increased with lower crop load, i.e. (27%) for cultivar Anna, followed by (26%) in Dorsette golden and (24%) for Princesa cultivars (Table 2), which showed non uniformity in fruit ripening for different crop loads. Also at lower crop load, there was an increased starch content which increases the concentration of soluble sugars with low sugar acid ratios (Table 2).

Relationships between crops load with fruit growth and yield parameters

A significant linear regression values were recorded between crop loads, growth and yield parameters for three apple cultivars tested (Table 3). Accordingly, for cultivar Anna, the average fruit weight (R^2 = 0.79), fruit diameter (R^2 = 0.61), fruit diameter greater than 60 mm of marketable quality (R^2 = 0.59), number of fruits per tree (R^2 = 0.77) and spurs per tree

Table 1 Growth and Yield characteristics of apple cultivars affected by crop load.

Cultivar	Crop load	TCSA (cm ^{2})	SP	NF	YD	FW	FD	FD > 60 mm	FDR
Anna	0	37.75±4.75	86.23 ±8.02 a	103.74±6.85 a	14.63±1.78 a	103.64± 6.65 b	61.12± 1.19 b	55±3.98 c	8.53± 0.15
	2	38.23± 5.42	78.43±5.23 b	61.4± 2.73 d	9.62±1.54 b	115.67±7.48 a	73.82± 1.75 a	76±4.42 a	5.18±2.09
	3	38.10± 4.98	87.77±2.96 a	85.00±4.86 c	10.04± 1.93 b	98.22±5.09 c	72.75±1.57 a	63± 4.18 b	5.44±0.86
	4	39.99±4.02	86.67±3.27 a	96.56±4.61 b	11.84± 1.57 b	97.56±5.25 c	66.12± 0.72	58±3.97 c	6.28±1.97
	F- test	ns	**	**	**	**	**	**	ns
D.golden	0	37.04±3.75	117.43±1.68 a	160.54±3.16 a	17.56±1.69 a	73.32±4.35 d	53.72±2.54 b	42±4.25 b	7.35±3.64
	2	39.03 ±0.63	106.67±3.16 c	69.92±7.99 c	7.85± 0.39 c	96.86±4.68 a	58.42± 0.45 a	50± 0.31 a	8.67±1.31
	3	40.49± 0.46	111.19±7.54 b	165.17±3.92 a	12.58± 0.47 b	91.97±4.53 b	52.61± 0.61 b	48± 0.38 a	5.68± 0.52
	4	36.01±1.05	98.83±4.67 d	124.92±4.12 b	10.87±0.13 c	87.69±1.32 c	49.42± 0.69 b	41± 0.57 b	5.71± 0.23
	F- test	ns	**	**	**	**	**	**	ns
Princesa	0	36.98±0.11	87.36±1.02 b	65.15±6.34 c	13.25±0.54 a	92.56±3.47 c	58.13±0.73 b	55±1.32 b	7.24± 0.64
	2	38.51 ± 0.28	68.23±0.46 a	86.67±0.64 a	8.02 ± 0.85 b	101.51±1.86 a	63.15±1.35 a	64 ± 2.94 a	4.36±1.83
	3	37.46±1.06	56.35±0.33 c	73.43±1.66 b	9.72±0.49 a	97.49±2.33 b	62.34±1.26 a	53 ±1.63 b	4.35± 0.69
	4	36.72±0.35	44.71±0.69 d	71.40±1.60 b	10.38±0.43 a	97.47±2.54 b	56.68±1.04 b	51 ±2.45 b	5.49±0.82
	F- test	ns	**	**	**	**	**	**	ns

Ns_ Non significant; ** _ significant at ($P < 0.05$). Data are the mean of three replications ± standard error. For each cultivar and column, values followed by the same letter are not statistically different according to the Tukey's (HSD) test. TCSA_ trunk cross sectional area in cm^2; SP_ spurs per tree; NF_ number of fruits per tree; YD_ yield per tree at harvest (kg); FW _ average fruit weight at harvest (g); FD_ average fruit diameter at harvest (mm); FD > 60 mm _ average fruit diameter greater than 60 mm in percentage (marketable fruit); FDR_ fruit drop in percent.

Table 2. Mean values for fruit quality characteristics of low chill apple cultivars affected by crop load.

Cultivar	Crop load	TSS	TA	PA	SA	ST	FF	RC	RY	SP	RI
Anna	0	12.45±0.24	0.63±0.49	0.042±0.02	296.43±0.36 b	2.6±0.32 c	80±1.52 b	47.33±1.67	13.00±5.00	41.67 ±4.41 a	0.12±0.6 b
	2	13.50±0.33	0.54± 0.44	0.032±1.33	421.88±0.11 a	5.0±0.19 a	85±1.47 a	72.33±7.26	15.00±0.01	16.33±4.42 d	0.27±0.5 a
	3	11.46±0.11	0.72± 0.10	0.048±2.01	238.75±0.01 d	3.5±0.34 b	78±1.52 b	58.33±6.01	18.33±3.33	25.33±4.41 c	0.15±0.3 b
	4	11.17±0.45	0.63±0.23	0.042±1.06	265.95± 0.15 c	3.3±0.25 b	75±0.73 c	52.00±7.03	16.67±3.33	30.00±3.01 b	0.12±0.4 b
	F- test	ns	ns	ns	**	**	**	**	ns	**	**
D.golden	0	11.36±0.35	0.73±0.13	0.048±0.43	236.67±0.03 c	2.8±1.10 b	78±1.23 b	62.89±5.33	17.01±0.02	30.00±2.32 a	0.19±0.2 b
	2	12.63±0.45	0.55± 0.32	0.033±1.32	382.72±0.12 a	4.7±0.35 a	83±.0.24 a	67.50±7.22	16.67±1.67	25.00±5.40 b	0.26±0.9 a
	3	11.73±0.47	0.53± 0.43	0.035± .48	335.12±0.15 b	2.5±0.20 b	81±1.38 a	55.75±6.87	18.67±1.67	27.25±8.19 b	0.16±0.2 b
	4	11.08±0.36	0.74± 0.37	0.049±0.36	226.13± 0.03 c	2.2±0.65 b	80±1.15 a	52.00±3.54	20.00±2.04	27.00±2.88 b	0.17±0.7 b
	F- test	ns	ns	ns	**	**	**	**	ns	**	**
Princesa	0	12.55±1.55	0.62±0.62	0.042±1.53	298.81±0.84 a	2.0±0.16 b	80±1.46 b	52.00±1.35	14.56±0.18	35. 58±9.11 a	0.18±0.8 b
	2	13.35±0.53	0.75±0.71	0.050± .22	67.0±0.17 c	4.5±0.11 a	87±0.15 a	76.75±5.91	16.07±1.33	30.08±3.33 b	0.24±0.3 a
	3	11.63±0.53	0.69±0.68	0.046±1.11	252.83±0.13 b	2.6±1.32 b	81±1.43 b	57.03±7.13	15.57±2.45	32. 23±7.23 b	0.15±0.4 b
	4	11.25±0.46	0.58±0.36	0.038±0.03	296.05±0.44 a	2.7±0.58 b	80±1.33 b	50.04±5.04	17.24±2.35	32.57±4.26 b	0.16±0.2 b
	F- test	ns	ns	ns	**	ns	**	**	ns	**	ns

Ns_ Non significant; **_ significant at ($P < 0.05$). Data are the mean of three replications ± standard error. For each cultivar and column, values followed by the same letter are not statistically different according to the Tukey's (HSD) test. Ground color scores 1-9, where 1 = fully red and 9 = bright yellow; Red over Yellow_ Red color on Yellow ground; Splash_ Yellow color on Red ground; Iodine starch test (scores 1-10), where 1 = dark and 10 = white (no starch); Percentage acid_ gm/ml of malic acid; Sugar-Acid ratio _ ^{O}Brix value/ percent acid; Firmness = N = Kg of force expressed in Newton. i.e. 1Kg force = 9.8 N; TSS_ total soluble solids (^{O}Brix); TA_ titratable acidity; PA_ percent acid; SA_ sugar acid ration; ST_ starch content; FF_ fruit flesh firmness (N); RC_ red color (%); RY_ red over yellow color (%); SP_ splash color (%); RI_ ripening index.

Table 3. Relationships between crop load with growth and yield variables for apple cultivars at harvest. Analysis of covariance was used to estimate the least square means for four different crop loads.

Cultivar	Parameters measured	R^2	Slope	P value	Crop load (fruits/ cm^2 of TCSA)			
					0	2	3	4
Anna	TCSA (cm^2)	0.38	1.16	0.0012	0.46	0.54	0.51	0.47
	Spurs per tree	0.85	0.08	0.0001	2.07	0.62	0.69	0.66
	Fruits per tree	0.77	0.06	0.0001	1.08	0.57	0.61	0.59
	Yield per tree (kg)	0.95	1.18	0.0002	11.5	5.5	6.3	5.9
	Average fruit weight	0.79	-5.77	0.0001	76	91	87	79
	Fruit diameter (mm)	0.61	-6.63	0.0001	84	73	52	48
	Fruit diameter > 60 mm	0.59	-4.45	0.0014	51	76	63	69
D.golden	TCSA (cm^2)	0.39	1.14	0.0022	0.49	0.57	0.53	0.48
	Spurs per tree	0.97	0.09	0.0001	2.85	0.84	0.59	0.53
	Fruits per tree	0.83	0.07	0.0001	1.17	0.73	0.68	0.60
	Yield per tree (kg)	0.81	1.16	0.0035	16.5	12.7	11.8	12.9
	Average fruit weight (g)	0.72	-5.71	0.0001	79	87	81	73
	Fruit diameter	0.53	-7.11	0.0044	59	63	60	52
	Fruit diameter > 60 mm	0.43	-2.63	0.0023	58	67	53	51
Princesa	TCSA (cm^2)	0.36	1.18	0.0001	0.41	0.40	0.40	0.43
	Spurs per tree	0.59	0.42	0.0001	0.74	0.60	0.55	0.52
	Fruits per tree	0.53	1.48	0.0001	0.52	0.40	0.28	0.36
	Yield per tree (kg)	0.85	1.19	0.0001	10.78	6.25	6.11	5.02
	Average fruit weight	0.85	-6.63	0.0001	77	89	68	61
	Fruit diameter (mm)	0.61	-5.63	0.0001	72	86	67	54
	Fruit diameter > 60 mm	0.54	-2.94	0.0001	46	51	50	42

All measurements were taken at harvest; Values significant at $P \leq 0.05$; Regression (R^2) values indicate how much percentage of the change in the response variable for cultivar is explained by changes in crop load; Positive slope values indicate that increasing crop load by one unit increases the indicated response variable by that slope value;Negative slope values imply that increasing the crop load by one unit reduces the response variable by the shown slope value; P-values greater than 0.05 indicate that the slope for a given variable of a particular cultivar was not significant while P-value less than 0.05 denote significant slopes.

Table 4. Relationships between crop load with fruit quality characteristics for three low chill apples. Analysis of covariance was used to estimate the least square means for four different crop loads.

Cultivar	Parameters measured	R^2	Slope	P-value	Crop load (fruits/ cm2 of TCSA)			
					0	2	3	4
Anna	Soluble Solid content (TSS)	0.38	-1.01	0.0310	11.5	12.5	11.02	11.00
	Titratable acidity (TA)	0.33	-0.62	0.0312	3.3	3.63	3.55	3.45
	Sugar-Acid ratio (TSS/TA)	0.36	-0.17	0.0365	2.03	2.25	2.74	2.69
	Starch	0.75	-0.06	0.0431	3.3	4.5	4.02	3.72
	Fruit Flesh firmness (N)	0.82	0.45	0.0005	83	92	90	79
	Color Red (%)	0.58	0.62	0.0410	52	55	51	51
	Red over yellow (%)	0.17	-0.15	0.0667	23	23	23	22
	Splash (%)	0.27	-0.19	0.0165	26	25	24	24
	Ripening index	0.85	0.01	0.0132	0.12	0.15	0.11	0.93
D.golden	Soluble Solid content (TSS)	0.36	-0.15	0.0455	11.7	12.5	11.2	10.8
	Titratable acidity (TA)	0.16	-0.32	0.3441	2.3	2.6	2.0	2.0
	Sugar-Acid ratio (TSS/TA)	0.47	-0.11	0.0520	2.23	2.01	2.12	2.02
	Starch	0.73	-0.02	0.0134	2.7	3.8	2.7	2.6
	Fruit Flesh firmness (N)	0.87	0.42	0.0451	82	94	88	79
	Color Red (%)	0.53	0.03	0.0357	51	56	52	51
	Red over yellow (%)	0.15	-0.13	0.0881	21	23	22	20.5
	Splash (%)	0.26	0.14	0.0237	23	21	21	20.5
	Ripening index	0.76	0.17	0.0322	0.15	0.16	0.15	0.16
Princesa	Soluble Solid content (TSS)	0.27	-0.36	0.0004	11.0	12.1	11.6	11.5
	Titratable acidity (TA)	0.29	-0.46	0.0400	2.5	2.7	2.5	2.6
	Sugar-Acid ratio (TSS/TA)	0.27	-0.01	0.0401	2.6	2.7	2.6	2.6
	Starch	0.75	-0.16	0.0282	2.4	2.9	2.5	2.4
	Fruit Flesh firmness (N)	0.76	-0.33	0.0244	82	93	90	86
	Color Red (%)	0.67	0.12	0.0446	54	55	54	54
	Red over yellow (%)	0.21	0.13	0.0551	23	23	24	23
	Splash (%)	0.28	0.31	0.0231	22	20.5	20	21
	Ripening index	0.74	0.42	0.0175	0.12	0.15	0.12	0.13

All measurements were taken at harvest; Values significant at $P \leq 0.05$; Regression (R^2) values indicate how much percentage of the change in the response variable for cultivar is explained by changes in crop load; Positive slope values indicate that increasing crop load by one unit increases the indicated response variable by that slope value; Negative slope values imply that increasing the crop load by one unit reduces the response variable by the shown slope value; P-values greater than 0.05 indicate that the slope for a given variable of a particular cultivar was not significant while P-value less that 0.05 denote significant slopes.

(R^2 = 0.85) were significant at P ≤ 0.05. A significant linear regression values were recorded between crop loads, growth and yield parameters for the three apple cultivars tested (Table 3). Accordingly, for cultivar Anna, the average fruit weight (R^2 = 0.79), fruit diameter (R^2 = 0.61), fruit diameter greater than 60 mm of marketable quality (R^2 = 0.59), number of fruits per tree (R^2 = 0.77) and spurs per tree (R^2 = 0.85) were significant at P ≤ 0.05 (Table 3). Fruit weight and diameter decreases with high crop load for all the tested cultivars (Table 3). Our study confirmed that for crop load treatments between zero (un thinned trees with higher crop load) and trees thinned with lower crop load (2 fruits per spur), there was (15g) reduction of fruit weight for cultivar Anna, followed by (12g) weight reduction in Princisa and (8g) reduction in Dorsette golden (Table 3). Similarly, marketable fruits (fruit diameter greater than 60 mm) showed (25 mm) reduction for Anna, (11mm) and (5 mm) reduction for Dorsette golden and Princesa respectively. Conversely, total, fruit yield per tree in cm^2 of trunk cross sectional area (TCSA) increases for higher crop loads (R^2 = 0.95; 0.81, and 0.85) for Anna, Dorsette golden and Princesa respectively (Table 3).

For cultivar Dorsette golden, other parameters strongly related with crop load treatments include spurs per tree (R^2 = 0.97), number of fruits per tree (R^2 = 0.83) and fruit yield per tree (R^2 = 0.81) at P ≤ 0.05 (Table 3). Also a significant linear regression was recorded between crop load and average fruit weight (R^2 = 0.72), fruit diameter (R^2 = 0.53) and fruit diameter greater than (60 mm), (R^2 = 0.43). In Princesa cultivar, there was a significant association between crop loads and different growth parameters measured (Table 3) as described as spurs per tree (R^2 = 0.59), number of fruits per tree (R^2 = 0.53), fruit yield per tree (R^2 = 0.85), fruit diameter (R^2 = 0.61), fruit diameter greater than 60 mm (R^2 = 0.54) and mean fruit weight (R^2 = 0.85) at P ≤ 0.05 (Table 3). In all the tested cultivars, trunk cross sectional area (TCSA cm^2) is little influenced by crop loads and showed weak association (R^2 = 0.38, 0.39 and 0.36) for Anna, Princesa and Dorsette golden respectively.

Relationships between crops load with fruit quality and yield parameters

Different crop loads significantly affected the quality of fruits as observed in all the three cultivars (Table 4). Accordingly, trees under the heavier crop load (un thinned trees) expressed the lower percentage of soluble solids, titratable acidity, starch contents, firmness and red color, whereas trees with lower crop loads (2 fruits per spur) showed a significant increments in these characteristics (Table 4). Crop loads also significantly affected ripening index and would result in a non-uniform fruit ripening. The starch content was also reduced for heavier crop loads (Table 4).

When comparing the association among yield and quality parameters in relation to crop loads, for the three low chill apple cultivars, there was a significant relationship existed between each other that would affect fruit quality. For example, cultivar Anna showed a significant regression between mean fruit weight and fruit sugar content (Fig.1 and Table 4), i.e. (R^2 = 0.79 and 0.38) respectively at different crop loads. Also, the regressions between crop load and fruit diameter represented as percentage of fruit greater than 60 mm diameter (R^2 = 0.43), titratable acidity (R^2 = 0.33), starch content (R^2 = 0.75), fruit flesh firmness (R^2 = 0.87) and red color score (R^2 = 0.58) were significant for Anna (Table 3). It indicates that the value for all these parameters increases with a decrease in crop loads. A similar relationship was presented for the cultivar Dorsette golden and Princesa regarding the quality parameters (Table 3 and Fig. 1).

Discussion

Increasing crop load negatively affected tree trunk cross sectional area (TCSA), growth and fruit quality characteristics as stated in the present study. Forshey and Elfving (1977) reported that there was a negative relationship between heavy crop load and fruit quality due to competition for assimilates between fruits as well as tree growth and development. The reduction in average fruit weight and percentage of marketable fruit (fruit diameter greater than 60 mm) at high crop load is due to competition for assimilates and limited number of leaf area to fruit ratio. This result was in conformity with Nielsen and Dennis (1993), and Hull et al., (1995) who reported that leaf area to fruit ratio in low crop load would result in increased fruit size and quality. As fruit yield is a function of factors including fruit number, and fruit size (Meland, 2009), increasing crop load typically increases total fruit yield per tree in which, large number of fruits remain undersized and low in quality. Palmer et al., (1997) suggested similar investigation while working on 'Braeburn' apple trees that heavy crop load produces smaller fruits compared to lighter crop load. Our study also confirmed the negative impact of heavy crop load on the average fruit weight, firmness, total soluble sugar, and starch contents in these three low chill apples (Anna, Dorsette golden and princesa). The low soluble sugar due to high crop load indicates that assimilates available for fruit growth and quality became limited; as a result, less starch was being stored in the fruit during the growing season. Furthermore, high crop load would result a delay in fruit maturity and non-uniform ripening. These results are in agreement with previous studies (Treder et al., 2010; Wright et al., 2006; Awad et al., 2001) in which an average fruit weight, starch content and total soluble sugar showed a negative correlation with the higher number of fruits per tree in cm2 of trunk cross sectional area (TCSA).

Tromp, (2000) and Meland, (1997) also confirmed that reducing the number of fruits per tree increases the relative amount of leaf area per fruit as well as the availability of carbohydrates for the remaining fruits. Thus, low fruit numbers per tree can improve flower bud induction and return bloom for the subsequent season. Nielsen and Dennis (1993) stated that apples harvested from heavier crop loads were smaller in size, had less sugar content and delayed fruit maturity as reported in their work on thinning of 'Delicious' apples. Dussi et al., (2006) also reported that competition among excessive fruit set for assimilates resulting in delayed maturation and a small-sized fruits of lower quality.

Koike et al., (2003) states that a (14%) increase in sugar levels in ‘Fuji’ apple fruit from hand-thinned trees compared with un thinned trees. Johnson (1995) suggested a similar effect for hand-thinned ‘Cox’s Orange Pippin’ apple. Also fruit firmness increased with decreasing crop load as indicated in this study supporting the results of Garriz et al., (2000) who found that fruit flesh firmness was significantly lower in 'Braeburn' apple trees carrying high crop loads than in trees with moderate or low crop loads. Jones et al., (1997b) also reported increased firmness with reduced crop load following chemical thinning of ‘Pink Lady’ and ‘Jonagold’ with ethephon and benzyladenine (BA). This study also indicates that high crop density significantly influence fruit quality and fruit ripening (non-uniform fruit ripening), as supported by the findings of Autio (1991) who reported that there was a strong positive correlation between crop density, fruit quality and date of ripening. We further confirmed that for these low chill apple cultivars, a crop load of 1, 2 or the maximum of 3 fruits per spur (i.e. in the range between 1 and– 3 fruits per spur in cm^2 of TCSA) resulted in high percentage of marketable fruits with adequate fruit quality attributes. This could have been due to adequate leaf area to fruit ratio that can easily channel the assimilates to satisfy the sink demand of the tree with minimum competition.

Materials and Methods

Plant materials

The experiment was conducted between September (2014) and February (2015) on 5-year-old trees of three low chill apple cultivars (Anna, Dorsette golden and Princesa) grafted on MM.106 rootstock. These cultivars are introduced from Spain in (2000) and planted in Faji temperate fruits and related product development farm at Debrebirhan in central Ethiopia. The cultivars were selected for their widespread planting in orchards under Ethiopian highland condition that allows successful bud break and flowering, as well as ease of synchronization in pollination for low chill apple cultivars.

Experimental site

The orchard is located at (2800) meter above sea level (m.a.s.l) and received an annual average rainfall of (900 mm) during the main rain season (between June and September) (National Meteorology Agency, 2014). The mean daily minimum and maximum temperatures of the location range from (4-10°C) in winter and (17-19°C) in summer respectively (National Meteorology Agency, 2014).

Orchard management

The trees were planted (4m x 4m) spacing, trained in a central leader training method and received routine horticultural care from early bud break to flowering and fruit development. The trees were irrigated two times a week from October to February and once a week from March to May. At each irrigation session, watering was stopped when the top soil near to the base of stem wetted at 5cm depth at a time. Nitrogen was applied in urea (46% N) form at a rate of (200g) per tree when mixed with well-rotted manure once in the season at the end of dormancy; while potassium was added twice as potassium sulphate in a split application at rate of about (100g) K_2SO_4 (44% K, or 48–53% in the form of K_2O) per tree after bud break and similar amount at the onset of flowering to avoid flower abortion and successful pollination.

Experimental design

The experimental design was (3 x 4) factorial, by considering four fruit thinning levels (unthinned or zero thinning, 2, 3 and 4) fruitlets per cluster [cm^{-2}] of the trunk cross sectional area (TCSA) and three apple cultivars (Anna, Dorsette golden and Princesa). Trees were thinned once at fruitlet stage when fruitlets are about (15–20 mm) in diameter at the beginning of October in (2014). Each treatment constituted three trees per cultivar and replicated three times for each of the four crop loads in all the tested cultivars. Thus, total of thirty six plants were considered from three cultivars for this experiment.

Fruit growth and yield parameters

The number of spurs per tree was counted and the circumference of the trunk was measured (25 cm) above the graft point to calculate trunk cross sectional area (TCSA); that would help to calculate the final fruit yield per tree in cm^{-2} TCSA. Fruit growth was measured on (15) representative fruits on each tree, for each treatment. Measurements were taken randomly and started when the fruit were approximately (30 mm) in diameter on 22nd of November, (2014) and were carried out four times at twenty days interval until the final measurement at harvest on 11th of February (2015). At harvest, the numbers and total yield of fruit per tree (kg) was recorded and those fruits with greater than (60 mm) in diameter were considered as marketable and blow which are unmarketable. Also, the number of fruit drops were counted for each treatment classes, and assumed to be part of the total fruit yield per tree.

$$\text{Percent fruit drop} = \frac{\text{No. of premature fruit drop} - \text{No. of mature fruit at harvest}}{\text{No. of premature fruit drop}} \times 100$$

The total fruit weight and fruit number per tree were used to compute the average fruit weight. Thus,

$$\text{Average fruit weight} = \frac{\text{Total weight of the harvested fruit}}{\text{Number of fruits per tree}}$$

Fruit quality parameters

A sample of fifteen fruits were selected randomly from each experimental tree to measure yield, weight, external and internal fruit quality (i.e., diameter, fruit weight, fruit flesh firmness, visual scores for background and surface color, total soluble solids concentration (TSS), titratable acidity (TA), sugar/acid ratio, starch content and ripening index (RI). All quality analyses were done at Center for Temperate Fruits and Nuts Research, Ethiopian Institute of Agricultural Research, based at Holetta Agricultural Research Center, Holetta, Ethiopia. The analyses were carried out according to AOAC International (2003), an official method for determination of fruit quality. Flesh firmness was measured using a digital table top penetrometer with an 11-mm probe [Penefel; Centre Technique Interprofesionnel des Fruits et Legumes (CTIFL), Paris, France]. Afterwards, the fruits were juiced by a blender mixer and subsequently filtered with A4 filter paper to measure the total soluble solids TSS (%), using digital hand-held refractometer (Pocket PAL-1, Atago, Japan). Titratable acidity (TA) was measured using the standard laboratory solution of (0.1M) Sodium Hydroxide (NaOH) and (1% w/v) solution of phenolphthalein in (95% v/v) ethanol. A drop of NaOH into the juice/water solution containing (10 ml) of juice and (50 ml) of distilled water was placed on a magnetic stirrer to keep it thoroughly mixed. Phenolphthalein (max. 3 drops) was added to juice/water solution that changes color rapidly from colorless to pink to take the readings to determine titratable acidity until the color change occurred.

The °Brix value for sugar/acid ratio is calculated and expressed as percent of malic acid equivalent, using the appropriate multiplication factor for apples (i.e. malic acid 0.0067) and the results expressed as percentage acid (Moyer et al., 1980; AOAC, 2003).

Thus,

$$\text{Percentage acid} = \frac{\text{TA} \times \text{acid factor}}{\text{10 (ml juice)}} \times 100$$

$$\text{Sugar acid ratio} = \frac{{}^{o}\text{Brix value}}{\text{Percentage acid}}$$

Results expressed as acid in gram/litre:

$$\text{g/l acid} = \frac{\text{Titre} \times \text{acid factor} \times 100 \times 10}{\text{10 (ml juice)}}$$

$$\text{Sugar acid ratio} = \frac{\text{Brix value} \times 10}{\text{g-1 acid}}$$

Starch content was also determined, using iodine solution prepared by dissolving (10g) of potassium iodide in (30 ml) of distilled water and then by adding (3g) of iodine according to AOAC standard procedure. Once the iodine has dissolved the mixture is made up to one litre by adding distilled water at (10-30°C). Using a sharp knife each fruit is sliced in half. It is very important that the surfaces are cleanly cut, without any additional damage occurring to the flesh of the fruit or the skin. Additional damage of this type may cause further starches to be released from the damaged cells, leading to an inaccurate result. One half of each freshly cut surfaces of the fruit is evenly coated with iodine solution. This can be applied using a dropper bottle, or spray bottle. The cut sections are left for two minutes before the results were recorded. The stage of ripeness (percentage surface of the fruit changing to a blue-black color) must be recorded and compared with the starch conversation chart of AOAC. Thus, the amount of blue-black color present on a tested sample may be directly related to the ripeness of the fruit. The results were recorded as well as all the details concerning variety and stage of maturity and ripeness of the produce were noted. Finally scoring for starch content on (1–10) point scale, where 1 = all tissue stained blue black (high starch content), 10 = no staining or starch present.

Data on firmness, starch and SSC were used for calculation of ripeness index.

Thus,

$$\text{Ripening Index (RI)} = \frac{\text{Firmness}}{\text{Starch} \times \text{TSS}}$$

Background color scores were made following AOAC scheme for apples to describe a range of color stages at ripeness. Scoring rate ranges (1–9), where 1 is fully red and 9 is bright yellow. The color of the fruits (typically background color of the individual fruit) was compared against the different color steps and expressed as percentage of that color. The tests should be done by daylight or under fluorescent white light. The color code which matches the skin color was noted for the background color. If the color of the fruit skin lies between two color codes, both codes are noted. Accordingly, different colors are expressed in percentage scale depending on the revealed background color.

Statistical analysis

Data were analyzed using the Statistical Analysis System (SAS) of the SAS Institute, Cary, NC. Analysis was done in one way (ANOVA) and means were separated by using Tukey's honestly significant difference (HSD) test at ($P \leq 0.05$) level of significance. The relationship between different crop loads with fruit yield and quality attributes were treated as a continuous variable and analyzed using analysis of covariance (ANCOVA). Slopes to determine the effects of crop load and estimates of the Least Square means were determined using SAS (Littell et al., 2006; Miliken and Johnson, 2002).

Conclusions

This study shows that an appropriate balance between crop loads and fruit quality can be achieved by early fruit thinning. A very high crop load (un thinned) trees and four fruits per spur in cm^2 of trunk cross sectional area (TCSA) resulted in a high fruit yield and low quality fruits. It indicates that a heavier crop load influences an increase in trunk cross sectional area (TCSA) which negatively influence fruit quality and productivity of trees in the following year. The study also represents the first evaluation of apple fruit quality characteristics of low chill apple cultivars grown at central Ethiopian highland conditions. We recommended that a crop load range of one to three fruits per spur was the suitable crop loads in cm^2 of (TCSA), which resulted in a high marketable fruits, higher (SSC) values, and more highly colored fruits. When considering the high market demand and values, two fruits per spur in cm^2 of (TCSA) were the most appropriate crop load for these low chill apples. However, the number of fruits per spur must not be greater than three fruits in cm^2 of (TCSA) to maintain both internal and external fruit quality characteristics. Thus, on average the lower crop load (2 fruits per spur) showed the clear effects on increased fruit size and quality in low chill apples. Seasonal growth pattern also showed that thinning the fruit early in the season with the lowest possible load increases the overall qualities of fruits; including fruit size, weight, soluble sugar contents, fruit flesh firmness and color.

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