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Effect of crop load on the yield, fruit quality, and fruit mineral contents of ‘RubyS’ apples

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Abstract

Crop load management in apple trees is important for achieving optimum productivity and crop value. Hence, we investigated the influence of different crop loads on the fruit quality, mineral content, and yield of the ‘RubyS’ apple variety. After 4 weeks of full bloom, the crop load was adjusted by hand thinning to different (5, 10, and 15 fruits·cm^{-2}) trunk cross-sectional areas (TCSA), representing low, medium, and high crop loads. The low crop load increased the fruit size and weight, the development of the red-blushed area, and the peel color *a** at harvest; however, it reduced the total number of fruits·tree^{-1} and yield compared with that of the other crop loads. The medium crop load improved the fruit weight, flesh firmness, and soluble solids content and reduced the fruits·tree^{-1} but did not affect the fruit size and yield. However, there were no significant differences in the titratable acidity and starch index among the crop loads. The fruit mineral content (phosphorus and potassium) was higher in the low and medium crop loads compared to the high crop load. However, the nitrogen, calcium, and magnesium contents in the fruits were not affected by the crop loads. Overall, this study suggests that a low crop load improves the fruit size and weight, but its effect on the quality and fruit mineral content is similar to that of a medium crop load. Therefore, the optimum crop load level for the ‘RubyS’ apple trees was approximately 10 fruits·cm^{-2} TCSA.

Key words: apple, crop load, fruit mineral contents, fruit quality, yield

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Introduction

‘RubyS’ (‘Alpsotome’ × ‘Sansa’) is a locally developed Korean apple cultivar released for commercial production in 2014. The demand for ‘RubyS’ apple is increasing due to its sweetness and storability (USDA, 2019). In addition, ‘RubyS’ is resistant to major apple pests and diseases and has a low number of pre-harvest fruit drops (Kwon et al., 2019). However, ‘RubyS’ has excessive fruiting (Kwon et al., 2019), leading to the reduction in fruit size and quality at harvest. Therefore, crop load management is necessary to improve the fruit quality and size of ‘RubyS’ apples.

Crop load is generally defined as the number of fruits per tree (fruits·tree^{-1}) or also described as fruits per cm^2 trunk cross-sectional area (fruits·cm^{-2} TCSA) (Racskó, 2006). Fruit thinning is a common crop load management practice for achieving a targeted final fruit number on trees (Dennis, 2000; Link, 2000), ensure consistent fruit production, and overcome biennial bearing (Embree et al., 2007; Yuri et al., 2011). The objective of fruit thinning is to eliminate the smallest fruits on trees, thereby increasing the size and quality of the remaining fruits (Racskó, 2006; Yuri et al., 2011; Samuolienė et al., 2016). However, the increase in fruit size depends on the timing of fruit thinning. Early thinning can result in larger fruits at harvest (Meland, 2009; Iwanami et al., 2018; Bound, 2019). Previous studies have reported that thinning within 30 d after full bloom results in optimum fruit size; however, its effect depends on the cultivar, tree size, rootstocks, canopy, and level of crop load set (McArtney et al., 1996; Byers and Carbaugh, 2002; Koike et al., 2003; Samuolienė et al., 2016).

In contrast, the production of high quality apple fruits is directly correlated with having the optimum tree crop load (Anthony et al., 2019). Serra et al. (2016) reported that crop load influences apple fruit quality and maturity at harvest and during storage. A high crop load can affect fruit size, color, appearance, acidity, and sugar levels (Embree et al., 2007). In addition, crop load can reduce the amount of fruit mineral nutrients, increasing fruit susceptibility to physiological disorders during storage (Link, 2000). Therefore, fruit mineral content is important for predicting the storage quality of apples (Robinson and Lopez, 2009). Some studies have reported that deficiency in or excess mineral nutrients, such as nitrogen, phosphorus, calcium, magnesium, and potassium makes apples prone to physiological disorders (Robinson and Watkins, 2003; Fazio et al., 2015). In addition, a high crop load on trees can increase the bitter pit incidence and physiological disorders (Ferguson and Watkins, 1992; Robinson and Lopez, 2009; Serra et al., 2016). Therefore, strict crop load management is required to optimize fruit quality and minimize losses in storage. However, there have been no reports on ‘RubyS’ apple crop load levels considering optimum fruit size, quality, and mineral content.

Therefore, the objective of this study was to determine the effect of different crop loads on the new apple cultivar, ‘RubyS’, on yield, mineral content, and fruit quality characteristics at the harvesting time.

Materials and Methods

Plant materials and field conditions

The experiment was conducted at a commercial orchard in Yeongcheon-si, Gyeongsangbuk-do, Korea. The trees were grafted on M.26 rootstock and planted at a spacing of 3.0 × 1.5 m. Six-year-old uniform ‘RubyS’ apple trees planted in the same soil and environmental conditions, were selected for this study. The orchard was irrigated using drip lines and sprinklers and mulched with coarse bark chips. The experimental field was managed with standard agricultural practices, and an integrated pest management was used to control pests and diseases.

Crop load treatments

In the experimental field, flowers were fully bloomed on April 19, 2021. The treatments were arranged in a completely randomized design. First, 27 trees with a uniform number of branches and canopy volume were selected and divided into 3 groups of 9 trees·group^{-1}, based on previous studies that grouped trees into low, medium, and high crop loads (Yuri et al., 2011; Peck et al., 2016; Ding et al., 2017; Yang et al., 2021). Next, the three crop load groups were subjected to different hand thinning densities of fruits·cm^{-2} trunk cross-sectional area (fruits·cm^{-2} TCSA) 4 weeks after full bloom (May 17, 2021). The low, medium, and high crop loads were thinned to 5, 10, and 15 fruits·cm^{-2} TCSA, respectively.

Assessment of the total number of fruits·tree^{-1} and yield

Fruits were harvested on August 18, 2021. The total number of final fruits was counted for each group and individual trees (fruits·tree^{-1}). All harvested fruits from individual trees were weighed, and the total fruit weight·tree^{-1} (yield) was recorded. After field assessment, the harvested fruits were immediately sent to the Apple Research Institute, Gunwi-gun, Korea, for fruit quality and mineral content assessments.

Assessment of fruit quality attributes

Ten fruits·tree^{-1} were randomly selected to assess fruit quality attributes at harvesting. First, fruit size, including fruit length and diameter, was measured using a caliper (CD-15APX, Mitutoyo Corp., Kanagawa, Japan). Next, fruit weight was measured using a digital weight balance (AND Co., Daejeon, Korea). Fruit color assessments (L^*, a^*, and b^*) were made by measuring on the fruit peel red cheek area of each fruit using a chroma meter (CR200, Konica Minolta, Tokyo, Japan). To assess red coloration in fruit peels, the fruit peels’ red-blushed-colored area was visually assessed according to Serra et al. (2016). Flesh firmness was measured at three locations around the equatorial regions of each fruit using a fruit hardness tester (Fruit firmness tester, TR Co., Forli, Italy). The soluble solids content was measured from the juice sample of each fruit using a digital refractometer (PR-201α, Atago Co., Tokyo, Japan). Titratable acidity was measured using the malic acid reduction method that involved titrating with NaOH (0.1 N) at pH 8.1 in accordance with the protocol proposed by Win et al. (2019). For the starch index measurement, the fruits were cut into slices and dipped into an iodine solution, in accordance with the Cornell starch index measurement method (Blanpied and Silsby, 1992). During fruit quality assessment, 5 g of fruit tissue were sampled from each fruit and used for mineral content analysis.

Fruit mineral content extraction and determination

Fruit mineral content extraction and determination were conducted according to Lee et al. (2019). The concentrations of five macronutrients, nitrogen, phosphorus, potassium, calcium, and magnesium, were determined in this study. First, the fruit tissue samples were oven-dried for approximately 3 d. Next, approximately 400 mg of dried apple fruit sample was extracted using sulfuric acid, heated at 420℃ for 1 h, and cooled to determine fruit nitrogen content. The solution was analyzed using an elemental analyzer (Foss Kjeltec 8400 Analyzer Unit, Fisher Scientific, Höganäs, Sweden). Next, approximately 1 g of dried fruit sample was extracted in 10 mL of digestive solution (10 nitric acid : 4 hydrochloric acid : 1 sulfuric acid), heated at 100℃ for 2 h, and cooled to determine the concentration of other minerals (phosphorus, potassium, calcium, and magnesium). Finally, the sample was diluted 100-fold, and the solution was analyzed using ICP-OES Integra XL (GBC Scientific Equipment Ltd., Hampshire, IL, USA). The internal standard was used to calculate mineral content.

Statistical analysis

All data were analyzed using SPSS (Version 25, SPSS Inc., Chicago, IL, USA). The data were subjected to analysis of variance, and the least significant difference method was used to determine the level of significance at $p < 0.05$.

Results and Discussion

Effect of crop loads on fruit size and weight, fruits·tree^{-1}, and yield

The final crop load levels in each TCSA were determined at harvesting for individual trees (Table 1). The high crop load trees had a higher number of fruits (fruits·tree^{-1}), compared with those in the low and medium crop load trees. Conversely, the number of fruits·tree^{-1} was markedly reduced when the fruits were thinned to a low crop load, compared with medium and high crop loads. Therefore, reducing the number of fruits·tree^{-1} resulted in a lower yield (kg·tree^{-1}) under a low crop load compared with that under medium and high crop loads. The trees with medium crop loads retained more fruits·tree^{-1} than those with low crop loads, but had less than those under high crop load. However, the yield of trees with medium crop loads was not markedly different from that of the high crop loads (Table 1).

Table 1. Effect of low, medium, and high crop loads on fruits·cm^{-2} trunk cross-sectional area, fruits·tree^{-1}, and yield of ‘RubyS’ apples at harvest.

Crop load	Fruits·cm^{-2} TCSA (no.)	Fruits·tree^{-1} (no.)	Yield (kg·tree^{-1})
Low crop load (5 fruits·cm^{-2} TCSA)	4.02 ± 0.23[z]c	125.83 ± 12.24c	9.13 ± 1.02b
Medium crop load (10 fruits·cm^{-2} TCSA)	8.77 ± 0.38b	177.10 ± 9.72b	12.16 ± 1.09a
High crop load (15 fruits·cm^{-2} TCSA)	12.80 ± 1.07a	224.54 ± 18.44a	14.34 ± 1.13a

TCSA, trunk cross-sectional area.

[z] Data are expressed as mean ± standard error.

a - c: Means in a column with different letters are significantly different ($p < 0.05$).

Fruit weight was markedly increased in trees with a low crop load compared with those with medium and high crop loads (Table 2). In addition, the largest fruit size (length and diameter) and length to diameter ratio were observed in trees with low crop load compared with those in other crop loads. However, the medium crop load increased the fruit weight of apples, but it did not affect fruit size (both in fruit length and diameter) compared with fruits from a high crop load (Table 2).

Table 2. Effect of low, medium, and high crop loads on fruit weight and size of ‘RubyS’ apples at harvest.

Crop load	Fruit weight (g)	Fruit size (mm)		
		Length (L)	Diameter (D)	L/D ratio
Low crop load (5 fruits·cm^{-2} TCSA)	74.18 ± 0.94[z]a	54.32 ± 1.71a	56.15 ± 0.31a	0.97 ± 0.03a
Medium crop load (10 fruits·cm^{-2} TCSA)	67.03 ± 0.63b	49.35 ± 0.44b	54.59 ± 0.26b	0.90 ± 0.01b
High crop load (15 fruits·cm^{-2} TCSA)	63.10 ± 1.36c	48.32 ± 0.61b	53.67 ± 0.36b	0.90 ± 0.01b

TCSA, trunk cross-sectional area.

[z] Data are expressed as mean ± standard error.

a - c: Means in a column with different letters are significantly different ($p < 0.05$).

Heavy fruit thinning (low crop load) reduced the number of fruits·tree^{-1}, subsequently reducing the overall yield·tree^{-1} at harvest. However, tree thinning to a low crop load increased the size and weight of the remaining fruits to marketable ranges, which is the main objective of thinning to low crop levels (Yuri et al., 2011; Serra et al., 2016). Fruit size is a major trait in commercial fruit production. An increase in fruit size might be due to the increase of cell number and cell size in fruit (Greybe et al., 1998). In this study, the largest fruit size was observed in heavily thinned trees (low crop load) with a low total fruit yield. Unlike with low crop load, the smallest fruit size with a high total fruit yield was observed in high crop load trees, as similarly reported in previous studies (Cho and Yoon, 2006; Embree et al., 2007; Peck et al., 2016; Serra et al., 2016; Bound, 2019). However, in this study, the total fruit yield of trees from medium crop load was not different from that of high crop load, which may be due to the production of heavier weight fruits from medium crop load trees than that of high crop load trees. Yield is an economically important factor for growers to increase profitability. Accordingly, Choi et al. (2009) reported similar yield·tree^{-1} between different crop load levels with increased fruit weight under low crop loads.

Effect of crop loads on fruit quality attributes

Fruit quality attributes were also measured on fruits from different crop loads at harvest (Table 3). Flesh firmness was higher in fruits from medium crop loads compared with that from high crop loads. However, flesh firmness of fruits from low crop loads was similar to that of fruits from medium and high crop loads. Soluble solids content (SSC) was markedly increased by low and medium crop loads compared with fruits from high crop loads. However, SSC was similar in fruits from low and medium crop loads. In addition, there were no significant differences in titratable acidity (TA), SSC/TA ratio, and starch index in fruits from the different crop loads (Table 3).

Table 3. Effects of low, medium, and high crop loads on flesh firmness, soluble solids content (SSC), titratable acidity (TA), SSC/TA ratio, and starch index of 'RubyS' apples at harvest.

Crop load	Flesh firmness (N)	SSC (%)	TA (%)	SSC/TA ratio	Starch index (1 - 8)
Low crop load (5 fruits·cm^{-2} TCSA)	91.16 ± 0.79^{z}ab	14.32 ± 0.11a	0.62 ± 0.02a	23.65 ± 0.70a	5.50 ± 0.19a
Medium crop load (10 fruits·cm^{-2} TCSA)	93.57 ± 1.22a	14.37 ± 0.18a	0.63 ± 0.02a	22.87 ± 0.68a	5.30 ± 0.20a
High crop load (15 fruits·cm^{-2} TCSA)	90.20 ± 0.62b	13.62 ± 0.18b	0.57 ± 0.03a	24.27 ± 1.12a	5.85 ± 0.47a

TCSA, trunk cross-sectional area.

[z] Data are expressed as mean ± standard error.

a, b: Means in a column with different letters are significantly different ($p < 0.05$).

The production of high quality fruits is important for consumer preference, increasing the demand for apples. The grading standards for apple quality generally include flesh firmness, SSC, and starch content (Harker et al., 2008). In general, flesh firmness determines the ripening or softening level of the fruit at harvest (Musacchi and Serra, 2018) and storability (Jung et al., 2019; Win et al., 2019). Many studies have reported that low crop load on trees is correlated with increased flesh firmness at harvest (Ding et al., 2017; Anthony et al., 2019; Bound, 2019). However, Serra et al. (2016) reported that flesh firmness was higher under low crop load compared with that under high crop load at harvest and after 6 months of storage. Therefore, crop load management is essential for improving fruit texture, quality, and storability of apples. However, in this study, flesh firmness was highest under medium crop load, followed by low crop load, with high crop load having the least firmness. Yuri et al. (2011) reported that there was no significant difference in flesh firmness among crop loads over three consecutive years. Therefore, the effect of crop load on flesh firmness could also depend on cultivar, rootstock, and other factors.

The taste properties of apples generally include sweetness, acidity, and astringency. SSC and TA are important internal quality traits crucial for consumer preference (Musacchi and Serra, 2018). A higher SSC was observed under low and medium crop loads in this study. Therefore, SSC decreased with an increase in crop load levels, consistent with previous studies (Robinson and Watkins, 2003; Yuri et al., 2011; Ding et al., 2017). However, no significance differences were observed in the TA and SSC/TA ratio results in the different crop loads in this study. The starch index is generally used to estimate the apple fruit harvest window and maturity (Doerflinger et al., 2015). Robinson and Watkins (2003) recorded a higher starch index rating under high crop load compared with other crop loads; contrastingly, Bound (2019) recorded no significant differences among the crop loads, consistent with the results from this study. Therefore, the starch index might vary depending on the crop level, cultivar, and other factors.

Effect of crop loads on fruit peel color attributes

The development of red-blushed fruit peel was markedly increased in fruits from low crop loads compared with those from high crop loads (Table 4). In addition, a^* in the fruit peel also increased in fruits subjected to low crop loads. However, L^* and b^* in the fruit peel were lower in fruits from low crop loads than those in fruits from high crop loads. However, there were no significant differences between the results of red-blushed color and peel color variables (L^*, a^*, and b^*) in fruits from medium crop loads and those from the low and high crop loads (Table 4).

Apple peel color is an important trait in the apple fruit market, and better-colored fruits are in high demand (Dar et al., 2019). Therefore, high quality apple production with high peel color is important for growers. Generally, L^* and b^* denote the fruit's lightness or darkness and blueness or yellowness of the fruit, whereas a^* represents the green or red color of the fruit. An increase in fruit peel variable a^* is probably due to the accumulation of anthocyanin pigments that induce red coloration in apple skin (Dar et al., 2019). In the present study, low crop load enhanced the area of red-blushed color and a^* in fruit peel. Serra et al. (2016) reported a reduction in the red-blushed color area in fruits from high crop loads. In addition, many studies have reported that fruits from high crop loads reduced the development of a^* in the apple peel (Cho and Yoon, 2006; Yuri et al., 2011; Serra et al., 2016), consistent with the results from this study. The production of poorly colored fruit probably indicates a deficiency in resources in trees due to the high crop load in trees leading to higher inter-crop competition within fruit clusters (Robinson and Watkins, 2003).

Table 4. Effect of low, medium, and high crop loads on fruit red-blushed color area and peel color (L^*, a^*, and b^*) of 'RubyS' apples at harvest.

Crop load	Red-blushed color (%)	Fruit peel color variables		
		L^*	a^*	b^*
Low crop load (5 fruits·cm^{-2} TCSA)	73.80 ± 0.58^{z}a	43.76 ± 0.68b	22.34 ± 0.66a	17.13 ± 0.27b
Medium crop load (10 fruits·cm^{-2} TCSA)	70.00 ± 3.13ab	46.61 ± 1.38ab	18.37 ± 1.30ab	18.17 ± 0.57ab
High crop load (15 fruits·cm^{-2} TCSA)	61.00 ± 5.43b	50.66 ± 2.61a	15.48 ± 1.70b	19.72 ± 1.05a

TCSA, trunk cross-sectional area.

[z] Data are expressed as mean ± standard error.

a, b: Means in a column with different letters are significantly different ($p < 0.05$).

Effect of crop loads on fruit mineral contents

The fruit's nitrogen, phosphorus, potassium, calcium, and magnesium contents were measured in this study (Table 5). At harvest, the fruit phosphorus and potassium content in fruits were markedly enhanced in the low and medium crop loads compared with that in fruits from the high crop load. However, there were no significant differences in phosphorus and potassium contents between low and medium crop loads. In addition, the fruit's nitrogen, calcium, and magnesium contents were not significantly different among fruits from all crop loads (Table 5).

Table 5. Effects of low, medium, and high crop loads on 'RubyS' apple fruit mineral contents (nitrogen, phosphorus, potassium, calcium, and magnesium) at harvest.

Crop load	Fruit mineral contents (%)				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Low crop load (5 fruits·cm^{-2} TCSA)	0.26 ± 0.01^{z}a	0.07 ± 0.01a	1.07 ± 0.05a	0.05 ± 0.00a	0.04 ± 0.00a
Medium crop load (10 fruits·cm^{-2} TCSA)	0.25 ± 0.01a	0.08 ± 0.01a	1.06 ± 0.06a	0.05 ± 0.00a	0.04 ± 0.00a
High crop load (15 fruits·cm^{-2} TCSA)	0.26 ± 0.01a	0.05 ± 0.00b	0.91 ± 0.00b	0.05 ± 0.00a	0.04 ± 0.00a

TCSA, trunk cross-sectional area.

[z] Data are expressed as mean ± standard error.

a, b: Means in a column with different letters are significantly different ($p < 0.05$).

Mineral content is involved in functioning of many physiological processes, including fruit quality and storability (Akšić et al., 2020); therefore, it should be determined at harvest to predict the storage quality of apples (Robinson and Lopez, 2009). Apple fruits with low calcium and high nitrogen and magnesium levels are susceptible to rot and storage disorders (Telias et al., 2006; Robinson and Lopez, 2009; Serra et al., 2016). However, Neilsen et al. (2008) found that apple fruits with a high phosphorus content are resistant to water core incidence at harvest. Previous studies have reported that fruits from high crop loads are more susceptible to the occurrence of physiological disorders (Robinson and Watkins, 2003; Robinson and Lopez, 2009; Serra et al., 2016). Anthony et al. (2019) found that a high crop load reduces fruit potassium concentration at harvest, probably due to the potassium dilution effect that disperses potassium across many fruits on the tree, consistent with findings from the present study. In addition, fruits with high potassium content have less risks of storage disorders (Robinson and Lopez, 2009). Moreover, Serra et al. (2016) reported that large fruits had low calcium and high magnesium contents. In the current study, the phosphorus and potassium levels were higher under low and medium crop loads compared with those in high crop loads; however, no significant difference was observed in the nitrogen, calcium, and magnesium contents in fruits from all crop loads. Similarly, Anthony et al. (2019) reported that the higher phosphorus and potassium contents were observed in fruits from low crop load trees. He additionally found that the nitrogen, calcium, and magnesium contents were not different in fruits from different crop load levels (Anthony et al., 2019), similarly observed in this study. Therefore, it was noted that fruits from low and medium crop loads have a lower risk of storage disorders and rotting. In addition, no physiological disorders or diseases were observed at harvest in 'RubyS' apple fruits from all crop loads (data not shown), probably because this cultivar is inherently resistant to major apple pests and diseases (Kwon et al., 2019).

Conclusion

In conclusion, according to the findings of this study, crop loads of 5 (low) to 10 (medium) fruits·cm^{-2} TCSA could achieve marketable or acceptable fruit weight and size. The development of fruit quality attributes is correlated with the crop load level of the tree. In this study, the low and medium crop loads resulted in good quality attributes. In addition, thinning fruits to medium crop load did not markedly reduce the yield·tree^{-1} compared with that in the high crop load. Moreover, fruits from low and medium crop loads are at a lower risk of physiological disorders and storage rotting. The high crop load resulted in a significant reduction in fruit size and quality. Therefore, a level of crop load of approximately 10 fruits·cm^{-2} TCSA is recommended for improving fruit weight and size, quality, storability, and commercial productivity of 'RubyS' apples.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

Author Contributions

NMW conducted experiments and wrote the original manuscript. DL, YYS, and JP assisted with the experiments. YSC, MYP, YL, HJK, JY, and IKK performed the experiments. JCN supervised the study.

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