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The Korean Society of International Agriculture

Yield and Fruit Characteristics of Korean Tomato (*Lycopersicon esculentum* Mill.) Cultivars Established at Different Cropping Seasons in Hanoi, Vietnam

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베트남 하노이지역 작기에 따른 국내 토마토 품종의 수확량 및 과실 특성

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ABSTRACT: This study was conducted to investigate the yield and fruit characteristics of Korean tomato (*Lycopersicon esculentum* Mill.) cultivars in two different cropping seasons (February 2011 to February 2012) in Hanoi, Vietnam. The experiment was arranged in a completely randomized block design, with three replications. Eight Korean cultivars, specifically, 'Pink Top', 'Kyupirang', 'Super Dotaerang', 'Sun Red', 'Sun Glove', 'TP-7 Plus', 'Lovely 250', and 'Gwangbok', and one Vietnamese cultivar, 'FM 120', were transplanted in an open field in March (spring-summer) and October (fall-winter) of 2011. The cropping season significantly affected the plant height (cm), stem diameter (mm), fruit (no.) and total yield (kg) per plant, fruit length (cm) and width (cm), fruit weight (g) per plant, and total soluble solids (TSSs, °Brix). However, the dry weight (%) and vitamin C (mg/100 g) content showed no significant differences in the different cropping seasons. The highest values for the growth and fruit characters of tomato appeared during the fall-winter season, whereas the highest TSSs (4.8 °Brix) was observed in the fruit harvested during the spring-summer season. The Vietnamese cultivar 'FM 120' showed highest values of fruit per plant (33.8), total yield (3.6 kg), and vitamin c content (13.9 mg/100 g) for both cropping seasons. However, the highest values for the plant height, fruit length, fruit width, and fruit weight were observed in the Korean cultivars. Therefore, the fall-winter cropping season is recommended as the optimum season for enhancing the fruit yield and characteristics of Korean tomato cultivars under the environmental conditions of Hanoi in Vietnam.

Key words: Korean tomato (*Lycopersicon esculentum* Mill.), Cropping seasons, Characteristics, Cultivars, Korea, Vietnam

The tomato (*Lycopersicon esculentum* Mill.) is the most important vegetable crops of Solanaceae and is grown throughout the world because of its wide adaptability and versatility. Tomatoes are cultivated in both the open field and in the greenhouse. The estimated world production of fresh tomato fruit is 141 million tons, corresponding to 4.9 million ha (FAOSTAT, 2009), and the consumption of tomatoes has increased with the trend of healthier diets. The fruit quality of tomato is complex and depends on many factors (Hong *et al.*, 2003; Lee, 1984). The cultivating temperature and climate are the most fundamental environmental factors that can influence the growth and fruit morphological development of tomato cultivars. In Korea, tomato plants are cultivated for five or six months after transplanting and are mostly produced by retarding, semi-forcing or forcing culture to allow it to survive the cold season. However, owing to high expenditure to regulate the temperature for indoor plastic house, the yield for tomato fruit can be limited in the winter. Therefore,

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to fulfill the demands for the winter season in Korea, the wide consumption of tomato fruit is dependent on imports from other countries. In contrast with the winter cultivation, the market price of tomato has plummeted, due to the over-production during the summer season in Korea (Choi *et al.*, 2002). Vietnam is considered an agricultural product exporter; because the northern region of Vietnam, including Hanoi, lies in the subtropical zone and experiences warm winters, tomato plants can be cultivated throughout the year.

Due to the increasing consumption as fresh fruit or industry processing in recent years, the total area for tomato cultivation has been increasingly expanded in Vietnam (Minh, 2003). Three major cropping seasons are available in Vietnam: the spring-summer, summer-fall, and fall-winter seasons have been developed in which seeds are sown from early January to February, July to August, and September to end of October with the first harvests being performed in May to June, October to November, and February to March respectively. Mostly, cultivating tomato for all cropping seasons has been undertaken in highland region such as Da Lat to avoid high temperature condition. For the successful production of tomato fruit in those seasons, special management for raising seedlings and disease control is required. Heat and high humidity are considered limiting factors for tomato production and can reduce the yield during the summer in Vietnam (Quang *et al.*, 2004). The most serious disorders in tomato under high temperature, such as reduced fruit set and physiological falling, lead to decreases in the marketable fruits in the summer season compared to the other cultivating seasons. Although the cultivation of tomatoes throughout the fall and winter season has been recommended to generate high yields, the seedlings can be subjected to abiotic stress induced by the high temperature (Ahmadi and Stevens, 1979). Agricultural scientists in Vietnam have investigated the creation of new varieties of tomatoes that can be grown under hot conditions for constant production during the summer season (Vien, 2006).

Most of the research examining the cultural conditions of tomato varieties have focused on plant spacing (Jang *et al.*, 2000), enhancing the fruit quality (Johnstone *et al.*, 2005), methods for fruiting (Choi, 2009), and optimal growth substrates (Ghehsareh *et al.*, 2011). However, due to environmental variations, the vegetative growth, fruit size, shape and quality of a tomato cultivar can vary by the phenotype, regardless of its indigenous traits. In a previous study, we examined yield and growth characteristics using various Korean tomato cultivars grown during a single season in Vietnam. Nevertheless, the yield and fruit characteristic performances of tomato in different cropping seasons using identical varieties under open field conditions has not yet been studied. The determination of superior tomato cultivars and the optimal cultivating season would be beneficial for the local tomato producers to export suitable fruits to Korea (Cho, 2011). Choosing Korean tomato varieties might be one of the viable ventures for not only tomato producers but also local marketers according to their preference. Furthermore, identifying potential cultivars among the Korean and Vietnamese cultivars subjected to various cropping seasons may help to develop new varieties that exhibit a high yield and quality in Vietnam. Therefore, the goal of this study was to determine how different cropping seasons affect the yield and fruit characters of Korean tomato cultivars.

MATERIALS AND METHODS

Eight Korean indeterminate type, flat-shape cultivars, specifically, 'Pink Top', 'Kyupirang', 'Super Dotaerang', 'Sun Red', 'Sun Glove', 'TP-7 Plus', 'Lovely 250', and 'Gwangbok', and one Vietnamese indeterminate type, round-shape, cultivar, 'FM 120', were used in this experiment. For the production of transplants, seeds of the tomato cultivars for the spring-summer and fall-winter cropping seasons were sown in Styrofoam trays filled with a mixed horticultural soil on the second and third weeks of February and September, respectively. The experiment plots were fertilized with compost manure (40 t/ha), P_2O_5 (1 t/ha), and calcium (1 t/ha) following the recommendation of the manual from Fruit and the Vegetable Research Institute (FAVRI). The total addition of urea (340 kg/ha) and potassium (260 kg/ha) was applied gradually until 40 days after transplanting. The seedlings were transplanted in double rows with 45-cm spaces between the plants in the open field of the FAVRI (N 21°33.05' E 105°35.05') on the 3rd of May and 14th of October, 2011 for the spring-summer and fall-winter experiments, respectively.

The plant height and stem diameter were measured at 60 days after planting in the field using a ruler. For the evaluation of the fruit characters, the fruits were harvested when the fruit of all of the cultivars turned red or nearly red until the last week of June 2011 and the first week of February 2012 for the spring-summer and fall-winter seasons, respectively; five fruits of each cultivar were randomly sampled. The fruit dry weight was obtained by the oven-dry method at 70°C for 72 h until a constant weight was reached. The vitamin C content (mg/100 g) was determined according to idometric titration methods. The total soluble solid (TSS) content of the fruit was measured by refractometry (N-1a, ATAGO, Japan). The experiment plots were arranged in a completely randomized block design with three replications, and each replicate consisting of ten plants. The data were subjected to an analysis of variance using SAS (v9.1, SAS

Table 1. Analysis of variance on yield and fruit characters for tomato cultivars grown in different cropping seasons in Hanoi, Vietnam.

Source	Plant height (cm)	Stem diameter (mm)	Total fruit / plant (no.)	Total yield / plant (kg)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)
Cultivar (C)	**	NS	**	**	*	**	**
Cropping Season (CS)	**	**	**	**	**	**	**
C × CS	**	**	**	**	**	**	**
Cultivar							
Pink Top	150.0ab[z]	10.4	11.5b	2.4b	5.9ab	6.8a	208.1a
Kyupirang	148.0ab	10.8	11.4b	2.3b	5.9ab	6.6a	200.4a
Super Dotaerang	139.1b	10.7	11.2b	2.3b	5.8abc	6.8a	200.7a
Sun Red	153.2ab	10.7	12.1b	2.5b	5.9ab	6.9a	208.8a
Sun Glove	139.0b	10.4	12.6b	2.2b	5.7bc	6.6a	171.1a
TP-7 Plus	150.1ab	10.8	10.3b	1.9b	5.7bc	6.5a	185.8a
Lovely 250	149.1ab	11.3	11.8b	2.6b	6.3a	6.9a	218.0a
Gwangbok	158.6a	11.0	11.0b	2.5b	5.9ab	7.1a	224.3a
FM 120	114.8c	11.2	33.8a	3.6a	5.3c	5.3b	107.6b
Cropping Season (CS)							
Spring–Summer	118.8b	9.5b	11.0b	1.6b	5.6b	6.2b	147.1b
Fall–Winter	170.5a	12.1a	16.9a	3.4a	6.0a	6.9a	224.1a

NS (nonsignificant), * and **significant at $P \leq 0.05$ and 0.01, respectively.
[z]Values in a column followed by the same letter are not significantly different ($P \leq 0.05$); Duncan's Multiple Range Test (DMRT).

Institute, NC) software, and the significant mean separations were compared using Duncan's Multiple Range Test (DMRT). Pearson's correlation coefficients of the parameters measured in the tomato cultivars grown in the different cropping seasons were conducted using the SAS program.

RESULTS AND DISCUSSION

Effect of cropping season on yield and fruit characteristics

The analysis of variance of the components for the growth and fruit characteristics of the Korean tomato cultivars grown at different cropping seasons are presented in Table 1. The plant height, total fruit number and yield per plant, fruit width, and fruit weight measured for the different varieties were highly significant ($P \leq 0.01$), but the fruit length and stem diameter were shown to be statistically significant at $P \leq 0.05$ and not significant, respectively. 'Gwangbok' had the highest plant height (167.9 cm), whereas the lowest (112.0 cm) was found for the Vietnamese cultivar 'FM 120'. The highest total fruit number (33.8) and fruit yield (3.6 kg) per plant were found for 'FM 120' but were not significantly different among the Korean varieties. 'Lovely 250' showed the highest value of fruit length (6.3 cm) followed by 'Pink Top', 'Kyupirang', 'Sun Red', and 'Gwangbok' (5.9 cm). The fruit width was the highest in 'Gwangbok' (7.1 cm), and the minimum was exhibited by 'FM 120' (5.3 cm); the Korean varieties demonstrated no significant variation with regard to fruit width. The fruit weight was the highest in 'Gwangbok' (224.3 g) and the lowest in 'FM 120' (107.6 g), but no significant differences among the Korean cultivars were noted. In general, variable parameters in the yield and fruit characters of tomato cultivars grown in different cropping seasons might be due to the potential genetic differences and vegetative performances based on their genotypes.

The overall yield and fruit characters measured during the different cropping seasons were statistically highly significant ($P \leq 0.01$) (Table 1). Of the two cropping seasons, all of the parameters for the yield and fruit, including the plant height (170.5 cm), stem diameter (12.1 mm), total fruit number (16.9) and yield (3.4 kg) per plant, fruit length (6.0 cm) and width (6.9), and fruit weight (224.1 g) per plant, were significantly higher for the fall-winter season. The interaction effect of the cultivars and cropping seasons was highly ($P \leq 0.01$) significant (Table 1). Comparable data for the yield and fruit characteristics of the tomato cultivars under the different cropping seasons is shown in Table 2. The plant height was highest for 'Gwangbok' (195.6 cm) grown in the fall-winter season, but there was no statistical difference among the values for 'TP-7 Plus', 'Lovely 250', 'Sun Red', 'Pink Top', and 'Kyupirang'. The total number of fruit per plant was the highest in 'FM 120' (45.0) grown in the fall-winter season followed by the spring-summer season (26.0). 'FM 120' grown in the fall-winter season also produced the

Table 2. Effect of different cropping seasons on fruit characters and yield in tomato cultivars.

Cultivar	Plant height (cm)	Total fruit / plant (no.)	Total yield (kg /plant)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)
Spring-Summer						
Pink Top	120.1de[z]	7.0g	1.0d	5.5de	6.2efgh	141.6fg
Kyupirang	116.9de	8.0fg	1.3d	5.7cd	6.4defg	161.1defg
Super Dotaerang	119.3de	9.0efg	1.4d	5.5de	6.4defg	156.0efg
Sun Red	123.5de	11.0defg	1.8d	5.7cd	6.3defgh	161.4defg
Sun Glove	117.1de	12.0cdefg	1.5d	5.3de	6.0gh	123.9fg
TP-7 Plus	111.0de	7.0g	1.0d	5.4de	6.2efgh	141.9fg
Lovely 250	113.7de	10.0defg	1.9d	6.1ab	6.7cdef	185.1cdef
Gwangbok	121.7de	9.0efg	1.2d	5.5de	6.1fgh	137.1fg
FM 120	126.2d	26.0b	3.0bc	5.6de	5.7hi	115.5g
Fall-Winter						
Pink Top	179.8ab	16.0c	4.0ab	6.2ab	7.2bc	252.5ab
Kyupirang	179.2ab	14.8cd	3.2abc	6.0bc	6.8bcd	218.8abcd
Super Dotaerang	158.8c	13.4cde	3.1abc	6.0abc	7.1bc	233.2abc
Sun Red	182.8a	13.1cde	3.3abc	6.1ab	7.3ab	250.5ab
Sun Glove	160.8bc	13.2cde	2.9c	6.1ab	7.0bc	219.2abcd
TP-7 Plus	189.2a	13.6cde	2.9c	5.9bc	6.7cde	215.0bcde
Lovely 250	184.6a	13.5cde	3.4abc	6.4a	7.1bc	248.2ab
Gwangbok	195.6a	13.0cde	3.6abc	6.3ab	7.9a	279.9a
FM 120	103.4e	45.0a	4.1a	5.2e	5.1i	99.1g

[z]Values in a column followed by the same letters are not significantly different by DMRT ($P \leq 0.05$).

highest yield (4.1 kg), which was statistically similar with 'Pink Top', 'Kyupirang', 'Super Dotaerang', 'Sun Red', 'Lovely 250', and 'Gwangbok'. The highest fruit length (6.3 cm) of tomato was observed for the 'Lovely 250' grown in the fall-winter season, and its value was statistically similar (6.1 cm) to that of the plants grown in the spring-summer season. 'Gwangbok' significantly produced the optimum (7.9 cm) fruit width with the highest (279.9 g) fruit weight. In this study, the cropping season affected the tomato plants, regardless of their origin as Korean or Vietnamese cultivars. The overall result of the growth performance of tomato was in agreement with earlier findings of Abdalla and Verkerk (1968) and Abdul-Baki (1991) that vegetative and reproductive organs and tissues of tomato plants for all cultivars were negatively affected by high temperature condition. The Korean tomato cultivars grown in the spring-summer season displayed dramatically decreased plant heights, total yields, and fruit weight in comparison to the fall-winter season, which are results that could be due to the high temperature and drought conditions during the summer season in Vietnam. The decrease in the number of fruit and yield per plant in this study may be due to flower and fruit drops occurring as a result of the high temperature and physical injury by the frequent rainfall (Khalid *et al.*, 2003). Indeed, the low yields of the tomato cultivars grown during the spring-summer season might have been affected by the high temperature and high rainfall during the summer season in Vietnam. Moreover, Choi *et al.* (2009) found that a high temperature during the daytime adversely affects pollination by pollinating bees (*Bombus terrestris*) at the blooming stage. The major effect of the continuous exposure of tomato to high temperatures markedly reduced the number of pollen grains per flower and decreased the viability of the developing anthers because of the decreased sugar concentration in the mature pollen grains (Pressman *et al.*, 2002). Peet *et al.* (1997) also reported that high temperature induces defect in ovule development and post-pollen production, regardless of chronic or sub-acute condition. The severe drought conditions induced by the rapid evaporation during the summer season in Vietnam also results in a decrease in the photosynthesis efficiency of tomato, and drought stress could reduce the yield of tomato. In particular, the yield of tomato could be increased with an increasing irrigation rate under conditions of high evaporation, but there is no significant difference between the yield and irrigation rate during low-evaporation seasons (Locascio and Smajstrla, 1996). In gen-

Table 3. Analysis of variance on fruit quality characters for tomato cultivars grown in different cropping seasons in Hanoi, Vietnam.

Source	Dry weight /fresh wt. (%)	Vitamin C (mg/100 g)	Total soluble solids (°Brix)
Cultivar (C)	NS	*	*
Cropping Season (CS)	NS	NS	**
C × CS	NS	NS	**
Cultivar			
Pink Top	5.3	13.0ab[z]	4.1c
Kyupirang	5.1	11.9bc	4.8ab
Super Dotaerang	5.3	9.1bcd	4.8ab
Sun Red	5.1	10.1d	4.2c
Sun Glove	5.2	10.6cd	4.6abc
TP-7 Plus	4.8	10.7cd	4.9a
Lovely 250	5.1	10.9cd	4.5abc
Gwangbok	5.4	12.6ab	4.7ab
FM 120	5.0	13.9a	4.3bc
Cropping Season (CS)			
Spring-Summer	5.3	11.3	4.8a
Fall-Winter	5.0	11.6	4.2b

NS (nonsignificant), * and **significant at $P \leq 0.05$ and 0.01, respectively.
[z]Values in a column followed by the same letters are not significantly different by DMRT ($P \leq 0.05$).

eral, a tomato stem diameter measuring between 1.2 ~ 1.4 cm can generate an optimum performance in yield attributes (Massaki and Ohno, 1987), and similar results were found for the stem diameter of tomatoes grown during the fall-winter season in this study.

Effect of different cropping seasons on fruit quality characteristics

The cultivars grown in the different cropping seasons significantly ($P \leq 0.05$) affected the fruit quality characters with the exception of the dry wt. (%) per fresh weight of fruit (Table 3). The highest vitamin C content (13.9 mg/100 g) was measured in the Vietnamese cultivar 'FM 120' followed by 'Pink Top' (13.0 mg/100 g) and 'Gwangbok' (12.6 mg/100 g). 'TP-7 Plus' demonstrated the highest (4.9 °Brix) TSS value, but the TSS value was not significantly different among 'Gwangbok', 'Kyupirang', 'Super Doetaerang', 'Sun Glove', and 'Lovely 250'. The responses of the cultivars were significantly different with regard to the vitamin C and TSS contents, and this difference might be due to the genetic differences among the cultivars. The interaction and cropping seasons effects on fruit quality were only significant ($P \leq 0.01$) for the TSS content, with the plants grown in the spring-summer season expressing higher TSS values (4.8 °Brix) among the two seasons. 'Kyupirang' grown in the spring-summer season significantly produced the highest (5.7 °Brix) TSS content (Fig. 1). Ordinarily, the fruit dry weight should be decreased by the limited photosynthesis rate resulting from conditions of drought and high temperatures (Kim *et al.*, 2000; Xu *et al.*, 1997), but our results

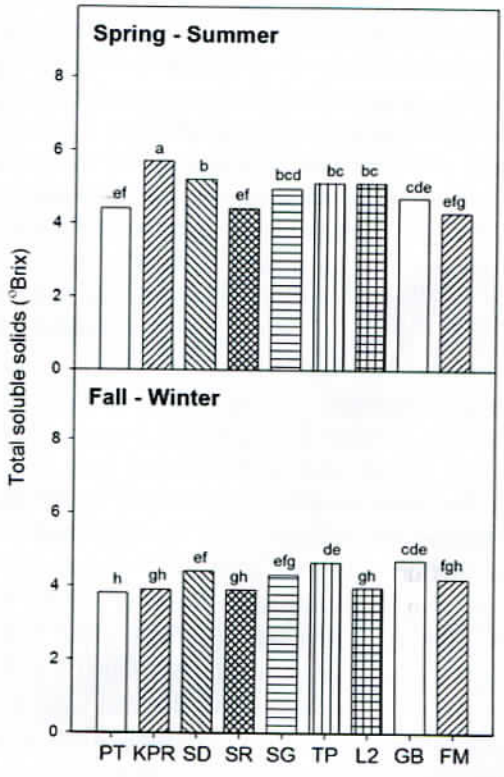

Fig. 1. The total soluble solids of fruits from tomato cultivars grown at different cropping seasons in Hanoi, Vietnam. Means separation at each cropping season and cultivars by DMRT ($P \leq 0.05$). PT, Pink Top; KPR, Kyupirang; SD, Super Dotaerang; SR, Sun Red; SG, Sun Glove; TP, TP-7 Plus; L2, Lovely 250; GB, Gwangbok; FM, FM 120.

Table 4. Pearson correlation coefficient analysis for parameters measured in tomato cultivars grown at different cropping seasons.

	PHT	SD	TFP	TY	FL	FW	FWT	FDW	VITC	TSS
PHT	1.000	0.688**	–0.072	0.660**	0.825**	0.820**	0.911**	–0.581*	-0.088	–0.552*
SD		1.000	0.484*	0.846**	0.454	0.389	0.590*	–0.617**	0.060	–0.644**
TFP			1.000	0.655**	–0.215	–0.459	–0.259	–0.414	0.458	–0.416
TY				1.000	0.541*	0.347	0.550*	–0.713**	0.224	–0.715
FL					1.000	0.892**	0.933**	–0.426	–0.187	–0.390
FW						1.000	0.963**	–0.231	–0.303	–0.221
FWP							1.000	–0.423	–0.230	–0.398
FDW								1.000	–0.078	0.417
VITC									1.000	–0.260
TSS										1.000

* and **Significance at 5 and 1%, respectively. PHT, plant height (cm); SD, stem diameter (mm); TFP, total fruits /plant (no.); TY, total yield (kg); FL, fruit length (cm); FW, fruit width (cm); FWT, fruit weight (g); FDW, fruit dry wt. /fresh wt. (%); VITC, Vitamin C content (mg/100 g · fresh wt.); TSS, total soluble solids (°Brix).

showed no significant difference on the fruit dry weight. The results of this study suggest that the tomato fruits harvested during the drought condition in the summer season had increased TSS contents. Kang *et al.* (2009) reported that deficient application of irrigation to tomato plants during the growing season enhances the fruit quality in terms of soluble sugars. The content of soluble sugars as a marker for the consumer is a major factor in determining the fruit quality among those factors that affect fruit quality. As products of photosynthesis in tomato fruit, the soluble solids are composed of sugars, such as hexose, glucose and fructose, and their compositions are mainly dependent on the growth phase of the plant and the environmental conditions (Rosales *et al.*, 2007). The analysis of the correlation between the yield component and fruit characters are presented in Table 4. The plant height was highly significantly ($P \leq 0.01$) correlated with the stem diameter (r = 0.688), total fruit yield (0.660), fruit length (0.825) and width (0.820), and fruit weight (0.911). The stem diameter was positively ($P \leq 0.01$) correlated with the total yield (r = 0.846) but negatively correlated with the fruit dry weight (–0.617) and TSS content (–0.644). There are also significant correlations ($P \leq 0.01$) between the total number of fruit per plant, total yield, fruit length and width. Massaki and Ohno (1987) found that the stem diameter positively correlated with the total yield in tomato, which agreed with the results of this study. There might be a positive correlation between the vegetative development and yield attributes in tomato. Gautier *et al.* (2009) reported that vitamin c and sugar content were correlated and increased with the ripening stage under normal condition. However, our result exhibited no significant correlations (r = –0.260) between vitamin c and sugar content. It might be variable factors between tomato genotypes and cropping seasons.

In conclusion, the two different cropping seasons affected the tomato fruit, regardless of whether the plants were Korean or Vietnamese cultivars. In general, the fall-winter season is suitable for tomato cultivation, and almost all of the Korean varieties exhibited an optimum yield and fruit weight. However, overall, the tomatoes grown in the spring-summer season produced a higher quantity of total soluble solids. Among the Korean cultivars, 'Lovely 250' was the most appropriate variety for cultivation during the spring-summer season. Our results indicate that the development of new potential varieties is required for future tomato cultivation during the spring-summer season in Vietnam.

적 요

본 연구는 베트남 하노이 지역에서 8가지 한국 토마토 품종(핑크탑, 큐피랑, 슈퍼도태랑, 선레드, 선글러브, TP-7 플러스, 러블리 250, 광복)과 1가지 베트남 품종(FM 120)을 대상으로 봄-여름 및 가을-겨울 작기에 따른 수확량 및 과실 특성을 비교 분석하였으며, 그 결과는 다음과 같다.

1. 작기에 따라 초장, 경장, 주당 과실수 및 수확량(kg)은 유의성이 있었으며 가을-겨울 작기에서 높게 나타났다. 전체적으로 한국품종이 베트남 품종에 비해 높은 생육특성을 보인 반면, 과실수와 수확량에서는 베트남 품종이 우수하였다.

2. 토마토 과실의 주요 특성인 과장, 과폭 및 과중은 작기에 따라 유의한 차이를 보였으며 가을-겨울 작기에서 높은 수치를 나타내었지만 TSS 함량은 봄-여름 작기에서 높았다. 건물중과 비타민C 함량은 작기에 따라 유의한 차이가 없었다. 품종별 과실 특성은 한국 품종이 우수하였지만 비타민C 함량은 베트남 품종이 높았다.

3. 봄-여름 작기에서 한국품종의 경우 수확량 및 과실특성에

서 가을-겨울 작기 재배에 비해 큰 감소를 보인 반면 베트남 품종은 큰 차이를 보이지 않았다. 따라서 본 실험에 이용된 8 가지 한국 품종의 경우 봄-여름 작기보다는 가을-겨울 작기 재배가 적합할 것으로 판단된다.

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