HORTICULTURAL STUDIES

Volume: 37 Number: 2 Year: 2020
ISSN 2717-882X
e-ISSN 2718-0069

Published by
Batı Akdeniz Agricultural Research Institute, TURKEY

TAGEM JOURNALS

HORTICULTURAL STUDIES

ISSN:2717-882X

e-ISSN:2718-0069

Aim and Scope

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Horticultural Studies (*HortiS*) is indexed in TR Index, DOAJ, CAB INTERNATIONAL, FAO AGRIS, INDEX COPERNICUS, FSTA, EUROPUB, GOOGLE SCHOLAR, OPEN AIRE, DRJI. Further information for "Horticultural Studies (*HortiS*)" is accessible on the address below indicated:

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HORTICULTURAL STUDIES

Editorial Information

HORTICULTURAL STUDIES

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HortiS 37(2):102-112
http://doi.org/10.16882/HortiS.791906

RESEARCH PAPER

Determination of The Harvesting Time of Hass Cultivar in Antalya Conditions

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Article History
Received 26 July 2019
Accepted 07 September 2020
First Online 01 October 2020

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Keywords
Avocado
Hass
Maturity
Ripening
Harvest
Harvest period

Abstract

Avocado cultivation in the world and Turkey, especially Hass cultivar, increases rapidly in recent years. The fruit quality of avocado is directly related to harvest maturity and post-harvest ripening process and the identification of maturity index has a very large commercial importance. For this purpose; in the fruit samples of Hass cultivar taken at 15-20 days interval from October to June, some fruit quality traits (dry matter, flesh firmness, weight loss, taste, colour of fruit skin and flesh) during the harvest and ripening process and relationships between of these parameters were analysed. As a result, it was found that the most reliable maturity index was the dry matter (DM) content and that there was a direct relationship between its accumulation and the harvesting time. In cases these index values were insufficient, the other postharvest analyses (taste, fruit skin colour, fruit hardness and weight loss) made a contribution to determination of maturity. During the ripening process, very high levels of a positive correlation between harvest time and dry matter (r= 0.92 to 0.96) was observed. According to the fruit maturity of the Hass cultivar, three different harvest periods were defined as early, optimum (most suitable) and late harvests. It was determined that from early October to late December as early harvest (23-25% DM), from January to late May as optimum harvest (26-37% DM), and from beginning to end of June as late harvest (≥38% DM).

1. Introduction

Recognizability of avocado fruit gradually increases and is much more involved in the health-related social networks in recent years. There is very high demand in the World for the production and consumption of avocado due to the positive effects on human health as a functional food and the high nutritional value (Anonymous, 2006). As a result, the consumption habits of avocado fruit develop, production areas increase, and fruits find consumers at high prices in the market. Avocado is cultivated in approximately 50 countries on 5 continents in the World as a subtropical fruit species (Zentmyer, 1987; Knight, 2002). There is two major avocado market in the world that are the United States and European Union countries (Naamani, 2007). Moreover, these two major markets comprise more than 90% of total imports in the World (Naamani, 2007; FAO, 2019). Japan and Canada follow these two major markets as smaller markets (FAO, 2019). In the world avocado market, a large portion of imports and exports consist of Hass cultivar (Naamani, 2007; Hernández et al., 2015) and it is the main cultivar of the avocado market with its superior fruit quality (Anonymous, 2005; Naamani, 2007). Furthermore, Hass is a very important cultivar in terms of post-harvest transport,

storage suitability, and high yield (Newett et al., 2002; Naamani, 2007). Besides, especially under cool subtropical cultivation conditions, after reaching physiological maturity, it has 'storage on the tree' characteristic that is an advantage for the market (Whiley et al., 1996; Hofman et al., 2002).

For the climacteric fruits such as avocado, in an export chain where supplying to reach distant markets as high quality of fruits, harvesting of the fruits in the right time with regard to the grade of maturity is a very important procedure (Ginsberg, 1985), and there may be significant differences in the composition of the fruit according to the harvesting time (Gonzales et al., 1992; Whiley et al., 1992; Ozdemir et al., 2003, Ozdemir and Topuz, 2004; Villa-Rodríguez et al., 2010). Harvesting of fruits in the early or late period to benefit from the high price advantage in the market cause of some great problems in ripening and quality of fruits. While irregular ripening, wrinkling, hardening and rotting of fruit flesh are observed in early harvest, deteriorating in fruit flesh, cracking and abscission in fruits are seen in late harvest (Young and Lee, 1978; Lee et al., 1983; Flitsanov et al., 2000; Hofman et al., 2002; Kassim et al., 2013; Carvalho et al., 2014; Magzawa and Tesfay, 2015). Furthermore, long flowering period, a low percentage of the fruit set, and not to ripening on the tree causes a heterogeneous and unpredictable fruit structure in the post-harvest period of Hass cultivar (Hernández et al., 2015). Therefore; during transport and storage of the avocado, harvesting time has a very important role to play on the shelf life and ripening (Osuna-Garcia et al., 2010; Osuna-Garcia et al., 2011; Carvalho et al., 2014), and determination of the most appropriate harvest period for high-value marketing of fruit may be the most critical decision need to be given.

Maturity dates of avocado fruits may vary widely even in a certain region and short distances (Coggins, 1984). The basis of the determination of the harvesting time in fruit is comprised of the maturity (Mizrach et al., 1999; Arpaia et al., 2003; Wedding et al., 2011) and it has a great importance for the start of the ripening after the harvest (Vakis et al., 1985; Woolf et al., 2003). The maturity of the fruit is most likely affected by many cultural and environmental factors along with altitude, location and direction (slope) of the garden (Coggins, 1984). Furthermore, for the determination of internal (fruit flesh texture and flavour) and external (visual appearance) eating qualities of mature avocado fruits, the maturity level of the fruit in harvest is the most important factor (Vakis et al., 1985; Magzawa and Tesfay, 2015). However, as in many biological subjects, in some cases, the definition of maturity can be quite complex. The external appearance of avocado fruit, as is known in many fruit species found in the horticulture, cannot adequately define the maturity (Osuna-Garcia et al, 2010; Wedding et al., 2011), and the internal structure of the fruit or the quality of eating cannot generally be an accurate guide alone for determining maturity (Lee et al., 1983; Wedding et al., 2011). Avocado should be harvested according to the maturity defined as physiological and horticultural characteristics (Magzawa and Tesfay, 2015).

A reliable maturity index is necessary for determining the harvesting time depending on fruit development of avocado and a measurable parameter should change according to the harvest (Woolf et al., 2003). Although some quality characteristics in fruit need to be defined for acceptable taste, there may also be some difficulties in the determination of these standards (Young and Lee, 1978; Lee, 1981a; Woolf et al., 2003). However, for the determination of the maturity of avocado, the dry matter content of the fruit flesh is still the most reliable index (Mizrach et al., 1999) and the other important standard is the taste (Lee, 1981; Mizrach et al., 1999; Kassim et al., 2013). Therefore; in many countries that produce avocados, the dry matter content of the fruit flesh is used as the optimal maturity standard to prevent the marketing of low-quality and immaturity fruit (Hofman et al., 2002; Woolf et al., 2003; Kassim et al., 2013; Carvalho et al., 2014). As the dry matter content of the fruit flesh increases, the acceptability of the fruit is positively affected (Arpaia et al., 2003).

In this study, it is aimed to determine of the fruit maturity standards and harvesting time of Hass cultivar in Antalya condition. In the fruit samples taken at certain periods, the changes of some fruit quality criteria were observed during the post-harvest maturation process (at ambient temperature in the laboratory). Analyses were carried out on the beginning day, 7th and 14th days of the post-harvest ripening period. As a result of the study, according to the maturity and ripening of the fruit, the harvest period of Hass cultivar was separated to three harvest interval as early, optimum and late.

2. Material and Method

2.1. Material

This research was carried out at the Fruit Growing Department of Batı Akdeniz Agricultural Research Institute in Antalya between 2010 and 2013. The 20-year old trees of Hass cultivar were used as the plant material of the study.

2.2. Method

The harvesting period of the first year were done from October-2010 to June-2011 and the second year studies were conducted between October 2012 and June 2013. Due to frost damage and periodicity, the experiment cannot be carried out at the harvest periods in 2011-2012. Twelve fruit

samples were taken from the four sides of trees for each replication at 15-20 days intervals during the harvest period. The harvested fruits were immediately transported to the laboratory and the first analyses were done on the same day. During the harvest period between October-June, the ripening process of fruits was carried out at the room temperature in the laboratory as in the study of Ozdemir and Topuz (2004), and the samples were kept for 7 and 14 days at this condition. Additionally, it was observed that the average temperature in the laboratory condition varied between 18ºC-30ºC, while the relative humidity ranged between 25%-85%.

According to Lee and Coggins (1982) dry weight (%), fruit flesh firmness (N) with 3 mm tip and T.R. Turoni 53200 (FT-327) penetrometer, and fruit weight loss (%) were measured. Furthermore, according to C.I.E. L * a * b * colour system belonging to Zerbini and Polesello (1984), the colour of the fruit skin and of the fruit flesh were determined with Minolta CR-400 chromameter. Additionally, the Chroma (C*) and hue (h0) values were calculated as reported by McGuire (1992). Taste analyses were evaluated according to their colour, texture and flavour. The taste evaluations were determined with a score of at least 5 panellists according to IPGRI's 1-5 (1: Very poor, 2: Poor, 3: Medium, 4: Good, 5: Very good) scoring principle. Statistical analysis, the physical and chemical traits of the Hass cultivar samples that were taken at different harvest times were analysed using the JUMP software program and differences between means were determined by LSD test. The experiment was carried out in a completely randomized design (CRD) with three replications and two trees at each replication.

3. Results and Discussion

During the harvest and harvesting process; dry matter, flesh firmness, weight loss and taste values are given in Table 1, while fruit skin colour and flesh colour (Lab) values are given in Tables 2 and 3, respectively. According to the seasonal distribution of each analysis made at harvest (0^{th} day) and in the ripening process (7^{th} and 14^{th} days) in both harvest periods (Table 1); although in the dry weight content (%) increased in between the months of October and June, there was no correlation between the analyses (0^{th}, 7^{th} and 14^{th} days) made for each harvest.

The fruit quality and market value of avocado are directly affected by the maturity level of the harvested fruit (Olarewaju, 2014) and as the maturity level of the fruit changes during the harvest period, the optimum harvesting time of fruit need to be determined (Olarewaju, 2014; Bayram and Tepe, 2018). Dry matter values of the fruit in avocado are the most important criteria for the determination of harvest maturity (Mizrach et al., 1999; Kassim et al., 2013; Calvalho et al., 2014). In the early and late harvest of avocado, an uneven ripening process occurs in fruits (Hofman et al., 2000; Osuna-Garcia et al., 2011; Kassim et al., 2013). It is a well-known fact that the dry weight values of the fruit increase during the harvest period and therefore the fruit quality changes in a positive aspect (Arpaia et al., 2003; Ozdemir et al., 2003; Parodi et al., 2007; Osuna-Garcia et al., 2011). In case the Hass cultivar were left on the tree during the winter months in Israel, the fruits continued to the physical development and fruit weight increased until the average of 31-43 g per unit (Winer et al., 2007). However, in New Zealand between September and April, it was stated that the average dry matter increased from 24.6% to 36.4% in Te Puke and from 24.1% to 32.3% in Far North cultivar (Requejo-Tapia et al., 1999). In addition, during the import period of Hass in New Zealand (between 2-5 months according to regions), the daily increase in dry matter percentage was reported to be in a linear structure between 0.06% and 0.11% (Pak et al., 2003). In studies that were done with Hass cultivar (Ozdemir and Topuz, 2004; Bayram and Aşkın, 2006; Osuna-Garcia et al., 2011) were observed that the dry matter content increased during the harvest period according to the degree of ripening. Additionally, in other studies that have been done in Turkey (Ozdemir and Topuz, 2004; Bayram and Aşkın, 2006) and in Mexico (Osuna-Garcia et al., 2011), it was observed that the dry matter content of Hass cultivar increased depending on maturation level of fruit during the harvest period. Similarly, the dry matter content in this study increased to a certain level during both harvest periods (from October to June) and it was found to be the most important maturity indicator. However, in the ripening process of fruits (1^{st}, 4^{th}, and 8^{th} days), although there are significant differences in dry matter and oil content values, it has been reported that there have been very few changes when compared to the fruits remaining on the tree (Ozdemir and Topuz, 2004). In another study conducted in Israel, it was determined that dry matter content of avocado did not change after harvest (Degani et al., 1986). In a way to support previously reported results, it was found that dry matter content was not a reliable index in determining the physiological changes associated with the postharvest ripening process in this study.

In the flesh firmness values (N), in the beginning analyses (0th day) during both harvest periods, although there was no regular a relationship in the early stages of the harvesting time, gradually decreasing was detected in the progressive process. The process of ripening in the postharvest was generally completed between 7 and 14 days. In this ripening process, with the softening of the fruit flesh, the firmness decreased up to zero level. Flesh

Table 1. The values of dry matter content (%), fruit flesh firmness (N), weight loss (%) and taste (1-5) during harvest and post-harvest ripening process of Hass cultivar (2010-2011 and 2012-2013 harvest period)

Harvesting time	Dry matter (%)*			LSD**	Flesh firmness (N)*			LSD**
	0th day	7th day	14th day		0th day	7th day	14th day	
05 October 2010	19.77 Ah	20.68 Ah	20.63 Ag	1.07	53.14 d	40.04 g	8.34 d	8.11
19 October	19.60 Ah	20.63 Ah	20.93 Ag	1.92	59.93 bc	52.19 bd	20.16 b	33.26
03 November	21.57 Agh	20.49 Ah	21.03 Ag	2.02	61.51 abc	54.75 ab	0.00 e	3.83
23 November	23.12 Afg	22.63 Agh	22.83 Afg	1.19	62.92 a	54.21 ac	0.00 e	7.11
12 December	24.37 Aef	23.62 Agh	23.51 Aeg	4.23	62.32 ab	57.86 a	0.00 e	4.12
29 December	24.43 Aef	25.04 Ag	26.52 Ae	4.01	62.38 ab	54.86 ab	38.41 a	12.01
13 January 2011	26.20 Ade	25.99 Afg	25.29 Aef	3.56	59.22 c	43.86 eg	8.88 cd	29.88
17 February	27.77 Ad	28.68 Aef	26.53 Ae	4.27	54.86 d	1.53 ı	0.00 e	7.29
10 March	31.84 Abc	29.65 Ade	30.49 Ad	2.93	59.65 bc	45.49 eg	0.00 e	7.49
23 March	30.68 Ac	30.90 Ace	31.17 Acd	3.95	55.51 d	10.95 h	0.00 e	31.70
08 April	30.94 Abc	32.78 Acd	34.39 Abc	3.56	52.62 de	43.75 eg	14.44 bc	31.84
25 April	33.39 Ab	34.19 Abc	33.93 Abd	4.27	53.93 d	47.83 df	8.50 cd	15.69
10 May	33.17 Abc	33.63 Abc	35.21 Aab	5.13	53.66 d	48.65 ce	0.00 e	1.43
24 May	37.50 Aa	36.67 Ab	37.08 Aab	7.57	54.21 d	46.85 df	RF****	5.70
13 June	36.45 Ba	40.29 Aa	38.37 ABa	3.18	49.74 e	42.50 fg	RF****	4.49
LSD***	2.62	3.43	3.50		2.89	5.56	5.97	
08 October 2012	19.23 Bf	20.69 ABe	25.06 Ag	5.61	55.08 b	45.85 ab	30.40 a	26.06
05 November	22.48 Aef	22.80 Ae	25.15 Afg	3.18	65.70 a	55.08 a	5.80 b	25.59
21 November	23.14 Aef	24.39 Ade	24.22 Ag	4.71	52.38 bc	37.35 bc	5.64 b	38.78
12 December	24.94 ABde	27.76 Acd	24.35 Ag	2.92	49.44 cd	25.41 def	0.00 c	37.69
03 January 2013	25.78 Ace	28.66 Acd	27.31 Aeg	5.08	50.58 c	32.93 cd	0.00 c	27.18
24 January	28.38 Acd	28.91 Acd	29.60 Adf	4.80	45.36 e	27.70 de	0.00 c	36.50
12 February	30.20 Bbc	32.09 Abc	31.53 ABde	1.54	45.76 e	4.25 g	0.00 c	16.23
06 March	33.90 Aab	32.16 Abc	33.16 Acd	3.42	44.87 ef	0.00 g	0.00 c	2.14
28 March	34.35 Bab	35.39 Bab	41.12 Aab	2.81	44.13 eg	0.00 g	0.00 c	4.90
17 April	34.21 Aab	35.31 Aab	37.52 Abc	12.05	46.34 de	0.00 g	0.00 c	2.75
14 May	38.15 Aa	38.26 Aa	38.44 Ab	11.92	40.94 g	20.10 ef	0.00 c	3.98
04 June	38.28 Aa	37.82 Aa	44.03 Aa	8.62	42.09 fg	17.16 f	0.00 c	7.66
LSD***	4.67	4.59	4.46		3.22	9.55	4.96	

Harvesting Time	Weight loss (%)*			LSD**	Taste (1-5)*			LSD**
	0th day	7th day	14th day		0th day	7th day	14th day	
05 October 2010	0.00 C	13.32 Ba	20.44 Aa	1.32	0.00 A	0.00 Ad	0.83 Ab	0.88
19 October	0.00 C	8.82 Bc	15.11 Ac	1.49	0.00 B	0.00 Bd	4.00 Aa	1.00
03 November	0.00 C	5.87 Bd	12.33 Ad	0.36	0.00 B	0.00 Bd	4.33 Aa	0.88
23 November	0.00 C	5.42 Bd	13.09 Ad	1.10	0.00 B	0.00 Bd	4.50 Aa	0.58
12 December	0.00 C	4.10 Bef	8.87 Aeg	1.80	0.00 B	0.00 Bd	4.33 Aa	0.67
29 December	0.00 C	4.38 Be	8.67 Afg	0.71	0.00 A	0.00 Ad	0.00 Ab	0.00
13 January 2011	0.00 C	4.11 Bef	8.70 Afg	0.46	0.00 B	3.50 Ac	4.17 Aa	1.05
17 February	0.00 C	5.39 Bd	8.25 Ag	0.75	0.00 C	4.00 Bb	4.67 Aa	0.67
10 March	0.00 C	3.48 Bf	9.69 Aeg	0.52	0.00 B	0.00 Bd	4.67 Aa	0.67
23 March	0.00 C	6.03 Bd	10.27 Aef	0.86	0.00 B	4.83 Aa	4.67 Aa	0.75
08 April	0.00 C	6.05 Bd	10.46 Ae	1.26	0.00 B	0.00 Bd	4.67 Aa	0.33
25 April	0.00 C	5.88 Bd	12.66 Ad	1.29	0.00 B	0.00 Bd	4.50 Aa	0.58
10 May	0.00 C	4.44 Be	10.58 Ae	0.82	0.00 B	0.00 Bd	4.17 Aa	0.33
24 May	0.00 C	8.29 Bc	18.61 Ab	3.62	0.00 A	0.00 Ad	RF*****	0.00
13 June	0.00 C	10.41 Bb	21.85 Aa	2.19	0.00 A	0.00 Ad	RF*****	0.00
LSD***	0.00	0.74	1.71		0.00	0.24	0.91	
08 October 2012	0.00 C	13.18 Ba	29.87 Aa	2.80	0.00 A	0.00 Ad	0.00 Af	0.00
05 November	0.00 C	8.44 Bc	18.42 Acd	4.16	0.00 B	0.00 Bd	2.50 Ae	0.58
21 November	0.00 C	7.06 Bd	16.05 Ad	2.78	0.00 B	0.00 Bd	2.33 Ae	0.88
12 December	0.00 C	6.93 Bd	10.85 Aeg	1.75	0.00 B	3.00 Ac	2.33 Ae	1.05
03 January 2013	0.00 C	5.19 Be	7.87 Ag	1.88	0.00 B	0.00 Bd	4.17 Abc	0.67
24 January	0.00 C	6.22 Bde	9.47 Afg	1.03	0.00 C	3.33 Bc	4.33 Ab	0.94
12 February	0.00 C	5.53 Be	9.91 Afg	1.44	0.00 C	5.00 Aa	4.67 Bab	0.33
06 March	0.00 C	5.22 Be	9.57 Afg	1.47	0.00 C	4.67 Ba	5.00 Aa	0.33
28 March	0.00 C	5.99 Bde	14.18 Adf	4.94	0.00 C	4.50 Aa	3.50 Bd	0.00
17 April	0.00 C	6.18 Bde	15.68 Ade	0.94	0.00 C	5.00 Aa	3.67 Bcd	0.33
14 May	0.00 C	9.68 Bb	23.78 Ab	12.97	0.00 B	3.67 Ab	0.00 Bf	0.33
04 June	0.00 C	10.77 Bb	22.18 Abc	4.03	0.00 B	0.00 B	2.17 Ae	0.33
LSD***	0.00	1.22	5.10		0.00	0.60	0.61	

* The difference between values in the same letter group is not significant (LSD<0.01).

** Capital letters; each harvest shows differences between days 0, 7, and 14.

*** Small letters; It shows the difference between harvest periods.

**** Taste=0.00; unripening or not tested for taste.

***** RF: Rotting fruit.

Table 2. The values of fruit skin colour (*L*C*h°*) during harvest and post-harvest ripening process of Hass cultivar (2010-11 and 2012-13 harvest period)

Harvesting time	L (*)			C (*)			h° (*)		
	0th day	7th day	14th day	0th day	7th day	14th day	0th day	7th day	14th day
05 October 2010	34.16 bc	33.65 ac	31.34 bc	19.53 ce	18.78 ad	12.66 bc	56.96 ab	55.22 a	66.09 a
19 October	33.50 bd	32.43 bd	32.45 b	19.60 ce	16.92 ce	16.97 ab	55.38 ab	56.23 a	58.17 a
03 November	35.99 a	35.02 a	35.51 a	21.47 ae	18.18 ad	19.82 a	51.08 ab	55.06 a	52.90 a
23 November	33.44 bd	34.08 ac	28.60 ce	17.28 e	16.62 df	6.87 df	55.03 ab	56.05 a	-53.66 c
12 December	32.71 cd	34.10 ac	32.74 ab	20.66 be	19.20 ad	13.67 bc	55.22 ab	54.10 a	70.44 a
29 December	33.58 bd	33.53 ac	32.86 ab	22.09 ac	20.79 ac	17.04 ab	57.00 ab	56.49 a	60.05 a
13 January 2011	33.78 bd	33.51 ac	31.92 b	22.76 ac	20.06 ad	16.00 ac	57.50 ab	62.60 a	74.82 a
17 February	34.55 ab	30.32 de	26.21 ef	21.68 ad	12.74 fg	6.99 df	58.24 ab	82.46 a	-34.17 bc
10 March	36.17 a	34.40 ab	25.62 ef	22.39 ac	21.28 ab	5.23 ef	59.64 ab	60.51 a	-31.22 bc
23 March	36.01 a	31.92 cd	24.35 f	24.15 ab	13.22 eg	4.25 ef	59.89 ab	76.06 a	-32.30 bc
08 April	34.70 ab	33.60 ac	27.71 de	20.70 be	19.14 ad	7.88 de	60.99 ab	61.80 a	-0.96 b
25 April	36.20 a	34.61 ab	26.63 ef	25.07 a	21.72 a	5.48 ef	61.20 ab	60.72 a	-72.41 c
10 May	32.30 d	32.91 ac	24.35 f	17.40 de	17.36 bd	2.98 f	65.31 ab	65.28 a	-48.48 bc
24 May	30.42 e	29.60 e	30.01 bd	12.16 f	10.44 g	11.30 cd	70.93 a	70.46 a	70.72 a
13 June	27.37 f	26.59 f	26.98 ef	7.16 g	6.16 h	6.66 df	26.69 b	-32.48 b	-33.05 bc
LSD	1.8	2.31	3.01	4.35	4.03	4.76	40.51	40.71	49.83
08 October 2012	36.46 ac	34.69 ab	31.17 ab	23.31 c	21.47 a	14.89 a	53.64 ab	53.34 a	64.82 a
05 November	37.89 ab	35.82 a	30.82 ac	25.44 ac	25.24 a	14.50 a	54.68 ab	55.81 a	-11.15 b
21 November	37.32 ab	36.41 a	30.08 ad	24.53 bc	23.82 a	15.36 a	54.23 ab	54.26 a	68.11 a
12 December	37.33 ab	34.87 ab	32.77 a	28.97 a	21.25 a	14.06 a	58.11 ab	55.84 a	81.53 a
03 January 2013	35.99 bc	37.08 a	29.96 ad	28.14 ab	25.43 a	11.31 ab	57.17 ab	56.94 a	-73.28 b
24 January	34.42 c	35.91 a	25.92 be	28.73 ab	22.67 a	7.94 bc	59.58 ab	60.32 a	-39.59 b
12 February	37.41 ab	34.09 ab	25.77 ce	25.09 ac	19.02 ab	5.11 c	57.45 ab	-17.18 ab	-44.95 b
06 March	39.08 a	31.82 bc	25.71 ce	27.79 ab	12.55 bc	5.43 c	58.19 ab	4.15 ab	-33.14 b
28 March	36.66 ac	25.62 e	23.30 e	22.46 c	5.32 c	4.44 c	66.53 ab	-36.58 ab	-65.24 b
17 April	36.94 ab	29.41 cd	24.06 e	23.00 c	9.02 c	3.75 c	63.68 ab	1.65 ab	-56.40 b
14 May	31.51 d	29.51 cd	24.96 de	12.36 d	7.81 c	5.45 c	74.74 a	80.03 a	-63.37 b
04 June	28.72 e	26.95 de	25.30 de	9.42 d	5.49 c	4.63 c	-6.53 b	-82.58 b	-65.26 b
LSD	2.75	3.11	5.33	4.29	7.52	5.63	73.73	117.85	66.01

(*) The differences between the averages indicated by the same letters in the same column were not statistically significant (p>0.05).

Table 3. The values of fruit flesh colour (L**C*h°*) during harvest and post-harvest ripening process of Hass cultivar (2010-11 and 2012-13 harvest period)

Harvesting time	L (*)			C (*)			h° (*)		
	0th day	7th day	14th day	0th day	7th day	14th day	0th day	7th day	14th day
05 October 2010	65.65 ac	62.86 dg	59.84 de	43.40 e	44.42 bf	41.58 bd	70.76 ac	69.73 a	71.06 a
19 October	61.02 ce	62.84 eg	56.50 e	41.49 f	42.41 df	44.06 ab	67.10 fg	69.45 ab	70.28 ab
03 November	66.38 ab	62.05 fh	64.21 bc	46.38 a	42.21 ef	44.27 ab	63.49 ı	69.02 ac	70.16 ab
23 November	57.00 e	60.88 gh	56.63 e	41.33 f	41.86 f	36.06 f	65.75 gh	67.93 bd	68.43 ac
12 December	60.67 de	63.77 cg	63.41 c	44.73 bd	44.93 ae	41.19 be	65.76 gh	67.91 bd	67.49 bd
29 December	63.35 ad	63.24 dg	65.71 ac	45.48 ad	45.26 ad	43.51 ac	67.32 f	67.41 ce	66.30 ce
13 January 2011	61.34 ce	59.70 h	64.19 bc	44.47 de	47.81 a	41.71 bd	65.35 h	67.36 ce	65.90 ce
17 February	64.41 ad	64.22 bf	65.20 bc	45.17 ad	41.78 f	39.84 de	67.86 df	67.29 de	65.62 ce
10 March	68.25 a	66.83 ab	64.23 bc	45.98 ab	43.82 cf	40.19 ce	68.94 ce	67.23 de	65.26 ce
23 March	66.78 ab	65.79 ad	65.22 bc	45.77 ac	42.00 ef	39.65 de	68.38 df	67.12 de	65.25 ce
08 April	63.24 bd	66.51 ac	62.61 cd	44.69 cd	44.24 cf	41.80 bd	67.47 ef	66.90 de	65.22 ce
25 April	65.73 ac	66.20 ac	64.61 bc	44.60 ce	44.50 bf	38.08 ef	70.30 ac	66.27 df	65.09 ce
10 May	68.26 a	67.84 a	68.89 a	44.75 bd	44.90 ae	42.44 bd	69.31 bd	65.91 ef	64.93 ce
24 May	67.08 ab	68.07 a	67.57 ab	45.94 ab	45.90 ac	45.92 a	70.85 a	65.78 ef	64.32 de
13 June	63.44 ad	65.66 ae	64.55 bc	46.14 a	47.27 ab	46.71 a	70.82 ab	64.59 f	63.85 e
LSD	4.94	2.94	3.39	1.25	2.96	3.33	1.52	1.69	3.56
08 October 2012	65.38 a	66.65 ab	63.67 ac	44.95 cd	47.24 a	49.21 a	65.68 h	67.28 ab	67.88 ab
05 November	65.92 a	68.09 ab	62.56 ac	46.92 a	45.74 ac	40.81 c	66.40 gh	68.22 a	69.49 ab
21 November	65.00 a	66.80 ab	67.04 ac	43.75 e	45.20 ac	42.67 bc	68.91 be	65.58 ab	66.93 ab
12 December	67.51 a	61.46 b	71.64 a	46.12 ac	43.50 be	40.92 c	69.00 bd	65.38 ab	67.16 ab
03 January 2013	51.73 b	68.02 ab	67.86 ac	46.17 ab	42.82 ce	42.14 bc	67.61 eg	66.73 ab	65.94 ab
24 January	69.61 a	69.24 a	69.52 ab	46.11 ac	43.78 ae	40.45 c	68.14 df	67.06 ab	67.15 ab
12 February	66.79 a	65.74 ab	58.75 c	46.80 a	41.59 de	38.71 c	66.98 fh	64.82 b	63.80 ab
06 March	69.79 a	63.33 ab	65.84 ac	45.12 bd	43.02 ce	41.11 c	68.51 de	64.29 b	66.83 ab
28 March	70.52 a	67.52 ab	63.82 ac	44.75 de	40.26 e	39.14 c	68.67 ce	67.37 ab	73.16 ab
17 April	67.44 a	66.58 ab	63.37 ac	44.35 de	43.94 ad	39.66 c	70.03 ac	68.21 a	73.21 ab
14 May	68.65 a	67.52 ab	68.44 ab	47.25 a	46.66 ab	47.53 ab	70.68 a	68.31 a	-1.98 b
04 June	66.74 a	63.98 ab	61.50 bc	46.76 a	45.47 ac	42.32 bc	70.23 ab	68.57 a	77.50 a
LSD	12.72	7.04	9.16	1.18	3.54	5.47	1.38	3.32	77.70

(*) The differences between the averages indicated by the same letters in the same column were not statistically significant (p>0.05).

firmness is one of the most reliable and accepted methods for assessing the maturity and ripening of avocado (Ginsberg, 1985; Magzawa and Tesfay, 2015) and the firmness gradually change depending on the maturity or ripening process of fruit (Magzawa and Tesfay, 2015). However, due to the rapid development of decay and other internal disorders as a progressive stage of ripening after harvest, determination of the firmness value of the fruit flesh is also great importance (White and Woolf, 2007). In case it is used as a measure of the post-harvest ripening stage; while the flesh firmness values are initially decreasing at the intermediate level, then the reduction rate increases and flesh firmness falls to near-zero level at the fully ripening stage of fruit (Magzawa and Tesfay, 2015). When these reports were evaluated together with the other studies that made in Mexico (Villa-Rodríguez et al., 2010; Osuna-Garcia et al., 2010), in New Zealand (Cox et al., 2004) and in Turkey (Bayram et al., 2016), the similar results were also obtained in the present study and flesh firmness values decreased.

Nevertheless, for the determination of the physiological maturity of avocado, the firmness of fruit flesh has very little (Kruger et al., 1995). Although, avocado consumers have the ability to distinguish between immature fruits and those ready to eat, in terms of firmness values, they cannot distinguish fruits from each other that are in different stages of maturity (Magzawa and Tesfay, 2015). Therefore, it was conducted a study investigating the relationship between the ripening and quality characteristics in fruits of Hass cultivar having at different maturity levels in Mexico by Osuna-Garcia et al. (2011). According to this study, although the firmness of fruit flesh was affected from the harvesting time, there was no certain relationship between firmness and determination of the degree of ripening, and between blackening degree of the fruit skin and reduction of firmness of fruit flesh. On the other hand, in case of the firmness value of the ripening fruit flesh in the Hass cultivar is between 4.4-6.7 N or less, it was reported that it increased of the consumers' purchase desire (Gamble et al., 2010; Obenland et al., 2012). In addition, the blackening of the fruit skin completely and 5-15 N of the firmness value of the fruit flesh were accepted as adequate for eating the fruit (Osuna-Garcia et al. 2011).

In the Hass cultivar, statistically significant differences were determined in fruit weight loss (%) according to harvest dates, maturity and ripening of fruits. It was found that the fruit weight loss were found to be higher in early (October-November) and late (April-June) harvests. However, as the maturity level of the fruit increased, the weight loss decreased due to the postharvest ripening process (7^{th} and 14^{th} days). Furthermore, the fruit weight loss of the fruit also changed according to the temperature and humidity of the ripening ambient. Moreover, the taste analyses, depending on the ripening of the fruit, were made at the 7^{th} day and/or 14^{th} day, and the highest were reached between January and April. It has been reported in many studies that the weight loss (%) of the fruit has decreased according to the harvesting time together with an increase of fruit maturity (Lee, 1981b; Vakis et al., 1985; Osuna-Garcia et al. 2011; Bayram and Tepe, 2018). In a study in Greece (Vakis et al., 1985), from the beginning of December until the first week of January, the fruit weight loss was measured once a week at 20°C and were generally seen to decrease. According to the study made in New Zealand by Requejo-Tapia et al. (1999), the fruits collected in November and January ripened in 14 days at 15°C, while losses of the fruit weight were founded as 2.7% in Far North and 3.8% in Te Puke. There is an inverse relationship between maturity and ripening process of avocado (Vakis et al., 1985) and weight loss varies according to the ripening degree of fruit (Osuna-Garcia et al., 2010). Therefore, in early harvests of the fruits that cannot be ripened less than 10-11 days time (Lee, 1981a; Vakis et al., 1985), a large amount of weight loss in fruits along with wrinkling of the fruit skin was determined. It was also reported that increase of the weight loss depend on the ripening degree associated with blackening of the fruit skin (Osuna-Garcia et al., 2011). It was observed that the obtained results were similar with these reports, and that the weight loss was directly affected by maturity and ripening of fruit.

According to the taste analysis done in California, it has been reported that the palatability of Fuerte cultivar rapidly increased along with rising of maturity and oil accumulation in fruit from September to January (Lee et al., 1983). In another study conducted in California (Obenland et al., 2012); fruit samples of Hass cultivar taken from two commercial packaging houses, and fruits that were imported from Mexico, Peru and Chile, were analysed in terms of taste between April 2009 and September 2010. According to these analyses; with the increase of maturation in fruit, it was stated that more soft and smooth of fruit flesh, creamier and less watery of fruit texture, and less grassy and richer taste of eating quality occurred. As a result, the acceptability of the fruit increased together with increasing the palatability (Lee, 1981a; Mizrach et al., 1999; Obenland et al., 2012; Kassim et al., 2013). In the fruits of Hass cultivar harvested in Spain at 3 different times (December 2011, January and March 2012), and which were ripened at 22°C and 90% relative humidity, some external and internal quality features were examined by sensory analysis and no significant relation could be detected. However, the quality of fruits was found to be at high levels during the harvest season from December to March (Cañete et al., 2018).

The colour values of fruit skin (Lab), the brightness and green color of the fruit in both

harvest periods usually decreased from October to June, which is observed to be at a higher level between May and June. In addition, although there was a slight increase between October-April in yellow color during both harvesting periods, a very high decrease was observed between May and June. At the end of the harvest periods, the fruits usually turned into a darker, dull and purplish-black appearance to according the beginning of the harvest. When the ripening process (0^{th}, 7^{th} and 14^{th} day) were examined; along with increasing fruit maturity during both harvest periods, it was observed in fruit skin that the brightness values decreased at a higher level between January and May and that the green and yellow colour values reduced at a higher level between the October and April. However, the reduction rate of the brightness, green and yellow colour in later periods was in lower levels.

Although there is no external and physical change in the fruit during maturation, the skin color of some cultivars changes from green to light green (Magzawa and Tesfay, 2015). In the fruit skin of the Hass cultivar, there is transforming from fully green colour to the different degrees of blackness (Osuna-Garcia et al., 2010; Osuna-Garcia et al., 2011). As in this study, although the skin colour is one of the indicators being a help to determine of the fruit quality of avocado (Kassim et al., 2013) and is different according to the harvest dates, it is not possible to state a very fast and clear change in the colour values. Therefore, the determination of maturity according to only colour values of fruit flesh is insufficient (Magzawa and Tesfay, 2015). However, along with a delaying harvest, the fact that the fruit skin of Hass cultivar firstly turning from green to purple and after turning into the black color shows that the skin colour can be used as a sign of maturity (Cox et al., 2004; Magzawa and Tesfay, 2015). Color change on the skin during the ripening process of fruits does not cause a problem in the green-skinned cultivars (if there is no disease and spotting), while it can cause problems in blackening by ripening cultivars such as Hass (Hofman et al., 2002). Despite the fact that the blackening of fruit skin of Hass cultivar is an indication of maturity characterized by low fruit flesh firmness and short shelf life (Hofman et al., 2002; Osuna-Garcia et al., 2010; Osuna-Garcia et al., 2011), it was determined that it was not associated with fruit quality (Osuna-Garcia et al., 2011). Although there were significant differences between the harvest dates in terms of fruit flesh color, it was found that fruit flesh color is not sufficient to determine maturity by itself, and similar results were obtained with Hofman et al. (2002) and Bayram and Tepe (2018).

The correlation coefficients (r) for each harvest periods were calculated between harvesting time with ripening and maturity, and between ripening and maturity. These correlation coefficients (r) are given in Table 4.

Throughout the ripening (0^{th}, 7^{th}, and 14^{th} day), there was a very high positive correlation between harvesting time and dry matter. It was determined that there was a negative relationship between harvest time and fruit flesh firmness, especially in the 2012-2013 harvest period. Between harvest time and fruit skin colour, it was observed that there was usually a relationship during the ripening process (0^{th}, 7^{th}, and 14^{th} day), especially in the 2012-2013 harvest period. In addition, during the ripening period (0^{th}, 7^{th}, and 14^{th} day), while a positive correlation was detected between dry matter values, positive and negative correlations were detected between the fruit skin values.

At the beginning of the ones should do to increase the competitiveness of the avocado industry and to preserve of existing confidence of consumers in the purchased product, there is need to introduce fruits to the market with consistent quality with predictable ripening (Magzawa and Tesfay, 2015). Therefore, depending on the processing of the fruit to the product and the transportation distance, fruits should be harvested according to physiological and horticultural maturity level (Magzawa and Tesfay, 2015). The maturity of avocado as horticultural characteristics was defined as the period that the harvested fruit is smoothly softened and have a minimum acceptable taste (Blumenfeld et al., 1992). As for the physiological maturity of avocado found generally correlated in a high degree with the maturity determined by taste analysis, and according to the occurrence of acceptable taste in the fruit occurred close to the same periods in each year (Lee, 1981a). In addition, the time of reaching to this maturity can vary from year to year and up to 3 weeks (Blumenfeld et al., 1992). Making a decision to harvest as a commercial for the avocado producers is very difficult because the fruits do not demonstrate easily identifiable physical properties when they reach to maturity. (Lee, 1981a; Olarewaju, 2014). In many countries where avocado is grown, according to the quality characteristics of fruit detected in an ongoing process before and after the harvest, it has been tried to separately determination of the fruit maturity and harvest period for each cultivar. Therefore; the variability of many factors affecting maturity and ripening process and their relations with each other, it has been investigated with regard to the determination of the fruit quality during the harvest period and encouraging the purchasing desire of producers.

When a single index is used to determine of maturity in the fruit; although it has reached the desired values, this index should adequate and protective to determine maturity standard and prevent marketing of fruits that are not on acceptable quality in terms of ripening (Hofman et al., 2002). Although the percentage of dry weight is a relatively useful method as a maturity standard, it is recommended to continue the studies for

Table 4. The correlation coefficients (r) calculated for each harvest periods

Variables		The correlation coefficients (r)		Variables		The correlation coefficients (r)		Variables		The correlation coefficients (r)	
X	Y	2010-2011 Harvest period	2012-2013 Harvest period	X	Y	2010-2011 Harvest period	2012-2013 Harvest period	X	Y	2010-2011 Harvest period	2012-2013 Harvest period
Harvesting time	Dry matter (0^{th} day)	0.96	0.96	Harvesting time	b (0^{th} day)	-0.23	0.51	Dry matter (0^{th} day)	Dry matter (7^{th} day)	0.92	0.94
	Dry matter (7^{th} day)	0.95	0.96		b (7^{th} day)	-0.30	-0.81	Dry matter (0^{th} day)	Dry matter (14^{th} day)	0.93	0.88
	Dry matter (14^{th} day)	0.95	0.92		b (14^{th} day)	-0.52	-0.82	Dry matter (7^{th} day)	Dry matter (14^{th} day)	0.94	0.85
	Flesh firmness (0^{th} day)	-0.58	-0.82		L (0^{th} day)	0.34	0.24	Flesh firmness (0^{th} day)	Flesh firmness (7^{th} day)	0.35	0.74
	Flesh firmness (7^{th} day)	-0.18	-0.74		L (7^{th} day)	0.66	-0.09	Flesh firmness (0^{th} day)	Flesh firmness (14^{th} day)	0.21	0.47
	Flesh firmness (14^{th} day)	-0.24	-0.58		L (14^{th} day)	0.62	-0.14	Flesh firmness (7^{th} day)	Flesh firmness (14^{th} day)	0.21	0.47
	Weight loss (7^{th} day)	-0.12	-0.12		a (0^{th} day)	0.37	0.65	Weight loss (7^{th} day)	Weight loss (14^{th} day)	0.88	0.93
	Weight loss (14^{th} day)	0.10	-0.03		a (7^{th} day)	0.20	0.41	L (0^{th} day)	a (0^{th} day)	-0.87	-0.83
	Taste (7^{th} day)	0.05	0.51		a (14^{th} day)	0.51	0.69	L (0^{th} day)	b (0^{th} day)	0.88	0.80
	Taste (14^{th} day)	-0.16	0.14		b (0^{th} day)	0.65	0.47	a (0^{th} day)	b (0^{th} day)	-0.88	-0.90
	L (0^{th} day)	-0.38	-0.55		b (7^{th} day)	0.38	-0.12	L (7^{th} day)	a (7^{th} day)	-0.86	-0.92
	L (7^{th} day)	-0.49	-0.79		b (14^{th} day)	0.27	0.06	L (7^{th} day)	b (7^{th} day)	0.87	0.98
	L (14^{th} day)	-0.62	-0.75					a (7^{th} day)	b (7^{th} day)	-0.80	-0.93
	a (0^{th} day)	0.60	0.79					L (14^{th} day)	a (14^{th} day)	-0.91	-0.70
	a (7^{th} day)	0.55	0.80					L (14^{th} day)	b (14^{th} day)	0.96	0.88
	a (14^{th} day)	0.48	0.62					a (14^{th} day)	b (14^{th} day)	-0.94	-0.81

developing another standard due to finding sometimes its poor relationship with mature fruit quality (Hofman et al., 2002). Measurements determining of the fruit quality such as fruit skin colour, fruit flesh firmness and dry weight ratio, in some cases unable to predict the variable ripening of fruit in post-harvest (Hernández et al., 2015; Rivera et al., 2017). Climate, soil and agricultural management conditions can have an effect on maturation variability (Coggins, 1984; Rivera et al., 2017). In the Hass cultivar, observed ripening variability or heterogeneity of ripening is the result of complex fruit physiology associated with pre-harvest and post-harvest factors (Hernández et al., 2015). Therefore, attempting to predict post-harvest behaviours by considering only a single pre-harvest variable may be a deceptive simplification of reality (Rivera et al., 2017) and if two maturity standards such as DM% and healthy ripening capacity are used together, the marketing risk of immature fruit reduces (Hofman et al., 2002).

In a study conducted by Pak et al. (2003) in New Zealand, the significant relationships have been observed between dry matter content and some fruit quality characteristics (especially in export control). According to this study, as the process of maturation of the fruit progressed, the rate of vascular fibrousness and decay in fruit decreased. It was found that the minimum dry matter content for fruit maturity was an acceptable index and increased in a linear line between July and September. However, the rates of dry matter accumulation in the fruit vary considerably at a certain harvest time (at the beginning and end of the season) and between harvest times. In general, when the dry matter rate is above 24.0%, it is the recommended ratio for early harvest as whole fruit flesh is more smoothly ripening and have better quality features in the post-harvest process. In another study made with Hass cultivar in New Zealand (Gamble et al., 2010); along with the increase in dry matter (between 22.0-27.0%), it has been reported that consumers' desire to buy increased. In the study in Colombia (Calvalho et al., 2014), as an acceptable level by the consumers, it was reported that dry matter rate needs to be between 22.0-26.0% with at least 11.2% minimum oil content in Hass cultivar. In a study conducted in Michoacán where 80.0% of avocado orchards were found in Mexico (Osuna-Garcia et al., 2011); although the harvest time of Hass cultivar is between September and April, it is stated that the dry matter content was between 21.5-28.0% in a certain period (mid-October and early January), which the ripening of the fruit is regular and the shelf life is at good level. For acceptable taste values for Hass cultivar, it was reported that it was reached in early December in California (Lee et al., 1983) and

in the second week of December in Greece (Vakis et al., 1985). In a study conducted for determination with various aspects of product quality of Hass cultivar and at the same time quantitative analysis of consumer preferences (Gamble et al., 2010); it was evaluated that dry matter rates ranged between 20.0% (minimum mature) and 40.0% (very mature) levels and found in the different stages of flesh firmness. As the rate of dry matter in the fruit increases, there has been a constant increase in the willingness and intention of consumers to buy. According to the results of this study, the consumers' preference maturity level for avocado was determined as values that the firmness of fruit flesh was 6.5 N or less and the dry matter content was between 22.0-27.0%. In another study, it was reported that dry weight rate for avocado distributed between the content values greater than 35.0%, which the fruit was most suitably process, and fewer values than 20.0%, which the taste and quality of fruit too low to sell (Clark et al., 2007).

In the research conducted with the Hass variety in Mexico; while the fruit skin colour firstly transformed from green to purple colour with the increase in harvest maturity, the fruit skin colour became blacking in the following stages along with the increase in avocado maturity index values (Villa-Rodríguez et al., 2010; Osuna-Garcia et al., 2011). Although this colour change in the fruit skin is accepted to be a very important index of maturity for both consumers and producers in avocado industry (Cox et al., 2004), these fruits are undesirable in some countries because it is thought to be associated with low fruit flesh firmness and short shelf life (Osuna -Garcia et al., 2010; Osuna-Garcia et al., 2011). Therefore, in the studies aimed at revealing the relationship between skin color and fruit quality, it was reported that the blackening of the fruit skin could not be associated with low fruit quality. However, it was stated that these fruits had lower firmness of fruit flesh according to the analysis made during the packaging process (Osuna-Garcia et al., 2010; Osuna-Garcia et al., 2011).

Fruits of Hass cultivar exported from Mexico to Canada was investigated during the harvest season (between October 2007 and April 2008) as shelf life and fruit quality (Osuna-Garcia et al., 2010). As a result, the dry matter content of the fruit flesh increased with the harvesting time and the degree of blackening of the fruit skin. Although the weight loss in fruit decreased with harvest date, it increased along with the degree of blackening of the skin. At the same time, even though the harvesting time had a significant effect on the firmness of the fruit flesh, there was no correlation between the blackening degree of the fruit skin and the decrease of firmness of fruit flesh. In similar with these reports, due to the occurrence of some problems in the ripening of the early or late-harvested fruit of Hass cultivar, the harvest time has been divided into 3 different periods by considering the physical and chemical development of the fruits (Bayram and Tepe, 2019). Each of the harvest periods has been defined according to the maturity and ripening of the fruit.

4. Conclusion

In this study, depending on the maturity and ripening of the fruit, the most suitable and acceptable harvest period for the Hass cultivar was generally determined. For the determination of the harvest maturity, observation of changes on fruit flesh firmness and in fruit skin colour takes a long time, moreover, taste analyses and fruit weight loss takes between 7-14 days, thus, these prevent to make a fast decision for marketing. During the maturation period, a very high positive correlation (r= 0.92-0.96) was observed between harvest time and dry matter. Furthermore, while the positive correlations at high-level (r = 0.85-0.94) between the dry matter values were determined, the positive and negative correlations at high-levels between colour values of the fruit skin were found.

As a result, it was found that the most reliable maturity index was dry weight content and that it had a direct relationship with harvesting time. In cases where these index values were insufficient, the other postharvest analyses (taste, fruit skin colour, and fruit flesh firmness and fruit weight loss) were helpful for the determination of the maturity of Hass cultivar. The harvesting time of Hass cultivar was determined for the three different periods divided as early, optimum (most suitable) and late harvest. 23-25% dry weight content between mid-October and late December as early harvest, 26-37% dry weight content between early of January and end of May as optimum harvest, and 38% dry weight content between beginning and end of June was determined as the late harvest.

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HortiS 37(2):113-122
http://doi.org/10.16882/HortiS.805196

RESEARCH PAPER

HORTICULTURAL STUDIES

Responses to Drought Stress Levels of Strawberry Grown in Greenhouse Conditions

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Article History
Received 30 July 2020
Accepted 29 September 2020
First Online 10 October 2020

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Keywords
Drought stress
Greenhouse
Strawberry
Vegetative parameters
Physiological parameters

Abstract

This experimental study was carried out using the 'Camarosa' cultivar strawberry plants grown in pots in greenhouse conditions. One control and two drought levels were created by bringing the existing soil water content of the pot to the field capacity (I_{100}-control) and using its 66% (I_{66}-mild drought stress) and 33% (I_{33}-severe drought stress) in irrigation. The experimental design of the randomized complete blocks design was applied in four replicates with 10 pots per replicate amounting to a total of 120 pots. In order to determine the plant response to the generated stress levels, stomatal conductivity (Sc, mmol m^2 s^{-1}), total chlorophyll content (SPAD, µmol m^{-2} s^{-1}), chlorophyll concentration (CC, mg g^{-1}), leaf surface temperature (LST, °C), photosynthetic quantum yield (Qy, %), photosynthetically active radiation (PAR, W m^{-2}), leaf water content (LWC, %), yield (g pot^{-1}), leaf area (LA, cm^2), leaf number (LN), and crop water use (ET) were measured in three plants per each replicate. 1.89, 3.62, and 5.82 L pot^{-1} were applied to I_{33}, I_{66}, and I_{100} as irrigation water, while 2.59, 3.92, and 5.59 L pot^{-1} were crop water used from them, respectively. Average strawberry yield varied between 80 and 400 g pot^{-1}. The increased drought stress decreased Sc, SPAD, CC, Qy, PAR, LWC, LA, and LN but increased LST. All the measured variables had significant relationships with irrigation water and crop water use. Yield had a linear relationship with LST and LN and a polynomial relationship with Sc, SPAD, CC, Qy, PAR, LWC, and LA. Water and light use efficiencies were quantified and predicted through the best-fit (non-) linear models.

1. Introduction

The irregularity and extremity of precipitation regimes due to global climate change have caused droughts in many regions of the world and enhanced its severity in the semi-arid regions. Drought is one of the most important environmental stressors that limit plant growth and development. Plants protect themselves against drought stress by morphological, biochemical and physiological mechanisms by increasing their water use efficiency. The most important physiological properties include stomatal conductivity, leaf temperature (Jones, 1999), photosynthetic capacity (Lawlor and Cornic, 2002), phenological periods (Slafer et al., 2005; Richards, 2006), leaf area (Walter and Shurr, 2005), and chlorophyll content (Jackson et al., 1996).

The first physiological symptoms against drought stress occur in stomatal conductivity. The tendency of stomata in the leaves to close in the case of water scarcity in the root region reduces the gas exchange between the leaf intercellular void and the atmosphere (Kerepesi and Galiba, 2000). The reduction of CO_2 use under a moderate drought stress usually relates to stoma closure (Mansfield

and Davies, 1981). If the drought time is prolonged, the decrease in photosynthesis is not caused by stomatal closure, but from the membrane damage in mesophilic cells, the decreased chlorophyll content, and the deterioration in the transport and synthesis of assimilation products. The amount of decrease in photosynthesis relates to the severity and duration of drought stress, plant type, development period and leaf age, the oxidation of chloroplasts, and the structure of proteins and pigments (Passioura et al., 1993). The drought-resistant varieties accumulate more biomass (leaf area, number of leaves, amount of stem, and stem biomass) in their leaves than the drought-sensitive ones (Kerepesi and Galiba, 2000). Drought tolerance levels of plants are closely related to the timing of the stress that they are exposed to. If its severity and duration are not lethal, the physiological factors may be restored back to normal with the disappearance of the stress. For example, the vine tree when exposed to drought stress was found to have recovered by about 60% after one night, and fully in four days, if watered in terms of net CO_2 assimilation rate (A), and stomatal conductance (Sc) (Flexas et al., 2004). Some studies indicated that photosynthesis recovered within 24 h after irrigation (Flexas et al., 2004; Mittler et al., 2001) depending on the stress severity, and the crop varieties (Flexas et al., 2004). Strawberries need to be irrigated for their optimum growth and development in areas where the amount of precipitation is not sufficient although their genotypic differences may trigger different responses to drought. Klamkowski and Treder (2008) reported that although drought stress reduced the leaf area in all the cultivars, the weakening root development, and low yield were observed only in the varieties of Elkat, Ghaderi, and Siosemardeh. They stated that membrane stability index, net CO_2 assimilation rate, stomatal conductance, transpiration rate, and chlorophyll content fell with the decreased soil water content. When exposed to drought stress, strawberry decreased its stomatal closure by rapidly increasing abscisic acid synthesis (ABA) at the roots (Blanke and Cooke, 2004). Thus, low transpiration rate may render strawberry drought-tolerant (Grant et al., 2010). The objective of this study was to determine the changes in crop water use, stomatal conductance (Sc), chlorophyll value (SPAD), photosynthetic quantum yield (Qy), photosynthetically active radiation (PAR), chlorophyll concentration, leaf surface temperature (LST), leaf water content (LWC), leaf area (LA), leaf number (LN), and yield in response to a changing drought stress level.

2. Material and Method

2.1. Soil, plant and cultivation characteristics

The research was carried out in an unheated plastic greenhouse with a dimension of 10.5 × 22 × 4 m, with a side ventilation, in 2016.

Camarosa (*Fragaria* × *ananassa* Duch.) strawberry cultivar was used as a tube seedling of four-weeks old with a minimum body thickness of 10 mm. Pots used in growing had a diameter of 42 cm, a length of 31 cm, and a volume of 22 L. Heavy potted soil brought from Amik Plain as a growing medium was first mixed with the sand brought from the stream bed and filled in pots with a total weight of 10 kg. In order to enable drainage, seven holes in an equal diameter under the pots were drilled. Drainage water was collected in a container placed under a pot. Irrigation water of C_1S_1 class was used. Soil salinity was determined as 0.19 dS m^{-1}. And the blend ratio of soil to sand was 2/1.

2.2. Experimental design and applications

The experiment was carried out in a total of 120 pots, with four repetitions, 10 pots in each repetition and one plant in each pot in response to three irrigation levels (IL) according to the experimental design of randomized complete blocks design. The three irrigation treatments were created by applying all the water required by a plant to reach the field capacity level (I_{100}-control), and 66% (I_{66}-moderate drought) and 33% (I_{33}-severe drought) of the irrigation water required by the plant. The irrigation water amount to be given to the plants was determined by measuring the irrigation water amount required to bring them to the field capacity before weekly watering three pots next to the experimental pots. In determining the irrigation water amount before each irrigation, three pots were determined where irrigation water was applied with a specific beaker at certain intervals until water began to leak from underneath the pots. As soon as leakage was seen from underneath the pot, water application was stopped to determine the volume of water (in L). This amount determined corresponded to the full irrigation (I_{100}), while 66% (I_{66}) and 33% (I_{33}) of this amount were applied to the other pots by creating the two soil water contents, and thus, the two drought stress levels.

2.3. Physiological measurements

In order to determine the plant physiological responses to the water stress levels created, the physiological parameters (Sc, SPAD, LST, Qy, PAR) were measured before each irrigation prior to harvest so long as the leaf sizes were measurable: SPAD, Qy, PAR, Sc, LST, and PAR measurements were begun on the 26th of February and repeated nine times during the experiments. LWC, LA, and LN measurements were made at the final harvest.

2.3.1. Stomatal conductivity (Sc, mmol m^2 s^{-1})

Stomatal conductivity was measured one day before irrigation between 11:00 and 14:00 under clear sky. A leaf porometer with a portable desiccant (DECAGON SC-1) was used. Its calibration was realized with standard calibration papers before each measurement. The measurements were made on the 4th, 5th, and 6th pots in the middle of the repetitions marked for each replication.

2.3.2. Total chlorophyll content (SPAD, µmol m^{-2} s^{-1}) and chlorophyll concentration (CC, mg g^{-1})

Total chlorophyll content is one of the best plant physiological signals under the stress conditions and was measured using a SPAD instrument (Minolta SPAD 502) based on the color change in the leaf. Measurements were taken as the average of four readings in three pots in each replication before each irrigation treatment and repeated nine times during the experiments. Chlorophyll concentration was determined analyzing total chlorophyll of young leaves that completed their development sampled near the harvest period, according to Arnon (1949). In the analysis, 0.1 mL of the leaf samples in porcelain mortar were homogenized by adding 1-2 mL of 80% acetone. The samples were filtered from a coarse filter paper into 10 mL glass tubes and completed with 80% acetone up to 10 mL. The absorbance values obtained from the wavelength of 652 nm using a spectrophotometer (SP-3000 Plus Spectrophotometer) were substituted into Eq. (1) where the total chlorophyll concentration was determined (Lichtenhaler and Welburn, 1983).

$$TCC = \frac{(A652 \times 27.8) \times 10}{Sample\ weight \times 1000} \quad (1)$$

2.3.3. Leaf surface temperature (LST, °C)

An infrared thermometer instrument (Spectrum Tech. Inc., IR Crop temperature meter) was used to measure LST as the average of four readings in the plants of three pots marked each time. Measurements were made one day before irrigation between 11:00-14:00 under the clear sky and repeated nine times during the experiments.

2.3.4. Photosynthetic quantum yield (Qy, %) and photosynthetically active radiation (PAR, W m^{-2})

Photosynthetic quantum yield and PAR were measured in the plants of three pots one day before irrigation between 11:00 and 14:00 under the clear sky using a portable FlourPen FP100 and repeated nine times during the experiments.

2.4. Vegetative and generative measurements

During the harvest period, the leaves of the plants in each replication at the end of the harvest season were counted after which the leaf areas were measured using a Li-3100C area meter. Once the leaves were counted, wet/fresh weight matter (FM) of the entire plant in the pot and after 24 h in pure water at 4°C, its saturated total weight (TM), and the leaf water contents were determined and converted to dry weight matter (DM) at 65°C for 72 h using Eq. (2) (Bacelar et al., 2006). The remaining biomass parts of the plant other than the leaves were weighed after drying for 24 h in a drying oven at 70°C (Önal, 1991).

$$LWC = \frac{(\mathrm{FM}-\mathrm{DM})}{(\mathrm{TM}-\mathrm{DM})} \times 100 \quad (2)$$

where LWC: leaf water holding capacity (leaf water content, %), FM: fresh leaf biomass (g), DM: dry leaf biomass (g), TM: turgid leaf biomass (g).

2.5. Harvest period operations

Fruits that reached harvest maturity were harvested in three periods (at about one-week interval: 24 March, 31 March, and 7 April). During the harvest, fruits in each replication were both counted and weighted. The data obtained were subjected to analysis of variance (ANOVA) and Duncan comparison tests at a significance level ($p<0.05$) using SPSS 18.0 (Bek and Efe, 1988).

2.6. Crop water use

Plant water consumption was determined weighing the pots in the period between two irrigations from three pots in each application. Before the irrigation treatment, the three control pots were weighed and irrigated at the intervals until water came from underneath the pot.

The volume of water given in each application was measured with the help of a specific beaker. After about a week, the same pots were weighed again to determine the amount of water consumed and crop water use in a week. To offset plant weights in the computation of irrigation requirements, the additional three pots were disintegrated in every 15 days for their measurements in each treatment.

2.7. Statistical analysis

Pearson's correlation matrix was performed to detect the strength and direction of linear relationships between the measured variables. The best-fit simple linear regression and non-linear models were chosen using the Bayesian Information Criterion (BIC).

Bayesian Information Criterion aims to balance the trade-off between the goodness-of-fit and parsimony by penalizing model complexity in the selection of the best model from among a set of alternative models.

3. Results and Discussion

3.1. Irrigation and crop water use

Water use increased with the increasing irrigation water amount. The highest and lowest seasonal water consumption belonged to I_{100} (5.82 L) and I_{33} (1.89 L), respectively (Figure 1). Compared to I_{100}, water consumption dropped by 54% with I_{33} and 31% with I_{66}. During the irrigation treatments, the water amount used ranged from 0.23 to 1.20 L. Strawberry has a shallow root system and a large leaf area with a high water requirement (Treder et al., 2009). Islam et al. (2016) determined the irrigation water requirement in three strawberry varieties as 85.25, 49.22 and 49 mm under the zero evaporation conditions and 351.45, 324.42 and 338 mm in field conditions when FAO's crop coefficients (Kc, the ratio of crop-specific and reference crop ET) were used. The water requirement of strawberry varied between 300 and 787 mm under a wide range of climatic conditions (Serrano et al., 1992; Trout and Gartung, 2004; Hanson and Bendixen, 2004; Strand, 2008).

During the growing period, the crop water use value initially increased and then decreased. Daily maximum water consumption was measured as 1.09 L for I_{100} at the beginning of the flowering period. Daily minimum water consumption was measured as 0.12 L for I_{33} near the harvest period. Crop water use decreased significantly due to the drought stress. Water consumption was previously reported to vary according to soil, climate, and cultivars. For example, crop water use varied between 430 and 453 mm with Sabrina cultivar and was estimated at 352 mm with Antilla cultivar based on lysimeters (Lozano et al., 2016). Maximum water consumption was found as 368 mm under -0.04 MPa (yield: 28.2 t ha^{-1}) by Giovanardi and Testolin (1984) and as 566 mm under -0.01 MPa by Serrano et al. (1992). They found that as the soil water content decreased, the water lost by transpiration decreased, while the water consumption amount at -0.03, -0.05 and -0.07 MPa was 424, 299 and 313 mm, respectively.

The drought stress reduced the amount of fruits, and the fruit weight ($p < 0.01$). According to the three harvests made, the fruit weight and number were higher in the second harvest, while yields were determined as 80, 229 and 400 g pot^{-1} with I_{33}, I_{66} and I_{100}, respectively. The total fruit weights ranged from 63 to 95 g pot^{-1} with I_{33}, 195 to 261 g pot^{-1} with I_{66}, and 329 to 538 g pot^{-1} with I_{100}. The drought stress also caused similar effects on the number of fruits. The average, (lowest and highest) fruit weights were 30.25 (25-38), 36.50 (34-42) and 41.25 (38-44) with I_{33}, I_{66} and I_{100}, respectively. Drought stress decreased fruit yield due to the lower fruit number and size (El-Farhan and Pritts, 1997; Grant et al., 2010; Serrano et al., 1992). The fruit yield was reported to decline by about 80%, while the number of fruits decreased by more than 30% (El-Farhan and Pritts, 1997). In our study, the decreases by 43% with I_{66} and by 80% with I_{33} were observed. Similarly, the number of fruits declined by 12% with I_{66}, and by 19% with I_{33}.

Relative to I_{100}, the FM value decreased by 47% and 18%, while the DM value decreased 44% and 14% with I_{33} and I_{66}. The lack of moisture in the root zone significantly reduced LWC for each sampling during the harvest period. When the soil water content in the root area was insufficient, water loss through transpiration reduced the water amount in the tissues (Klamkowski and Treder, 2008). This response was also observed in many other plant species (Blanke and Cooke, 2004; Lawlor and Cornic, 2002). In our study, LWC was 60, 44.87 and 17.22% in the stress-free, moderate and severe drought stress levels, respectively. Ghaderi and Siosemardeh (2011) stated that the irrigation done

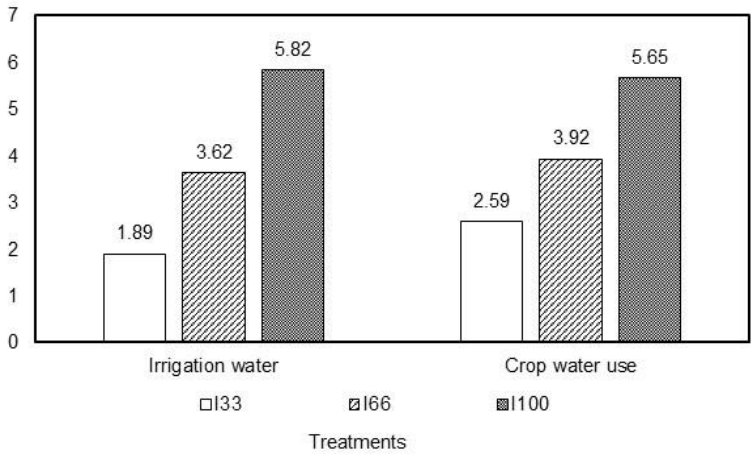

Figure 1. Amount of applied irrigation water and measured crop water use in the study (L pot^{-1})

with 50% (I_1) and 25% (I_2) of the available water capacity decreased LWC by 7% in I_1 and 31.5% in I_2 compared to the full irrigation, and one day after the plants were irrigated in full, LWC was recovered by 97% and 88% in two varieties due to the intra-specific differences in leaf moisture content, and interactions between genotype and irrigation applications.

Leaf area was on average 379, 582 and 894 cm^2 (Figure 2), while the number of leaves was 18, 23 and 31 with I_{33}, I_{66} and I_{100} (Figure 3), respectively. According to I_{100}, the decrease was by 35% and 58% in leaf area, and by 26% and 42% in the number of leaves with I_{66} and I_{33}, respectively. The drought stress level adversely affected the number of leaves rather than the leaf area. This suggests that the increased stress did not prevent the plant from growing its existing leaves, but its new leaf formation. The numbers of runners, crowns and leaves were previously observed to decrease in long and frequent droughts (El-Farhan and Pritts, 1997). Both leaf area and leaf number had the same relationship with the yield according to the regression models in this study. One cm^2 increase in the leaf area and one unit increase in the number of leaves caused 23 and 0.6 g increases in the yield, respectively.

Osmotic regulation, low transpiration rate, and small leaf area are also the important parameters in the selection of drought tolerant strawberry varieties (Grant et al., 2010). In the strawberry plant exposed to water stress, the leaf expansion rate decreased, while the leaf area of the fully watered plants during the season doubled compared to the plants exposed to stress. Leaf expansion started one hour before sunset, and leaf expansion rate peaked for the next five hours. The leaves of the strawberry plant exposed to the mild drought stress (75% of the required water) for four months had less than half the leaf area of the fully watered plant. Part of this difference in the leaf area resulted from stress conditions accelerating the aging and death of all leaves, in particular, old leaves. Under the moderate water stress, young leaves had a relatively higher water content, which reduced the death of young leaves (El-Farhan and Pritts, 1997).

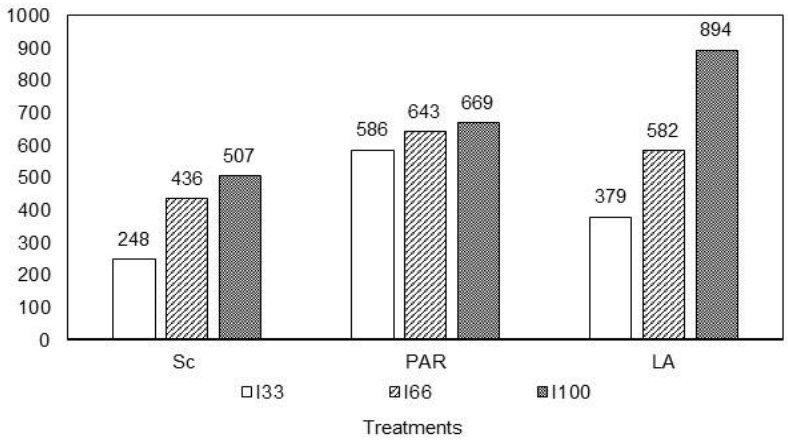

Figure 2. Changes in stomatal conductivity (Sc, mmol m^2 s^{-1}), photosynthetically active radiation (PAR, W m^{-2}) and leaf area (LA, cm^2) of strawberry leaf in the study

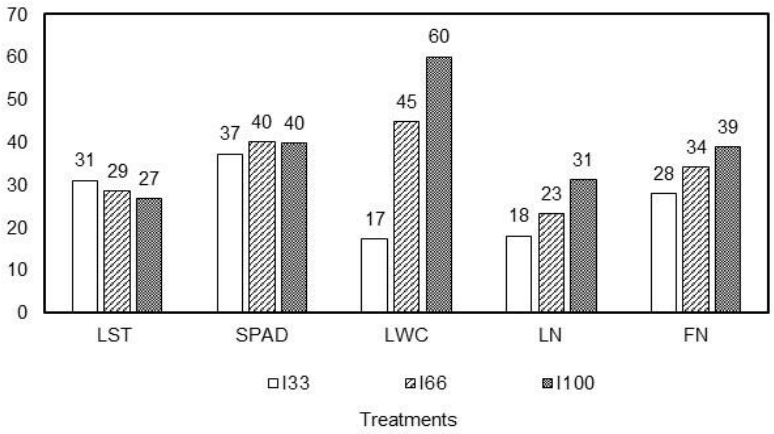

Figure 3. Changes in leaf surface temperature (LST, °C), total chlorophyll content (SPAD, µmol m^{-2} s^{-1}), leaf water content (LCW, %), leaf number (LN) and fruit numbers (FN) of strawberry plant in the study

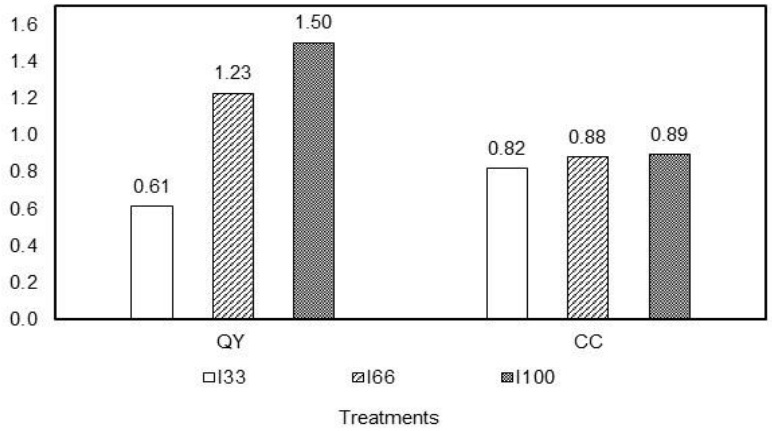

Figure 4. Changes in photosynthetic quantum yield (Qy, %) and chlorophyll concentration (CC, mg g^{-1}) of strawberry leaf in the study

The protection of LWC under the drought stress is an important factor in ensuring the drought tolerance of the plants. In preventing the reduction of LWC, the increased osmotic regulation, and the decreased transpiration may increase the drought resistance. Therefore, the stomatal responses of plants can be considered a primary driver to the drought. The stomata are responsible for the gas exchange between the leaf's intercellular space and the atmosphere and sensitive to drought stress (Kerepesi and Galiba, 2000). Stomatal closure protects plants from excessive water loss but also limits the entry of CO_2 into the tissue where photosynthesis takes place (Chaves et al., 2003). In our study, Sc decreased linearly as the drought stress severity increased. Sc was estimated at 248 and 507 mmol m^2 s^{-1} under the severe drought stress and stress-free conditions, respectively (Figure 2). A significant linear increase was found between Sc and yield. According to the development period of the plant, the Sc rate decreased in the aging leaves as it approached the harvest time. The highest time-dependent Sc was measured prior to the fruit formation.

Closing stomata in the drought stress decreased the net CO_2 assimilation rate (A) and ET but increased LST. The LST value of the strawberry leaves was 31, 29 and 27°C under the severe and moderate drought stress and stress-free conditions, respectively (Figure 3). Ödemiş et al. (2017) pointed out that the increased Sc cooled down the leaf surface as the drought stress decreased and found that each 1°C increase in the cotton leaf temperature decreased its yield by 88.7 kg da^{-1} in the first year and by 61.2 kg da^{-1} in the second year. In this study, each 1°C increase caused a decrease by about 75 g.

SPAD and chlorophyll concentrations decreased with the increased drought stress. SPAD values were 37.22, 39.93 and 39.74 µmol m^{-2} s^{-1} (Figure 3), while chlorophyll concentration was 0.82, 0.88 and 0.89 mg g^{-1} (Figure 4) under the severe and moderate drought stress and stress-free conditions, respectively. No significant difference was found in chlorophyll concentration between the severe and moderate drought levels. As the drought stress increased for strawberry (Ghaderi and Siosemardeh, 2011), apple (Sircelj et al., 2007) and cotton (Ödemiş et al., 2017), the chlorophyll content decreased. Ghaderi and Siosemardeh (2011) found differences in the chlorophyll content and chlorophyll degradation of two strawberry varieties with prolonged drought stress as well as no recovery with their irrigation.

Photosynthetic quantum yield is a measure of photosynthetic activity expressed as moles of photons absorbed per mole of oxygen released or per mole of CO_2 taken (Long et al., 1993). In this study, as drought stress increased, Qy increased linearly. Qy was 0.61, 1.23 and 1.50 under the severe and moderate drought stress and stress-free conditions, respectively (Figure 4). Ödemiş et al. (2017) pointed out that Qy in cotton initially increased and then decreased due to the increased irrigation water amount. El-Farhan and Pritts (1997) estimated the photosynthetic rates as 35 mg CO_2 dm^{-2} h^{-1} and 16 mg CO_2 dm^{-2} h^{-1} in stress-free and stressful conditions, respectively.

The decreased leaf area and number as a result of the increased drought stress severity reduced PAR that strawberry plants could absorb in photosynthesis. PAR was 586 W m^{-2} with I_{33} and 669 W m^{-2} with I_{100} (Figure 2). Many studies showed that yield had a positive relationship with light use efficiency (Whitfield and Smith, 1989; Chen et al., 2003; Li et al., 2008). Our results were consistent with the study by Plénet et al. (2000) that the ratio of PAR absorbed by the canopy depended on leaf area index (LAI), and canopy geometry.

3.2. Relationships of water use efficiency and light use efficiency with other variables

Linear or quadratic relationships were obtained between irrigation water, crop water use, and yield (Table 1). The increased irrigation water amount

and crop water use linearly increased yield, fruit number, leaf area, and leaf number. The FM and DM weights and LWC had polynomial relationships with the irrigation water amount and crop water use. The irrigation water and crop water use affected Sc, SPAD, and Qy but chlorophyll concentration. LST decreased with the increased irrigation water and crop water use. PAR did not respond significantly to the increased irrigation water and crop water use (Table 1). The linear relationship between LST and leaf number was found, while the second-order relationships between all the other variables were obtained.

Pearson's correlation matrix analysis showed that water use efficiency (WUE = fruit weight/ crop water use) were positively correlated with Qy and PAR at $p < 0.001$ and Sc and LWC at $p < 0.05$ (Figure 5). Light use efficiency (LUE = fruit weight/PAR) was linearly associated with crop water use and irrigation level (IL, I_{33} -> I_{66} -> I_{100}) at $p < 0.05$ (Figure 6). Not only did multicollinearity exist among Sc, Qy, PAR, and LWC but also between crop water use and IL. Hence, the non-linear models were best fit to WUE and LUE as a function of the individual predictors according to the smallest BIC values (Table 2).

Table 1. Relationships of measured variables with irrigation water and evapotranspiration (n = 3)

Response	Irrigation water	r^2	Evapotranspiration	r^2
Yield (g)	81.124x - 69.888	0.99**	104.12x-185.54	0.99**
Fruit number	2.7098x + 23.349	0.98**	3.4755x+ 19.496	0.97**
Leaf area (cm^2)	131.43x + 122.04	1**	168.78x - 65.69	1**
Leaf number	3.38x + 11.39	0.99**	4.34x + 6.55	0.99**
Dry weight (g)	$-0.13x^2 + 1.50x + 0.31$	1**	$-0.21x^2 + 2.45x - 2.19$	1**
Fresh weight (g)	$-0.12x^2 + 1.62x + 0.39$	1**	$-0.21x^2 + 2.58x - 2.29$	1**
Leaf water content (%)	$-4.31x^2 + 39.75x - 42.49$	1**	$-7.19x^2 + 67.63x - 109.68$	1**
Stomatal conductance (mmol m^2 s^{-1})	$-46.36x^2+405.42x-352.96$	1**	$-77.14x^2+697.27x-1040.8$	1**
Total chlorophyll content (µmol m^{-2} s^{-1})	$-0.26x^2 + 1.34x + 38.34$	1**	$-0.43x^2+2.65x+35.95$	1**
Chlorophyll concentration (mg g^{-1})	0.0053x + 0.84	0.07 ns	0.0069x + 0.83	0.07 ns
Leaf surface temperature (°C)	-1.05x + 32.78	0.97**	-1.35x + 34.28	0.96**
Photosynthetic quantum yield (%)	$-0.059x^2 + 0.68x - 0.47$	1**	$-0.099x^2+1.11x-1.60$	1**
Photosynthetically active radiation (W m^{-2})	8.045x + 602.26	0.14 ns	10.49x + 590.12	0.14 ns

ns and **, not significant and significant $p < 0.01$, respectively

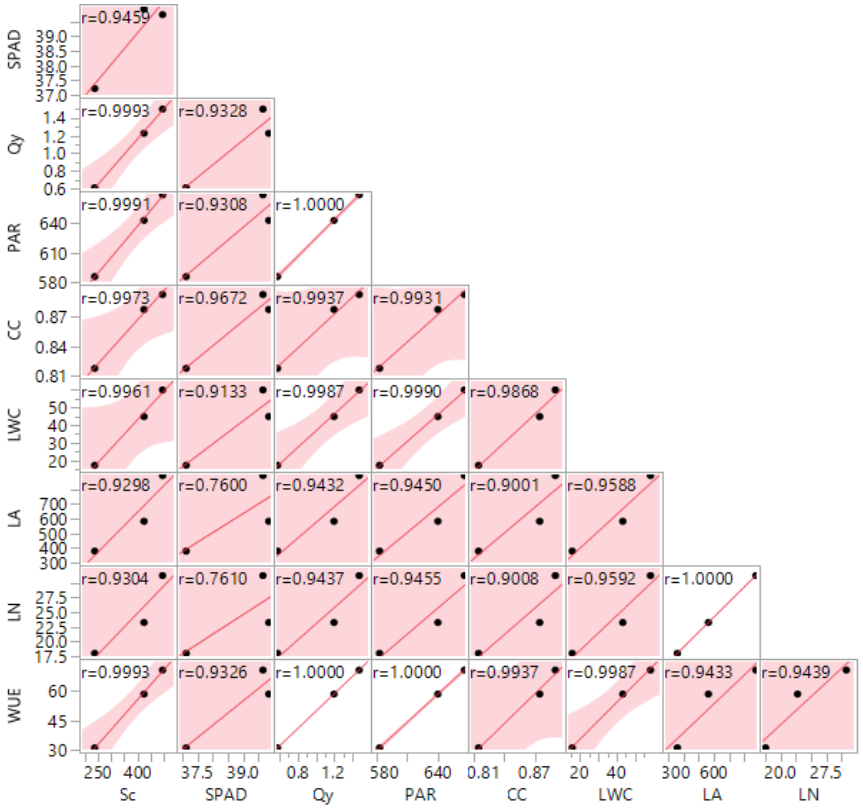

Figure 5. Pearson's correlation matrix of WUE and LN, LA, LWC, CC PAR, Qy, SPAD measured in the drought treatments (WUE: Water use efficiency, LUE: Light use efficiency, LN: Leaf number, LA: Leaf area, LWC: Leaf water content, CC: Chlorophyll concentration, PAR: Photosynthetically active radiation, Qy: Photosynthetic quantum yield, SPAD: Total chlorophyll content, Sc: Stomatal conductance)

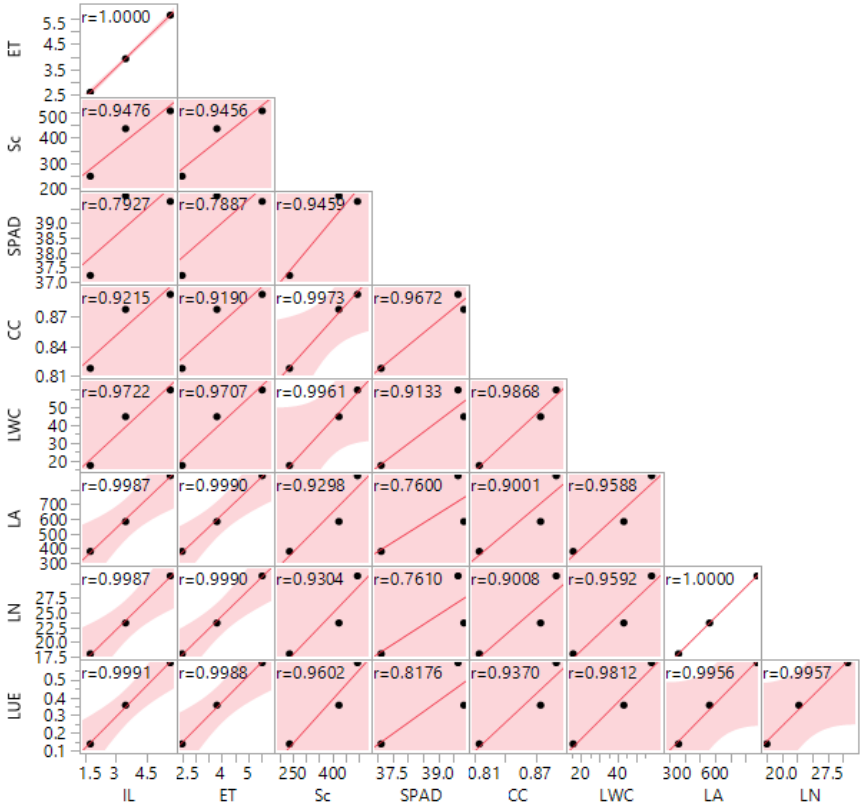

Figure 6. Pearson's correlation matrix of LUE and LN, LA, LWC, CC, SPAD, Sc, ET measured in the drought treatments (LUE: Light use efficiency, LN: Leaf number, LA: Leaf area, LWC: Leaf water content, CC: Chlorophyll concentration, SPAD: Total chlorophyll content, Sc: Stomatal conductance, ET: Crop water use, IL: Irrigation level)

Table 2. The best-fit non-linear models of water use efficiency (WUE = fruit weight/ET) and light use efficiency (LUE = fruit weight/PAR) as a function of the best individual predictors based on the Pearson's correlation matrix analysis ($r^2 \approx 1$)

Response	Predictor	Parameter	Estimate	Prediction model	BIC
WUE	LWC	*a* = growth rate	0.0459	$\frac{c}{(1+\exp(-a*(LWC-b)))}$	-162.1
		b = inflection point	31.0096		
		c = asymptote	89.4496		
	PAR	*a* = asymptote	89.3603	$a*(1-\exp\left(-\left(\left(\frac{PAR}{b}\right)^{c}\right)\right))$	-179.1
		b = inflection point	639.0374		
		c = growth rate	9.7769		
	Qy	*a* = area under curve	-141.8424	$\left(\frac{(a*b*c)}{c-b}\right)*\left(exp(-b*Qy)-exp(-c*Qy)\right)$	-152.6
		b = elimination rate	-0.4379		
		c = absorption rate	0.9214		
	Sc	*a* = asymptote	-64.2371	$a*\left(1-b*exp(-c*Sc)\right)$	-141.6
		b = scale	1.0630		
		c = growth rate	-0.0013		
LUE	ET	*a* = intercept	-0.3755	$a+b*ET+c*ET^2$	-179.3
		b = slope	0.2197		
		c = quadratic	-0.0084		
	IL	*a* = growth rate	0.8507	$\frac{c}{\left(1+exp\left(-a*(IL-b)\right)\right)}$	-206.6
		b = inflection point	3.5092		
		c = asymptote	0.6811		

WUE: Water use efficiency, LUE: Light use efficiency, LWC: Leaf water content, PAR: Photosynthetically active radiation, Qy: Photosynthetic quantum yield, Sc: Stomatal conductance, ET: Crop water use, IL: Irrigation level

4. Conclusion

Our results showed that the cultivar of 'Camarosa' was drought sensitive related to literature in terms of both physiological and yield parameters. Farmers in semi-arid regions should adopt drought-tolerant varieties, varieties with the highest WUE, an appropriate irrigation schedule, or the best management practices that enhance WUE, based on our results.

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HortiS 37(2):123-133
http://doi.org/10.16882/HortiS.810011

RESEARCH PAPER

HORTICULTURAL STUDIES

Effect of Irrigation Waters in Different Salinity Levels on Crop Yield and Energy Use in Greenhouse Tomato Production in Turkey: A Case Study in Kırklareli Province

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Article History
Received 17 August 2020
Accepted 05 October 2020
First Online 15 October 2020

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Keywords
Energy use efficiency
Greenhouse
Irrigation
Salinity
Tomato

Abstract

This study was carried out in a quonset type plastic covered unheated greenhouse on the lands of Atatürk Soil Water and Agricultural Meteorology Institute in Kırklareli, Turkey. In the study, the effect of different salinity and irrigation water levels which were applied to tomato plant, irrigated by drip irrigation in greenhouse, on yield and energy use efficiency was evaluated and the optimum irrigation application was determined. In the study, 'Swanson F1' type tomato was grown as plant material. The trial was carried out on 36 plots with three replications according to split plots experimental design and four different irrigation water salinity levels were on main plots and three irrigation levels were on sub plots. The best result was obtained from T_1S_2 subject in terms of yield and energy use efficiency. The average yield was determined as 109 060 kg ha^{-1} and energy output/input ratio, energy productivity and specific energy were found as 1.51, 1.89 kg MJ^{-1} and 0.53 MJ kg^{-1} in T_1S_2 subject, respectively. It was concluded that the optimum method should be on low salinity level and the irrigation water application should be on the level in order to bring the current moisture level to the field capacity.

1. Introduction

Irrigated farming has an important role in the compensation of food requirement of rapidly increasing World population besides modern agriculture techniques. Nevertheless, domestic and industrial purposeful water usage gradually increases with the increase of population and industry and a great competition occurs with the agricultural purposeful water usage (Ul, 2007). On the other hand, supply of qualified irrigation water from nature becomes difficult day by day against the deterioration of the water in terms of qualification and quantity, environment pollution and climate changes (Atay, 2006). Nowadays, the quality of the irrigation water constitutes a significant problem as the provision of the adequate water. Considering the decrease of the water against the uncontrolled increase of the world population and the water share problem, the usage of low quality waters in the agricultural irrigation will be an essential requirement in the compensation of the increasing requirement.

Considering that the agricultural areas are restricted and the food requirement increases in the world, productive usage of the current areas becomes obligatory. Providing the sufficient irrigation water in the agricultural areas becomes difficult day by day. Especially in the arid and semi-arid regions, decrease and pollution of the natural sources for irrigated farming, being obliged to make irrigation with low qualified irrigation water generally cause the salinization of the agricultural areas. Irrigation water and soil salinity effect the development of the plants negatively and reduces the quality of the crop significantly. Researches are conducted in order to make harmless farming in the soil and the plant by using saline water in the world.

All the cultivated plants are sensitive against salinity at a certain level. A continuous decrease in the yield occurs by the increase of the salinity. Especially in the vegetables, determination of the changes in plant characteristics, yield and quality and the salinity in the agricultural areas is quite significant in case of the usage of the low quality waters.

Tomato which is a fibroid and lycopene rich plant and a quite delicious vegetable, has an important role in our country economy due to the diversely consumption and processing. It is one of the significant income sources of the farmers in the cultivated regions. In Turkey, the most produced and consumed crop is tomato in raw vegetable production. Tomato is grown in a wide range of climate zone and it is not a selective plant in terms of soil requests. It shows an intermediate precision against soil salinity and the fruit yield decreases when the electrical conductivity is over 2.5 dS m^{-1} (Tülücü, 2003). Tomato plant can be used as a model plant in the improvement of the saline areas and the usage of the bad qualified waters due to the rich information existence about its physiology and genetics (Cuartero and Fernandez-Munoz, 1999).

Greenhouse farming enables the marginal evaluation of the small areas by providing the obtainment of high amounts of yields from unit area and besides it is one of the most significant agricultural activities due to the regular labor usage in Turkey (Sevgican et al., 1990). Greenhouse farming increases rapidly as it is obtained more income when compared with open field farming.

Greenhouse farming is a new agricultural activity in Thrace Region and it rapidly increases due to the big consumption center, İstanbul, in the region. On the other hand, the limited water sources and the threatening of these sources in terms of quality and quantity by the rapidly and unplanned developing industry, restrict the amount and quality of the waters. It was observed that the quality of the waters decreased and the salt ratios increased of in the region.

Tomato, cucumber, pepper and eggplant farming are done in the ratios of 51%, 20.2%, 17.3% and 8.6%, respectively in greenhouse conditions in Turkey. In the remaining area with the ratio of 2.9%, the vegetable kinds such as melon, bean and squash are grown (Anonymous, 2018a). In Turkey, 5.9 million tons of vegetables constitute the total of 6.1 million tons of greenhouse production. Total greenhouse existence is 59 900 ha and 31 700 ha (53%) of this is composed of high systems. Turkey takes place in the first four countries in the world and is placed on the top with Spain in Europe in terms of greenhouse existence. In the last ten years, greenhouse land size reached to 0.4 ha from 0.2 ha in Turkey (Anonymous, 2018b). According to 2018 year data of Turkish Statistical Institute, total of 3 888 555 tons of tomato production occurred in 28 081 ha area in Turkey and total of 5 838 tons of tomato production occurred in 13.8 ha area in Thrace Region.

Energy use efficiency continuously decreases in spite of the increase of the energy consumption in order to increase the productivity in the agriculture in Turkey. Further to that, efficient energy usage is required in order to conduct a sustainable farming, decrease the air pollution, decrease the usage of the fossil fuels and provide the economic achievements. For this reason, the researchers concentrated on the energy analysis on different agricultural production areas for the planning of the sources in the ecosystem (Ekinci et al., 2005). Several studies were conducted in order to determine the energy use efficiency in vegetable production and evaluate the environmental effects in open field and greenhouse conditions, such as tomato (Hatırlı et al., 2006; Çetin and Vardar, 2008; Pashaee et al., 2008; Mihov and Tringovska, 2010; Rezvani Moghaddam et al., 2011; Jadidi et al., 2012; Bilalis et al., 2013; Sepat et al., 2013; Taki et al., 2013; Sabaghi and Masihi, 2014; Dimitrijević et al., 2015; Mirasi et al., 2015), tomato, cucumber, pepper, eggplant (Özkan et al., 2004; Çanakçı and Akıncı, 2006), lettuce, clover and broad bean (Razavinia et al., 2015), tomato and cucumber (Taki et al., 2012), basil (Pahlavan et al., 2012), cucumber (Mohammadi and Omid, 2010; Monjezi et al., 2011; Pahlavan et al., 2011; Darijani et al., 2012; Yousefi et al., 2012; Sami and Reyhani, 2015), onion, tomato, sweet pepper, hot pepper (İbrahim, 2011), potato (Mohammadi et al., 2008), tomato, melon, water melon (Çanakçı et al., 2005), lettuce (Dimitrijević et al., 2010), tomato, pepper and lettuce (Kuswardhani et al., 2013), water melon and melon (Baran and Gökdoğan, 2014).

In this study, the effects of irrigation waters in different irrigation levels of tomato crop irrigated by drip irrigation under greenhouse conditions in Kırklareli province on crop yield and energy use were evaluated and the optimal irrigation application was determined.

2. Material and Method

2.1. Material

The study was carried out between 2014 and 2016 in the quonset type plastic covered unheated greenhouse which had an area of 608 m^2 (76 m × 8 m) on the lands of Atatürk Soil Water and Agricultural Meteorology Research Institute located 4 km west of Kırklareli province. Kırklareli province is located within 41°42' North latitude and 27°14' east longitude and total surface area of the province is 655 036 ha.

In the study, "Swanson F1" variety of tomato (*Lycopersicon esculentum*) was used as the plant material. The fruits of Swanson F1 tomato variety's shelf life is long. It is an appropriate variety for open

field tomato farming and greenhouse farming in Thrace Regions. The fruits of this variety are round and 180-190 g.

2.2. Method

The experiment was carried out according to split plot design with three replications. The four different irrigation salinities (T_1: Dam water, ECw: 0.38 dS m^{-1}, T_2: Well water, ECw: 1.1 dS m^{-1}, T_3: ECw: 2.5 dS m^{-1}, and T_4: ECw: 5.0 dS m^{-1}) were the main plots and the three irrigation levels (S_1: Irrigation water application on the level of 70% of the field capacity on the current moisture level in the profile, S_2: Irrigation water application on the level of bringing the current moisture in the profile to the field capacity, and S_3: Irrigation water application more than 30% of the field capacity on the current moisture level in the profile)were the sub plots of the experiment and the experiment was carried out in total of 36 plots for three years. The planting of the tomato plant was done as 0.8 m inter-row and 0.5 m intra-row (Planting: 3.2 × 3.0 = 9.6 m^2, Harvesting: 2.0 × 1.6 = 3.2 m^2). Between the plots, there was a 1 m of interspace.

The irrigation water used in the experiment was obtained from the deep well within the institute land borders and Kırklareli Dam. The T_3 and T_4 subjects, which were created as artificial, were created by adding in different ratios of salts in 5 tons of tanks. Some chemical characteristics of the irrigation waters and the irrigation water classes are given in Table 1. The salts which were used in order to create the T_3 and T_4 subjects and the amounts are given in Table 2.

The amounts of the inputs used in tomato production (human labor, machinery, diesel, pesticides, fertilizers, electricity, irrigation water, seed and farmyard manure) and the output (yield) were calculated per hectare in order to calculate the energy equivalents. Then, these values were multiplied by the energy equivalent coefficients (Table 3). Energy equivalents of the inputs and outputs for greenhouse tomato production were obtained from the previous studies. Energy equivalents of the inputs and the outputs were expressed in mega joule (MJ). The calculations were done according to the averages of three years data for all the main and the sub plots.

Following the calculation of energy input and output equivalents, the energy use efficiency, energy productivity, specific energy and net energy were calculated according to the following formulas (Mandal et al., 2002).

$$\text{Energy use efficiency}=\frac{\text{Energy output(MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}$$

$$\text{Energy productivity}=\frac{\text{Tomato production (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})}$$

$$\text{Specific energy}=\frac{\text{Energy input (MJ ha}^{-1})}{\text{Tomato production (kg ha}^{-1})}$$

$$\text{Net energy}=\text{Energy output} - \text{Energy input}$$

The energy inputs were examined in direct, indirect, renewable and non-renewable forms. The direct energy includes human labor, diesel fuel, irrigation water and electricity. The indirect energy consists of pesticides, fertilizers, farmyard manure, seed and machinery. On the other hand, renewable energy includes human labor, farmyard manure, seed and irrigation water whereas non-renewable energy consists of diesel fuel, fertilizers, pesticides, machinery and electricity (Yılmaz et al., 2010).

The data of the tomato yield were subjected to variance analysis and evaluated. The statistical evaluations were done by using JMP package program. The evaluations were done on 0.01 and 0.05 significance levels and the significant subjects were subjected to LSD test.

3. Results and Discussion

3.1. Yield

Ten harvestings were done between 12 July and 16 September in 2014 which was the first year of the research, 10 harvestings were done between 9 July and 9 September in the second year and 9 harvestings were done between 1 July and 29 August in the third year. The yield values are given

Table 1. Characteristics of the irrigation waters

	pH	EC (dS m^{-1})	Na	K	Ca + Mg	Cl	SO_4	Irrigation water class*
			meL^{-1}					
T_1	7.58	0.38	0.45	0.07	2.94	0.25	0.23	C_2S_1
T_2	7.30	1.10	2.25	0.20	8.93	2.50	0.89	C_3S_1
T_3	7.22	2.50	5.07	0.37	21.83	17.50	2.33	C_4S_1
T_4	7.30	5.00	5.42	0.59	40.56	30.00	3.57	C_4S_1

*Irrigation waters were classified according to ABD system

Table 2. Salts and the amounts used in T_3 and T_4 subjects (g L^{-1})

EC (electrical conductivity)	SAR (sodium absorption ratio)	NaCl	$MgSO_4$	$CaCl_2$
2500	0.69	0.14	0.22	1.14
5000	0.56	0.16	0.27	2.47

in Table 4. The highest yield was obtained from T_1S_2 subject with the value of 109 430 kg ha^{-1} and the lowest yield was obtained from T_4S_1 subject with the value of 67 600 kg ha^{-1} in 2014. In the second year, the highest yield was obtained from T_1S_2 subject with the value of 108 680 kg ha^{-1} and the lowest yield was obtained from T_4S_1 subject with the value of 46 820 kg ha^{-1}. Similarly, in 2016, the highest and the lowest values were obtained from T_1S_2 and T_4S_1 subjects with the values of 109 070 kg ha^{-1} and 54 070 kg ha^{-1}, respectively.

According to the analyses which the three year data were evaluated separately and collectively, it was determined that the yield was effected from irrigation water levels ($P<0.01$). In S_2 and S_3 irrigations, the differences between the yields was not statistically significant and the yield was low in S_1 irrigation level. According to the collective variance analysis, the yield amounts were 91 700 and 93 423 kg ha^{-1} in S_2 and S_3 irrigations and the yield amount was lower and determined as 64 913 kg ha^{-1} in S_1 irrigation.

According to the analyses which the three year data were evaluated separately and collectively, it was determined that the salinity of the irrigation water effected the yield ($P<0.01$) (Table 4). In the first year of the experiment, it was determined that the yield decreased as the irrigation water salinity increased but the differences between the yield amounts in T_3 and T_4 salinity levels were not statistically significant ($P>0.01$). In the second year, the effect of the irrigation water salinity on the yield was different from the first year and the differences between the yield amounts of the plants irrigated by the waters on T_1, T_2, T_3 and T_4 salinity levels were not statistically significant ($P>0.01$). In the third year, the yields of the plants irrigated by the waters on T_1 and T_2 salinity levels were in a group whereas the yields of the plants irrigated by the waters on T_3 and T_4 salinity levels were in another group.

Table 3. Energy equivalents of inputs and outputs in greenhouse production

	Energy equivalents(MJ unit^{-1})	References
Inputs		
Human labor (h)	1.96	(De et al., 2001; Singh, 2002)
Machinery (h)	64.80	(Singh, 2002; Baran et al., 2016)
Pesticides (kg)		
Insecticide	101.20	(Rafiee et al., 2010)
Fungicide	216.00	(Rafiee et al., 2010)
Fertilizer (kg)		
Nitrogen	60.60	(Singh, 2002)
Phosphorus	11.15	(Singh, 2002)
Potassium	6.70	(Singh, 2002)
Micro	120.00	(Çanakçı and Akıncı, 2006)
Farmyard manure (t)	303.10	(Yaldız et al., 1993)
Seed	2.36	(Mihov and Antonova, 2009)
Diesel (l)	56.31	(De et al., 2001; Singh, 2002)
Electricity (kWh)	3.60	(Yaldız et al., 1993)
Irrigation water (m^3)	0.63	(Yaldız et al., 1993)
Output		
Yield (kg)	0.80	(Yaldız et al., 1993)

Table 4. Effect of irrigation water salinity and irrigation levels on tomato yield in three growing period (kg ha^{-1})

Growing period	Irrigation water level	Irrigation water salinity				
		T_1	T_2	T_3	T_4	Average
2014	S_1	81110	74340	68650	67600	72925 B
	S_2	109430	98860	83810	76540	92160 A
	S_3	101770	93380	85650	86350	91788 A
	Average	97437 A	88860 B	79370 C	76830 C	
2015	S_1	70310	71130	66310	46820	63643 B
	S_2	108680	105040	89000	64780	91875 A
	S_3	102520	104120	103760	81400	97950 A
	Average	93837 A	93430 A	86357 A	64333 B	
2016	S_1	60650	60460	57500	54070	58170 B
	S_2	109070	107410	75830	71940	91063 A
	S_3	101300	100000	86200	78330	91458 A
	Average	90340 A	89290 A	73177 B	68113 B	
Average of the years	S_1	70690	68650	64150	56160	64913 B
	S_2	109060	103770	82880	71090	91700 A
	S_3	101860	99170	91870	80790	93423 A
	Average	93870 A	90530 A	79633 B	69347 C	

S_1=70%, S_2=100%, S_3=130%, T_1=0.38 dS m^{-1}, T_2=1.1 dS m^{-1}, T_3=2.5 dS m^{-1} T_4=5.0 dS m^{-1}, CV 9.5%

On the evaluation of the three years data together, it was concluded that the yield amounts decreased by the increase of the irrigation water salinity but there were not differences between the yields obtained on T_1 and T_2 salinity levels. In previous studies, Restuccia et al. (2002) obtained the highest yield from ET=100%+irrigation water with 1.6 dS m^{-1} salinity level in tomato production irrigated with the waters on 1.6 dS m^{-1} and 6.00 dS m^{-1} salinity levels in unheated plastic covered greenhouse. In another study, Pascale et al. (2003) stated that it was possible to improve carotenoids and ascorbic acid contents and antioxidant activity of tomato, with an acceptable yield reduction (10%), by irrigating with saline water containing sea salt up to 4.4 dS m^{-1} and also they stated that the fruit nutritive value of tomato could be increased by the irrigations with saline irrigation waters. According to Yaylalı (2007), the yield amounts decreased on the ratio of 41% by the increase of the salinity in the irrigation water (between 0.5 and 2.5 dS m^{-1}). According to many researches (Lopez and Satti, 1996; Maas and Grattan, 1999; Kesmez, 2003; Abdel Gawad et al., 2005), it was concluded that the yield amounts in tomato plant decreased by the increase of irrigation water salinity.

When the results were evaluated in terms of irrigation water levels, it was determined that S_1 application in all salinity level subjects caused decreases in the yield amounts. S_2 irrigation application became prominent in T_1 and T_2 subjects in terms of yield whereas the yield amounts in T_3 and T_4 subjects. The yield amounts were higher in T_1 and T_2 subjects in S_3 irrigation level in accordance with S_1 and S_2 irrigation levels.

There were not significant losses in the yield amounts under the T_3 salinity levels in S_2 irrigation level but the yield amounts decreased when the irrigation level was increased to S_3 in these salinity levels. On the other hand, the yield amounts increased with S_3 irrigation on the salinity level of T_3 and above. Similarly, Flowers et al. (2010) stated that the salinity levels under T_3 did not affect the yield amounts and the additional irrigation in high salinity levels had a curative effect on the yield.

3.2. Input and energy use

The amounts of the inputs used in T_1 and T_2 subjects by sub subjects in greenhouse tomato production are given in Table 5. As seen in Table 5, 7 267 h human labor, 10.50 h machinery, 25.30 L diesel fuel, 25 t farmyard manure, 352.50 kg nitrogen, 122.50 kg phosphorus, 650.20 kg potassium, 9.10 kg insecticides, 4.10 kg fungicides and 11.00 kg seed per hectare were used for tomato production in T_1 and T_2 subjects. Besides, 2 400 m^3 water and 520.20 kWh electricity were used in S_1 irrigation level, 3 340 m^3 water and 740.60 kWh electricity were used in S_2 irrigation level and 4 290 m^3 water and 951.20 kWh electricity were used in S_3 irrigation level.

The amounts of the inputs used in T_3 and T_4 subjects by sub subjects in greenhouse tomato production are given in Table 6 and Table 7, respectively. In T_3 and T_4 subjects, the input amounts used per hectare in S_1, S_2 and S_3 irrigation levels were the same as the input amounts in T_1 and T_2 subjects and differently, micronutrient elements were used in T_3 and T_4 subjects. In T_3 subject, 3.33 kg, 4.59 kg and 6.22 kg micronutrient element application per hectare was done in S_1, S_2 and S_3 irrigation levels whereas in T_4 subject, 7.17 kg, 10.06 kg and 12.78 kg micronutrient element application per hectare was done in S_1, S_2 and S_3 irrigation levels, respectively.

The energy equivalents of the inputs used in T_1 and T_2 subjects are given in Table 8, the energy equivalents of the inputs used in T_3 subject are given in Table 9 and the energy equivalents of the inputs used in T_4 subject are given in Table 10. In all subjects, the energy equivalents of the inputs were calculated as 14 243.32 MJ human labor,

Table 5. Use of inputs in T_1 and T_2 subjects for greenhouse tomato production

Inputs	T_1S_1-T_2S_1	T_1S_2-T_2S_2	T_1S_3-T_2S_3
Human labor (h)	7267.00	7267.00	7267.00
Machinery (h)	10.50	10.50	10.50
Diesel (L)	25.30	25.30	25.30
Farmyard manure (t)	25.00	25.00	25.00
Fertilizer (kg)			
Nitrogen	352.50	352.50	352.50
Phosphorus	122.50	122.50	122.50
Potassium	650.20	650.20	650.20
Micro	0.00	0.00	0.00
Pesticides (kg)			
Insecticide	9.10	9.10	9.10
Fungicide	4.10	4.10	4.10
Water (m^3)	2400.00	3340.00	4290.00
Electricity (kWh)	520.20	740.60	951.20
Seed (kg)	11.00	11.00	11.00

S_1=70%, S_2=100%, S_3=130%, T_1=0.38 dS m^{-1}, T_2=1.1 dS m^{-1}, T3=2.5 dS m^{-1}

Table 6. Use of inputs in T_3 subject for greenhouse tomato production

Inputs	T_3S_1	T_3S_2	T_3S_3
Human labor (h)	7267.00	7267.00	7267.00
Machinery (h)	10.50	10.50	10.50
Diesel (L)	25.30	25.30	25.30
Farmyard manure (t)	25.00	25.00	25.00
Fertilizer (kg)			
Nitrogen	352.50	352.50	352.50
Phosphorus	122.50	122.50	122.50
Potassium	650.20	650.20	650.20
Micro	3.33	4.59	6.22
Pesticides (kg)			
Insecticide	9.10	9.10	9.10
Fungicide	4.10	4.10	4.10
Water (m^3)	2400.00	3340.00	4290.00
Electricity (kWh)	520.20	740.60	951.20
Seed (kg)	11.00	11.00	11.00

S_1=70%, S_2=100%, S_3=130%, T_3=2.5 dS m^{-1}

Table 7. Use of inputs in T4 subject for greenhouse tomato production

Inputs	T_4S_1	T_4S_2	T_4S_3
Human labor (h)	7267.00	7267.00	7267.00
Machinery (h)	10.50	10.50	10.50
Diesel (L)	25.30	25.30	25.30
Farmyard manure (t)	25.00	25.00	25.00
Fertilizer (kg)			
Nitrogen	352.50	352.50	352.50
Phosphorus	122.50	122.50	122.50
Potassium	650.20	650.20	650.20
Micro	7.17	10.06	12.78
Pesticides (kg)			
Insecticide	9.10	9.10	9.10
Fungicide	4.10	4.10	4.10
Water (m^3)	2400.00	3340.00	4290.00
Electricity (kWh)	520.20	740.60	951.20
Seed (kg)	11.00	11.00	11.00

S_1=70%, S_2=100%, S_3=130%, T_3=2.5 dS m^{-1} T_4=5.0 dS m^{-1}

680.40 MJ machinery, 1 424.64 MJ diesel, 7 577.50 MJ farmyard manure, 21 361.50 MJ nitrogen, 1365.88 MJ phosphorus, 4 356.34 MJ potassium, 920.92 MJ insecticide, 885.60 MJ fungicide and 25.96 MJ seed per hectare. In all subjects, 1 512 MJ water and 1 872.72 MJ electricity was used in S_1 irrigation level, 2 104.20 MJ water and 2 666.16 MJ electricity was used in S_2 irrigation level and 2 702.70 MJ water and 3 424.32 MJ electricity was used in S_3 irrigation level, The energy equivalents of micronutrient elements were determined as 399.84 MJ in S_1 irrigation level, 550.80 MJ in S_2 irrigation level and 745.92 MJ in S_3 irrigation level in T_3 subject whereas they were determined as 860.44 MJ, 1 206.70 MJ and 1 534.03 MJ in S_1, S_2 and S_3 irrigation levels in T_4 subject, respectively (Table 8, 9, 10).

When all the main and sub subjects were examined, it was determined that nitrogen consumed the most energy use in green house tomato production, followed by human labor and farmyard manure.

The output values of greenhouse tomato production and the energy equivalents by the main and sub subjects are given in Table 11. Based on the energy outputs, it was noticed that the highest energy outputs in greenhouse tomato production were obtained from T_1S_2, T_2S_2 and T_1S_3 subjects with the values as 87 248, 83 016, and 81 488 MJ, respectively. The lowest energy outputs were obtained from T_4S_1, T_3S_1, T_2S_1 and T_1S_1 subjects. It was determined that the energy equivalents of the yield were lower in S_1 irrigation application.

The energy parameters by the main and sub plots are given in Table 12. Energy use efficiency was found as 1.01, 1.51, and 1.38 in T_1 subject in S_1, S_2 and S_3 irrigation levels, respectively. Energy productivity points out the crop quantity per energy use and it was calculated as 1.26, 1.89, and 1.73 kg MJ^{-1} in T_1 subject in S_1, S_2 and S_3 irrigation levels, respectively. Specific energy points out the used energy quantity per crop and this coefficient was found as 0.80, 0.53, and 0.58 MJ kg^{-1} in T_1 subject in S_1, S_2 and S_3 irrigation levels, respectively. Net energy points out the difference

Table 8. Energy equivalents in T_1 and T_2 subjects for greenhouse tomato production (MJ ha^{-1})

Inputs	T_1S_1-T_2S_1		T_1S_2-T_2S_2		T_1S_3-T_2S_3	
	Energy equivalent	%	Energy equivalent	%	Energy equivalent	%
Human labor (h)	14243.32	25.33	14243.32	24.72	14243.32	24.15
Machinery (h)	680.40	1.21	680.40	1.18	680.40	1.15
Diesel (L)	1424.64	2.53	1424.64	2.47	1424.64	2.42
Farmyard manure (t)	7577.50	13.48	7577.50	13.15	7577.50	12.85
Fertilizer (kg)						
Nitrogen	21361.50	37.99	21361.50	37.08	21361.50	36.22
Phosphorus	1365.88	2.43	1365.88	2.37	1365.88	2.32
Potassium	4356.34	7.75	4356.34	7.56	4356.34	7.39
Micro	0.00	0.00	0.00	0.00	0.00	0.00
Pesticides (kg)						
Insecticide	920.92	1.64	920.92	1.60	920.92	1.56
Fungicide	885.60	1.58	885.60	1.54	885.60	1.50
Water (m^3)	1512.00	2.69	2104.20	3.65	2702.70	4.58
Electricity (kWh)	1872.72	3.33	2666.16	4.63	3424.32	5.81
Seed (kg)	25.96	0.05	25.96	0.05	25.96	0.04
Total energy input	56226.78	100.00	57612.42	100.00	58969.08	100.00

S_1=70%, S_2=100%, S_3=130%, T_1=0.38 dS m^{-1}, T_2=1.1 dS m^{-1}, T_3=2.5 dS m^{-1}

Table 9. Energy equivalents in T3 subject for greenhouse tomato production (MJ ha^{-1})

Inputs	T_3S_1		T_3S_2		T_3S_3	
	Energy equivalent	%	Energy equivalent	%	Energy equivalent	%
Human labor (h)	14243.32	25.15	14243.32	24.49	14243.32	23.85
Machinery (h)	680.40	1.20	680.40	1.17	680.40	1.14
Diesel (L)	1424.64	2.52	1424.64	2.45	1424.64	2.39
Farmyard manure (t)	7577.50	13.38	7577.50	13.03	7577.50	12.69
Fertilizer (kg)						
Nitrogen	21361.50	37.72	21361.50	36.73	21361.50	35.77
Phosphorus	1365.88	2.41	1365.88	2.35	1365.88	2.29
Potassium	4356.34	7.69	4356.34	7.49	4356.34	7.30
Micro	399.84	0.71	550.80	0.95	745.92	1.25
Pesticides (kg)						
Insecticide	920.92	1.63	920.92	1.58	920.92	1.54
Fungicide	885.60	1.56	885.60	1.52	885.60	1.48
Water (m^3)	1512.00	2.67	2104.20	3.62	2702.70	4.53
Electricity (kWh)	1872.72	3.31	2666.16	4.58	3424.32	5.73
Seed (kg)	25.96	0.05	25.96	0.04	25.96	0.04
Total energy input	56626.62	100.00	58163.22	100.00	59715.00	100.00

S_1=70%, S_2=100%, S_3=130%, T_3=2.5 dS m^{-1}

Table 10. Energy equivalents in T_4 subject for greenhouse tomato production (MJ ha^{-1})

Inputs	T_4S_1		T_4S_2		T_4S_3	
	Energy equivalent	%	Energy equivalent	%	Energy equivalent	%
Human labor (h)	14243.32	24.95	14243.32	24.22	14243.32	23.54
Machinery (h)	680.40	1.19	680.40	1.16	680.40	1.12
Diesel (L)	1424.64	2.50	1424.64	2.42	1424.64	2.35
Farmyard manure (t)	7577.50	13.27	7577.50	12.88	7577.50	12.52
Fertilizer (kg)						
Nitrogen	21361.50	37.42	21361.50	36.32	21361.50	35.31
Phosphorus	1365.88	2.39	1365.88	2.32	1365.88	2.26
Potassium	4356.34	7.63	4356.34	7.41	4356.34	7.20
Micro	860.44	1.51	1206.70	2.05	1534.03	2.54
Pesticides (kg)						
Insecticide	920.92	1.61	920.92	1.57	920.92	1.52
Fungicide	885.60	1.55	885.60	1.51	885.60	1.46
Water (m^3)	1512.00	2.65	2104.20	3.58	2702.70	4.47
Electricity (kWh)	1872.72	3.28	2666.16	4.53	3424.32	5.66
Seed (kg)	25.96	0.05	25.96	0.04	25.96	0.04
Total energy input	57087.21	100.00	58819.11	100.00	60503.11	100.00

S_1=70%, S_2=100%, S_3=130%, T_3=2.5 dS m^{-1} T_4=5.0 dS m^{-1}

Table 11. Yield (output) amounts and energy equivalents in greenhouse tomato production

Subjects	S_1		S_2		S_3	
	Yield (kg ha^{-1})	Energy equivalent (MJ ha^{-1})	Yield (kg ha^{-1})	Energy equivalent (MJ ha^{-1})	Yield (kg ha^{-1})	Energy equivalent (MJ ha^{-1})
T_1	70690.00	56552.00	109060.00	87248.00	101860.00	81488.00
T_2	68650.00	54920.00	103770.00	83016.00	99170.00	79336.00
T_3	64150.00	51320.00	82880.00	66304.00	91870.00	73496.00
T_4	56160.00	44928.00	71090.00	56872.00	80790.00	64632.00

S_1=70%, S_2=100%, S_3=130%, T_1=0.38 dS m^{-1}, T_2=1.1 dS m^{-1}, T_3=2.5 dS m^{-1} T_4=5.0 dS m^{-1}

Table 12. Energy parameters in greenhouse tomato production

Subjects	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})	Net energy (MJ ha^{-1})
T_1S_1	1.01	1.26	0.80	325.22
T_1S_2	1.51	1.89	0.53	29635.58
T_1S_3	1.38	1.73	0.58	22518.92
T_2S_1	0.98	1.22	0.82	-1306.78
T_2S_2	1.44	1.80	0.56	25403.58
T_2S_3	1.35	1.68	0.59	20366.92
T_3S_1	0.91	1.13	0.88	-5306.62
T_3S_2	1.14	1.42	0.70	8140.78
T_3S_3	1.23	1.54	0.65	13781.00
T_4S_1	0.79	0.98	1.02	-12159.21
T_4S_2	0.97	1.21	0.83	-1947.11
T_4S_3	1.07	1.34	0.75	4128.89

S_1=70%, S_2=100%, S_3=130%, T_1=0.38 dS m^{-1}, T_2=1.1 dS m^{-1}, T_3=2.5 dS m^{-1} T_4=5.0 dS m^{-1}

between the used energy and the output energy. Net energy was calculated as 325.22, 29 635.58, and 22 518.92 MJ ha^{-1} in T_1S_1, T_1S_2 and T_1S_3 subjects, respectively.

Energy use efficiency was found as 0.98, 1.44, and 1.35 in T_2 subject in S_1, S_2 and S_3 irrigation levels, respectively. Energy productivity was calculated as 1.22, 1.80, and 1.68 kg MJ^{-1} in T_2 subject in S_1, S_2 and S_3 irrigation levels, respectively. Specific energy was found as 0.82, 0.56, and 0.59 MJ kg^{-1} in T_2 subject in S_1, S_2 and S_3 irrigation levels, respectively. Net energy was calculated as -1 306.78, 25 403.58, and 20 366.92 MJ ha^{-1} in T_2S_1, T_2S_2 and T_2S_3 subjects, respectively.

Energy use efficiency was found as 0.91, 1.14, and 1.23 in T_3 subject in S_1, S_2 and S_3 irrigation levels, respectively. Energy productivity was calculated as 1.13,, 1.42, and 1.54 kg MJ^{-1} in T_3 subject in S_1, S_2 and S_3 irrigation levels, respectively. Specific energy was found as 0.88, 0.70, and 0.65 MJ kg^{-1} in T_3 subject in S_1, S_2 and S_3 irrigation levels, respectively. Net energy was calculated as -5 306.62, 8 140.78, and 13 781 MJ ha^{-1} in T_3S_1, T_3S_2 and T_3S_3 subjects, respectively.

Energy use efficiency was found as 0.79, 0.97 and 1.07 in T_4 subject in S_1, S_2 and S_3 irrigation levels, respectively. Energy productivity was calculated as 0.98, 1.21, and 1.34 kg MJ^{-1} in T_4 subject in S_1, S_2 and S_3 irrigation levels, respectively. Specific energy was found as 1.02, 0.83, and 0.75 MJ kg^{-1} in T_4 subject in S_1, S_2 and S_3 irrigation levels, respectively. Net energy was calculated as -12 159.21, -1 947.11, and 4 128.89 MJ ha^{-1} in T_4S_1, T_4S_2 and T_4S_3 subjects, respectively.

The best result was obtained from T_1S_2 subject in terms of energy parameters and T_2S_2, T_1S_3 and T_2S_3 subjects followed this. When evaluated in terms of irrigation water levels, S_1 irrigation level in all salinity level subjects caused decreases in energy use efficiency, energy productivity and net energy and increase in specific energy. The best results were obtained from T_1S_1 subjects within the subjects in which deficient water was applied and the lowest values were obtained from T_4S_1 subject. It was determined that the energy use efficiency decreased as the salinity level increased. Mihov and Tringovska (2010) investigated the effect of different organic fertilizer applications on energy use efficiency of greenhouse tomato farming and they determined the energy use efficiencies as 0.92, 1.19 and 1.11, respectively. They concluded that the best application was 1 L ha^{-1} organic fertilizing application. In previous studies conducted in greenhouse tomato farming, the energy use efficiencies were determined as 1.26 (Özkan et al., 2004), 0.18 (Rezvani Moghaddam et al., 2011), 0.92 (Taki et al., 2012), 0.85 (Kuswardhani et al., 2013), 0.75 (Mirasi et al., 2015), 0.52 (Dimitrijević et al., 2015), 0.92, 1.48 and 0.99 (Shamsabadi et al., 2017) and 0.75 (Yelmen et al., 2019).

The distributions of the inputs according to the direct, indirect, renewable and non-renewable energy groups are given in Table 13. In all subjects, the ratios of direct energy in total energy were determined to be lower than the ratios of indirect energy in total energy. The ratios of the direct energy in total energy were the lowest in S_1 irrigation applications in all salinity level subjects.

Renewable energy sources are non-consumable energy sources and they do not damage the nature. Non-renewable energy sources

are limited and a great majority of these sources damage the nature. In the research area, in all subjects, the ratios of renewable energy in total energy were determined to be lower than the ratios of non-renewable energy in total energy. The ratio of renewable energy in total energy was the lowest in T_4 subject in which the salinity level was the highest.

4. Conclusion

Yield and energy use efficiency of tomato plant grown in green house conditions and irrigated by drip irrigation method in different salinity and water levels were calculated and the optimum irrigation application was determined in the research area. When the three year data were evaluated collectively, it was determined that the yield amounts decreased in the ratios of 3.6%, 15.2% and 26.1% when the irrigation water salinity increased to T_2, T_3, and T_4 from T_1, respectively. The best result was obtained from T_1S_2 subject in terms of yield and energy use efficiency. Energy output/input ratio was found as 1.51 in T_1S_2 subject and it was concluded that the inputs were used efficiently according to the other subjects. Energy output/input ratio was found as 1.44 in T_2S_2 subject and this value was adjacent to the value of T_1S_2 subject. Usage of marginal water in the agriculture is essential as a result of the restricted and polluted water sources in the region. According to the results of this study, the yield amounts and energy use efficiency of T_2S_2 subject were adjacent to T_1S_2 subject even though T_1S_2 subject came to the forefront. This result indicates that T_2 subject, which has T_2 salinity level and appears in the third class (high saline water) can be used in greenhouse farming as the moisture is high and the effect of salt harm is in the minimum level in greenhouses according to the open field farming. Likewise, the salt concentrations of most of the underground and over ground water sources are between 1.0 and 1.5 dS m^{-1} and they take part in the third class in terms of salt criteria.

Acknowledgements

We would like to thank TAGEM (Project Number: TAGEM/TSKAD/14/A13/B02/08) for their financial support to this study.

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HortiS 37(2):134-143
http://doi.org/10.16882/HortiS.823968

RESEARCH PAPER

HORTICULTURAL STUDIES

Effects of Different Rootstocks on Storage Life and Quality of Loquat Fruit (cv. Gold Nugget)

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Article History
Received 14 October 2020
Accepted 10 November 2020
First Online 25 November 2020

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Keywords
Hawthorn
Loquat
Quince
Rootstock
Storage

Abstract

In this study, the effects of rootstocks on storage life and quality in Gold Nugget loquat grafted on quince, hawthorn and loquat rootstocks were investigated. After harvest, fruit were placed in plastic boxes (2 kg) covered with stretch film and stored for 45 days at 5 ± 0.5°C and 90 ± 5% RH. Weight loss, fruit firmness, total soluble solid, titratable acidity, maturity rate, respiration rate, ethylene production, CO_2 and O_2 concentrations in package, skin colour (L*,a*,b*,C*,h°), decay rate and sensory quality of fruit were determined at 15-day intervals during storage. The same analyzes were repeated for shelf life evaluation after keeping fruit 2 days in ambient condition (20°C and 70±5 RH%). Fruit grown on quince rootstock had the best results for maintaining external appearance, titratable acidity, maturation rate and vivid skin colour. The lowest decay rate and respiration rate during storage were also obtained from this combination. Quince and loquat seedling rootstocks had similar results for sensory quality and decay rate. Covering boxes by stretch film (20 µm) reduced the weight loss in the all the combination of scion/rootstock but, increased pathogens development. These findings revealed that fruit, obtained from the combinations of Gold Nugget variety with quince and loquat seedling rootstocks, can be stored with good quality for 30+2 days at 5°C and 90 ± 5 RH%.

1. Introduction

Loquat (*Eriobotrya japonica* Lindl.), belonging to the Rosaceae family, is a subtropical evergreen fruit-tree and originated from south-eastern China. Loquat is grown in the subtropical regions of China, Japan, India and the Mediterranean countries (Zhang et al., 1990; Cuevas et al., 2003; Ferreres et al., 2009; Polat, 2007; Liguori et al., 2017; CABI, 2020). China is the largest loquat producer country in the world with a production of 650 000 tons (Zheng et al., 2019) followed by Spain, Pakistan and Turkey (Caballero and Fernandez, 2003; TUIK, 2019). The chemical composition of fruit and vegetables may vary depending on the ecological conditions, variety, cultural practices, harvest time and post-harvest processes (Cemeroğlu et al., 2001). At the beginning of fruit orchard establishment, the choosing of appropriate rootstock is crucial for fruit quality and storage (Karaçalı, 2002). The Gold Nugget variety, determined by selection studies, is recommended to producers (Tepe, 2013). Bolat and İkinci (2019) have reported that the rootstocks are used for many different purposes, and affect the grafted variety for many characteristics. Seedling rootstock of loquat (*Eriobotrya japonica* Lindl.) is used widely compared to quince (*Cydonia oblonga* Mill.) and hawthorn (*Crataegus oxyacanthus* L.) in Turkey and worldwide (Polat, 1995; García-Legaz, 2010;

Bermede and Polat, 2011; M.de Almeida et al., 2018). There are some studies about the effect of rootstock on salinity stress in loquat but, no study could be found with regard to fruit quality and storage (López-Gómez et al., 2007). Loquat fruit, in general, are consumed in local markets, because it can not be exported to overseas markets due to quality losses during transportation.

Post-harvest losses in fresh fruit and vegetables have become a serious problem in developing countries (Warjuki and Sutrisno, 1998). The quality losses after harvest may be reduced by using appropriate package and storage techniques. The storage period of loquat fruit, depending on their postharvest physiology, is very short in comparison to other fruit species (Tepe, 2013). Cold storage technique is applied to protect fruit quality and offer higher quality products to the consumer (Qui and Zhang, 1996). The temperature is the most important limiting factor for the storage period of fruit. Kahramanoğlu (2020) reported that low temperature (5 to 7ºC) was very important in reducing postharvest losses and extending storage period of loquat. Most tropical and subtropical fruits are extremely sensitive to low temperatures due to chilling injury. Loquat, a subtropical fruit, is also very sensitive to low temperatures. For example, fruit stored at 5°C are of higher quality than those stored at 0°C and moreover, storage at room temperature can reduce the storage life of fruit by up to 6 days. (Lin, et al., 1999; Zheng et al., 2000; Ding et al., 2002; Cai et al., 2006a,b; Song et al, 2016). Therefore, the cold storage of loquat at low-temperatures limit its postharvest quality and life (Cai et al., 2006c; Xua et al., 2012). The controlled atmosphere, modified atmosphere and polyethylene bags give good results for storage of loquat fruit like other fruit species (Ding et al., 1998; Ding et al., 2002; Amorós et al., 2003; Ding et al., 2006). In Turkey, carton boxes are widely used in the storage and marketing of loquats. Moreover, the plastic or foam plates covered with stretch film are also used for loquats in the grocery chain. The studies about the effect of packaging material on the storage of loquat fruit are very limited. As far as we know, there is no detailed study evaluating the effects of rootstocks on the fruit quality and cold storage of loquat. In this study, the effects of different rootstocks on storage life and quality of loquat fruit cv. Gold Nugget were investigated.

2. Material and Method

2.1. Material

This study was carried out with 16 years old Gold Nugget loquat trees grafted on loquat seedlings (*Eriobotrya japonica* Lindl.), quince (*Cydonia oblonga* Mill.) and hawthorn (*Crataegus oxyacanthus* L.) rootstocks in Antalya/Turkey.

2.2. Method

The fruit were picked at optimum harvest time (the greenness of the fruit completely disappeared, which was considered as the mature stage) (Ferreres et al., 2009). Harvested fruits were transferred to laboratory immediately (within one hour), and foreign parts and injured fruits were removed. After homogenization and visual examination, fruit were divided into two lots. The first group was packaged (each containing 25 fruits) in plastic boxes (2 kg) covered with 20 µm thick stretch film (STHF) [O_2 permeability 15300 ± 20%, CO_2 permeability 78000 ± 20%, N_2 permeability 11000 ± 10% ($cm^3\ m^{-2}\ 24hbar^{-1}$) at 38°C and 90% relative humidity]. Second (control) group loquats were placed in same packaging materials without covering STHF. Packaged fruits were stored at 5 C and 90 ± 5% relative humidity (RH) for 45 days (Chong et al., 2006). All treatments and packaging procedures were carried out under sanitary conditions in the laboratory. After cold storage, fruit were kept at 20°C and 70 ± 5% RH for 2 days for shelf-life evaluation. The following chemical and physical analyses were performed at 15-day intervals during cold storage and shelf life.

Weight loss of fruit was measured based on the initial weight and calculated as percent (%) during storage. The weight of each sample group was measured at each analysis day (0, 15, 30 and 45) at the end of cold storage and shelf life. Weight loss during shelf life was calculated from the difference between the initial and final sample weight as percent (%).

The fruit firmness (FF) was measured by Fruit Pressure Tester using stainless steel probe (width: 5 mm) and expressed a Newton (N).

The soluble solid content (SSC) of fruit juice was determined with a refractometer (Digital-Atago Pocket PAL-1) and expressed a percent. For titratable acidity (TA), fruit juice (10 mL) was titrated with 0.1 N sodium hydroxide up to pH 8.1, and results were expressed as percentage.

Maturity rate was calculated by rating of SSC to TA (SSC/TA). Skin colour was measured with a colorimeter (Minolta CR- 400). The colour was evaluated according to the CIE L* (represents brightness-darkness changing from 0 to 100), a* (represents the degree of red-green colour; + a*: red, − a*: green), b* (represents the degree of yellow–blue colour; + b*: yellow, − b*: blue), C* (represents vividity of color) and hº (represents perceived color) system. The chroma (C*) and hue angle (hº) values were calculated by the following formulas; $h° = \tan^{-1}(b^* a^{*-1})$, $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$. (Koyuncu et al., 2019).

Ethylene production and respiration rate were assessed according to the procedure described by Ding et al. (1998) using Finnigan Trace GC Ultra (Model: K072389201000). Results were calculated as µL ethylene $kg^{-1}\ h^{-1}$ and ml $CO_2\ kg^{-1}\ h^{-1}$ for

Table 1. Changes in weight loss (%), firmness (N), soluble solids content (%), titratable acidity (%) and maturity rate of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD							Mean of RS/T	Mean of RS	Mean T
			0	15	15+2	30	30+2	45	45+2			
WL (%)	Loquat	STHF	-	0.80	1.34	1.16	2.29	1.67	3.00	1.71 a	6.00 C	STHF 1.72 A
		Control	-	4.72	9.07	10.45	13.32	10.36	13.82	10.29 b		
	Hawthorn	STHF	-	0.45	1.15	1.31	2.43	2.24	2.51	1.68 a	4.80 A	Control
		Control	-	3.39	5.39	7.99	9.63	10.40	10.68	7.91 b		
	Quince	STHF	-	0.43	1.77	1.45	3.04	1.30	2.54	1.76 a	5.35 B	9.05 B
		Control	-	3.99	7.89	6.60	13.25	8.65	13.27	8.94 b		
	Mean of SD		-	2.29 A	4.44 B	4.83 B	7.33 D	5.77 C	7.64 D			
FF (N)	Loquat	STHF	21.87	25.69	26.58	26.28	25.89	28.15	30.6	26.38 NS	26.18 A	STHF 25.50 NS
		Control	21.87	20.89	29.32	26.48	26.08	29.32	27.75	25.99 NS		
	Hawthorn	STHF	23.83	27.75	21.77	24.42	25.79	26.67	28.64	25.61 b	26.28 A	Control
		Control	23.83	25.89	30.20	27.26	25.69	26.09	29.42	26.97 a		
	Quince	STHF	20.00	22.65	22.26	28.93	23.54	25.4	22.65	23.63 b	24.12 B	25.50 NS
		Control	20.00	25.80	26.38	27.75	21.67	25.69	25.3	24.61 a		
	Mean of SD		21.87 D	24.81 C	2.66 B	26.87 A	24.81 C	26.87 A	27.36 A			
SSC (%)	Loquat	STHF	10.90	9.33	9.87	9.60	8.10	9.80	7.47	9.30 a	9.83 A	STHF 9.76 A
		Control	10.90	10.33	10.40	9.20	10.83	11.93	8.87	10.35 b		
	Hawthorn	STHF	8.88	10.13	11.13	13.73	10.67	7.95	7.62	10.02 NS	9.88 A	Control
		Control	8.88	10.47	10.13	11.27	10.87	8.42	8.15	9.74 NS		
	Quince	STHF	10.82	9.20	12.27	11.33	8.03	8.52	9.65	9.97 NS	10.15 B	10.14 B
		Control	10.82	10.40	10.67	11.13	10.63	9.92	8.65	10.32 NS		
	Mean of SD		10.20 C	9.98 C	10.74 D	11.04 D	9.86 C	9.42B	8.40 A			
TA (%)	Loquat	STHF	0.76	0.48	0.50	0.46	0.45	0.42	0.34	0.49 a	0.47 B	STHF 0.51 NS
		Control	0.76	0.40	0.43	0.37	0.42	0.37	0.36	0.45 b		
	Hawthorn	STHF	0.75	0.48	0.54	0.39	0.50	0.22	0.30	0.45 NS	0.45 B	Control
		Control	0.75	0.44	0.47	0.42	0.43	0.24	0.42	0.45 NS		
	Quince	STHF	0.86	0.77	0.77	0.61	0.56	0.29	0.28	0.59 NS	0.60 A	0.50 NS
		Control	0.86	0.73	0.78	0.47	0.75	0.25	0.37	0.60 NS		
	Mean of SD		0.79 A	0.55 C	0.58 B	0.46 E	0.52D	0.30 G	0.34 F			
MR	Loquat	STHF	15.04	25.28	23.77	25.79	23.46	23.86	19.61	22.40 b	24.04 A	STHF 21.38 B
		Control	15.04	25.73	29.27	21.75	31.83	30.35	25.85	25.69 a		
	Hawthorn	STHF	14.36	19.64	19.94	21.01	18.02	23.63	21.79	19.77 b	22.19 B	Control
		Control	14.36	26.09	24.08	24.82	25.84	32.38	24.76	24.62 a		
	Quince	STHF	12.51	12.04	15.98	18.53	14.26	29.85	34.94	19.73 NS	19.93 C	22.78 A
		Control	12.51	14.26	13.75	23.38	14.52	39.11	23.40	20.13 NS		
	Mean of SD		12.89 D	19.63 C	19.42 C	25.05 B	20.05C	32.59 A	24.93 B			

SD: Storage day; T: Treatments; STHF: Stretch film; RS: Rootstock; WL: Weight loss (%); FF: Firmness of the fruit (N); SSC: Soluble solids content (%); TA: Titrable acidity (%); MR: Maturity rate. NS represents non-significance; Means followed by different letters within the same column are significantly different ($p<0.05$). Capital letters show the differences among overall averages and lower case letters represent the differences among the averages for each rootstock/stretch film combinations.

ethylene production and respiration rate, respectively. CO_2 value (%) in the plastic package was measured with a gas analyser (Bühler IR-Analysator Typ 3000 Inj.). O_2 values (%) in the package was measured by Servamex Oxygen Analyzer.

The results were expressed as percentage. The sensory analysis were performed by evaluation panel consisted of 10 members of the research staff who were experienced in sensory analysis of horticultural crops. The hedonic scale was used for external appearance and taste (Erbaş and Koyuncu, 2016). External appearance (scale 1-9): poor quality: 1-3; marketable quality: 3-5; good quality: 7; excellent quality: 9. Taste (scale 1-9): very poor: 1; poor: 3; mild: 5; good: 7; excellent: 9. Determination of fungal agents was assessed according to the procedure described by Kalyoncu et al. (2008). The decay rate (%) was calculated by rating of decayed fruits to the total number of fruits.

The data, obtained from three replicates for each rootstock, was evaluated by one-way analysis of variance (ANOVA). The differences among means (at a significance level of 0.05) were analysed using LSD (Least Significant Difference) test.

3. Results

3.1. Weight loss

The weight losses (WL) of fruit increased, regardless of rootstocks and packaging, throughout the cold storage, and reached to 5.77%. The highest fruit weight loss was obtained from fruit grown on loquat rootstock (6.00%) followed by quince (5.35%) and hawthorn rootstocks (4.80%), respectively. As with the combination of rootstock/stretch film, the difference between averages covered with stretch film (1.72%) and uncovered (9.05%) was statistically significant (Table 1).

3.2. Fruit firmness

Fruit firmness (FF) of loquats during storage is presented in Table 1. The firmness of fruit increased significantly at the end of storage (26.87 N) compared to initial value (21.87 N), contrary to expectations. The FF value of the fruit grown on the quince rootstock (24.12 N) was lower than those grown on the loquat (26.18 N) and hawthorn

rootstock (26.28 N). Stretch film treatments did not affect the fruit firmness of loquats. According to mean values of rootstock/stretch film, the loquat rootstock/stretch film combination did not affect the FF value of fruit, while the treatments in other combinations decreased this value.

3.3. Soluble solids content

Soluble solids content (SSC) of fruit, which was 10.20% at the beginning of storage, decreased significantly at the end of cold storage (9.42%) and shelf life (8.40%). The effects of both rootstock and stretch film on SSC were significant. The SSC measured in the control (10.14%) group was higher than the fruits covered with stretch film (9.76%). The average SSC of samples was higher when fruits were grown on quince rootstock (10.15%) compared to hawthorn (9.88%) and loquat (9.83%) rootstocks (Table 1).

3.4. Titratable acidity

At harvest, the titratable acidity (TA) of loquats changed between 0.75% (hawthorn) and 0.86% (quince). Acidity contents of loquats decreased significantly over time in all fruits obtained from trees grafted on different rootstocks. Stretch film treatment did not affect the amount of TA but, the acidity content of fruits grown on quince rootstock (0.60%) was significantly higher than those of Loquat (0.47%) and hawthorn (0.45%) rootstocks (Table 1).

3.5. Maturity rate

Maturity rate (MR) of all treated fruits increased in parallel with increasing storage period (from 12.89 to 32.59). The MR values of loquats in stretch film covered boxes were lower compared to control group in all rootstocks, especially in hawthorn. The highest maturity rate was obtained from the fruits grown on loquat rootstock (24.04) followed by the fruits grown on the hawthorn (22.19) and quince rootstocks (19.93), respectively. The effects of stretch film, rootstock and storage periods on MR were significant (Table 1).

3.6. Respiration rate

There was no statistically significant difference between the respiration rates (RR) measured at the end of cold storage and the values determined at harvest. However, the respiration rate value (26.14 ml CO_2 kg^{-1} h^{-1}), determined by keeping the fruits in room conditions for 2 days, was significantly higher than the value determined at the end of the cold storage (23.65 ml CO_2 kg^{-1} h^{-1}). Stretch film treatments did not affect the respiration rates**.** Respiration rate of fruits grown on loquat rootstock was remarkable higher (26.97 ml CO_2 kg^{-1} h^{-1}) than other rootstocks (hawthorn: 23.45 and quince: 22.19 ml CO_2 kg^{-1} h^{-1}) (Table 2).

3.7. Ethylene production

In cold storage and shelf-life studies, the effects of rootstock, stretch film and storage period on ethylene production (EP) were statistically significant. The maximum ethylene production (1.55 µL kg^{-1} h^{-1}) was found at the beginning of storage. Stretch film treatments significantly increased the ethylene production. The ethylene value, which was 1.31 µL kg^{-1} h^{-1} in control group, was measured as 1.46 µL kg^{-1} h^{-1} in stretch film treatments. The highest ethylene production was determined in fruits grown on quince rootstock (1.78 µL kg^{-1} h^{-1}), while fruits grown on hawthorn rootstock gave the lowest value (1.03 µL kg^{-1} h^{-1}) followed by fruits grown on loquat rootstock (1.61 µL kg^{-1} h^{-1}). Rootstock / package combination had no significant effect on ethylene production (Table 2).

3.8. Gas composition of the package

The O_2 and CO_2 concentrations in the package were statistically affected by storage time and rootstock during cold storage. The gas composition in the package changed during cold storage. The initial O_2 content (21 ± 0.1%) of packages decreased to 10.02% at the 15th day of storage and changed between 5.81% and 6.77% in the rest of the cold storage period. The average initial CO_2 concentration increased and reached to a peak value of 3.19% in the first 30 days of cold storage. In the shelf life studies carried out by keeping the fruits in room conditions for 2 days, the O_2 and CO_2 concentrations increased significantly compared to the cold storage. The loquat rootstocks gave the lowest O_2 (9.56%) value, followed by quince (10.36%) and hawthorn (10.56%) rootstocks, respectively. The lowest CO_2 value (1.97%) was measured in fruits obtained from quince rootstock (Table 3).

3.9. Fruit colour

Colour is an important quality parameter in loquat fruit and directly affects its market value. Colour changes of loquat fruits during storage are presented in Table 4. As it can be seen in Table 4, all fruit skin color values fluctuated, in general, over time showing differentiations according to cold storage and shelf life conditions. However, a*, b* and C* values increased at the end of cold storage compared to the beginning of storage. Moreover, L* value decreased, and h° value did not change. While the C* and a* values decreased significantly, L* and h° values increased, and b * values remained the same in fruits kept in room conditions for 2 days after cold storage. The packaging treatments did not

Table 2. Changes in respiration rate (ml CO_2 kg^{-1} h^{-1}) and ethylene productions (µL kg^{-1} h^{-1}) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD			Mean of RS/T	Mean of RS	Mean of T
			0	45	45+2			
RR (ml CO_2 kg^{-1} h^{-1})	Loquat	STHF	26.33	25.32	29.13	26.93 NS	26.97 A	STHF 24.48 NS
		Control	26.33	28.23	26.45	27.00 NS		
	Hawthorn	STHF	23.16	24.42	26.88	24.82 a	23.45 B	Control 23.98 NS
		Control	23.16	21.93	21.13	22.07 b		
	Quince	STHF	21.17	22.19	23.66	21.68 NS	22.19 B	
		Control	21.17	19.82	27.13	22.71 NS		
	Mean of SD		23.55 B	23.65 B	26.14 A			
EP (µL kg^{-1} h^{-1})	Loquat	STHF	1.66	1.62	1.57	1.62 NS	1.61 B	STHF 1.46 A
		Control	1.66	1.65	1.53	1.61 NS		
	Hawthorn	STHF	1.11	0.94	0.98	1.01 NS	1.03 C	Control 1.31 B
		Control	1.11	1.11	0.95	1.05 NS		
	Quince	STHF	1.89	1.78	1.63	1.77 NS	1.78 A	
		Control	1.89	1.81	1.65	1.78 NS		
	Mean of SD		1.55 A	1.48 B	1.39 C			

ST: Storage Time; T: Treatments; STHF: Stretch film; RS: Rootstock (%); RR: Respiration rates (ml CO_2 kg^{-1} h^{-1}); EP: Ethylene production; (µL kg^{-1} h^{-1}); NS represents non-significance; Capital letters show the differences among overall averages, and lower case letters represent the differences among the averages for each rootstock/stretch film combinations

Table 3. Changes in CO_2 and O_2 ratio (%) of loquat fruits depending on rootstock and storage time during cold storage and shelf life

	RS	SD							Mean of RS
		0	15	15+2	30	30+2	45	45+2	
O_2 (%)	Loquat	21.00	8.47	11.67	6.00	4.80	5.90	9.00	9.56 A
	Hawthorn	21.00	10.93	9.43	7.97	6.10	4.97	13.53	10.56 AB
	Quince	21.00	10.67	9.27	6.33	6.40	7.67	11.13	10.36 AB
	Mean of SD	21.00 C	10.02 B	10.12 B	6.77 A	5.80	6.18 A	11.22 B	
CO_2 (%)	Loquat	0.03	4.90	4.90	3.17	2.50	3.63	2.53	2.87 A
	Hawthorn	0.03	2.27	2.27	1.90	5.60	3.07	4.93	3.03 A
	Quince	0.03	2.30	2.30	4.50	2.10	1.93	2.07	1.97 B
	Mean of SD	0.03 C	3.16 A	3.16 A	3.19 A	3.40	2.88 AB	3.18 A	

SD: Storage day; RS: Rootstock; O_2: Oxygen ratio (%); CO_2: Carbondioxide ratio (%); NS represents non-significance; Capital letters show the differences among overall averages. and lower case letters represent the differences among the averages for each rootstock/stretch film combinations

have an effect on the L* value. However, the a*, b*, C* values increased, and the hº value decreased depending on packaging. Rootstocks had no effect on hº value but, L*, a*, b*, C* values were higher in fruits grown on quince rootstock compared to those grown on other rootstocks.

3.10. Decay rate

Decay rate (DR) was statistically affected by storage time, rootstock and stretch film during storage. While there was no decayed fruit on the 15th day of cold storage, the decay rate on the 45th day was 16.67%. Keeping fruits at 20°C and 70 ± 5% relative humidity for 2 days for shelf life evaluation and applying stretch film significantly increased decay rate. The highest decay rate was determined in fruits (9.76%) grown on hawthorn rootstock followed by loquat (8.41%) and quince rootstocks (7.46%), respectively (Table 5). *Phytophthora* spp. has been identified as a fungal agent causing infection in fruits.

3.11. Sensory analysis

Storage time and rootstocks significantly affected the external appearance and taste of fruits during cold storage and shelf life period. The external appearance and taste scores of fruits decreased in cold and room conditions, as the storage time increased. Fruits with good quality (score ≥ 7) were only obtained on the 30th day of storage. While the highest external appearance score (7.06) was obtained from fruits grown on quince, loquat rootstock gave the highest taste score (6.79). The lowest external appearance and taste scores (6.30 and 5.95, respectively) were obtained from fruits grown on hawthorn rootstock during storage (Table 6).

4. Discussion

Weight loss of horticultural product is a crucial commercial parameter for storage as it directly refers to the decrease in product weight (Bülüç and Koyuncu, 2020). In the present study, the weight loss of fruits increased with prolonged storage duration. This change was higher in shelf life condition in comparison with cold storage as expected (Table 1). It is known that, the main reason for increasing of weight loss is water loss from the fruit throughout the storage period. The shelf life of loquat is very short due to its high water

Table 4. Changes in L*. a*. b*. hº and C* values (CIEL* a*b*) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD							Mean of RS/T	Mean of R	Mean of T
			0	15	15+2	30	30+2	45	45+2			
L*	Loquat	STHF	54.79	54.95	60.29	63.00	61.29	56.82	58.39	58.50 b	59.26 B	STHF
		Control	58.61	58.61	60.95	64.98	62.34	57.31	57.25	60.01 a		60.00 NS
	Hawthorn	STHF	58.10	58.10	60.64	61.71	61.43	52.85	60.64	59.07 b	59.61 B	
		Control	58.59	58.59	60.69	63.26	60.58	58.71	60.69	60.16 a		Control
	Quince	STHF	56.86	60.57	60.71	67.03	62.35	54.40	59.78	60.24 b	60.79 A	
		Control	57.98	61.96	60.68	67.89	61.97	57.07	61.76	61.33 a		59.77 NS
		Mean of SD	57.49 E	58.80 D	60.66 BC	64.64 A	61.66 B	56.19 F	59.75 C			
a*	Loquat	STHF	24.07	23.48	24.69	23.63	25.40	27.69	23.49	24.72 a	23.42 B	STHF
		Control	23.35	21.33	20.96	20.41	22.84	25.38	18.61	22.13 b		24.37 A
	Hawthorn	STHF	22.99	21.86	24.27	21.69	24.27	24.74	23.42	23.48 NS	23.36 B	
		Control	23.92	22.30	22.03	22.66	22.03	26.39	21.69	23.24 NS		Control
	Quince	STHF	22.91	22.25	26.69	23.99	27.53	24.62	25.73	24.91 a	24.22 A	22.96 B
		Control	23.53	22.62	23.35	23.48	23.96	25.42	21.42	23.53 b		
		Mean of SD	23.46 CD	22.28 D	23.67 C	22.64 D	24.34 B	25.71 A	22.39 D			
b*	Loquat	STHF	47.60	45.67	46.92	45.76	45.56	49.80	49.81	47.30 a	45.69 B	STHF
		Control	40.45	40.72	44.99	41.35	45.21	47.30	48.53	44.08 b		46.52 A
	Hawthorn	STHF	41.16	44.27	47.02	38.86	47.02	47.05	47.94	44.76 b	45.57 B	
		Control	44.85	46.27	45.47	45.16	45.47	50.91	46.60	46.39 a		Control
	Quince	STHF	47.50	46.12	47.81	42.74	47.86	50.65	49.71	47.49 NS	46.94 A	
		Control	46.04	46.65	44.16	44.67	45.76	50.86	46.56	46.39 NS		45.62 B
		Mean of SD	44.60 C	44.95 BC	46.06 B	43.09 D	46.15 B	49.43 A	48.19 A			
hº	Loquat	STHF	63.13	62.13	62.23	62.72	60.84	60.81	64.73	62.37 b	62.81 NS	STHF
		Control	60.04	60.02	64.99	63.77	63.20	61.75	69.03	63.26 a		62.29 B
	Hawthorn	STHF	60.80	62.47	62.68	60.75	62.67	64.11	63.94	62.49 b	63.02 NS	
		Control	61.83	62.66	64.23	63.39	64.20	63.46	65.11	63.55 a		Control
	Quince	STHF	64.19	63.57	60.83	60.66	60.09	62.17	62.64	62.02 b	62.50 NS	
		Control	62.90	63.24	62.13	62.28	62.37	62.62	65.28	62.98 a		63.26 A
		Mean of SD	62.15 B	62.35 B	62.85 B	62.26 B	62.23 B	62.49 B	65.12 A			
C*	Loquat	STHF	53.35	51.65	53.02	51.51	52.16	57.04	55.08	53.40 a	51.40 B	STHF
		Control	46.72	47.02	49.64	46.13	50.67	53.70	51.98	49.41 b		52.54 A
	Hawthorn	STHF	47.14	49.91	52.92	44.53	52.92	53.18	53.37	50.57 NS	51.24 B	
		Control	50.85	52.09	50.56	50.53	50.55	57.34	51.43	51.91 NS		Control
	Quince	STHF	52.76	51.52	54.76	49.02	55.22	56.36	55.98	53.66 a	52.84 A	
		Control	51.71	52.26	49.97	50.47	51.66	56.88	51.25	52.03 b		51.11 B
		Mean of SD	50.42 D	50.74CD	51.81 BC	48.70E	52.19B	55.75A	53.18 B			

SD: Storage day; T: Treatments; STHF: Stretch film; RS: Rootstock (%); L: Lightness; a* red; b*: yellow; C*: Chroma; h°: Hue angle
NS represents non-significance; Capital letters show the differences among overall averages. and lower case letters represent the differences among the averages for each rootstock/stretch film combinations.

Table 5. Changes in decay rate (%) of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

RS	T	SD						Mean of RS/T	Mean of RS	Mean of T
		15	15+2	30	30+2	45	45+2			
Loquat	STRF	0.00	2.86	3.81	11.43	19.05	20.00	9.52 NS	8.41 AB	STRF
	Control	0.00	0.95	2.86	6.66	16.19	17.14	7.30 NS		10.64 B
Hawthorn	STRF	0.00	2.86	3.81	6.67	30.48	31.43	12.54 b	9.76 B	
	Control	0.00	2.86	0.95	4.76	16.19	17.14	6.98 a		Control
Quince	STRF	0.00	0.95	1.91	10.48	10.48	35.24	9.84 b	7.46 A	
	Control	0.00	0.00	0.95	3.81	7.62	18.09	5.08 a		6.45 A
	Mean of SD	0.00 A	1.74 A	2.38 A	7.30B	16.67 C	23.18 D			

Table 6. Changes external appearance and taste of loquat fruits depending on rootstock, stretch film and storage time during cold storage and shelf life

	RS	T	SD							Mean of RS/T	Mean of R	Mean of T
			0	15	15+2	30	30+2	45	45+2			
EA	Loquat	STRF	8.47	8.60	8.00	6.80	6.13	5.13	5.47	6.94 NS	6.99 A	STRF
		Control	8.47	8.00	8.20	7.13	6.13	5.80	5.47	7.03 NS		6.84 NS
	Hawthorn	STRF	7.87	7.73	7.37	7.63	5.80	4.13	4.47	6.43 NS	6.30 B	
		Control	7.73	7.53	8.07	7.80	3.93	4.93	3.27	6.18 NS		Control
	Quince	STRF	8.60	8.60	8.20	8.27	5.27	7.60	3.60	7.16 NS	7.06 A	
		Control	8.60	8.53	7.87	5.60	7.13	4.13	6.80	6.95 NS		6.72 NS
		Mean of SD	8.29 A	8.17 A	7.95 A	7.21 B	5.73C	5.29 CD	4.84 D			
TAS	Loquat	STRF	8.80	7.80	7.13	7.27	4.80	5.80	4.47	6.58 NS	6.79 A	STRF
		Control	8.80	8.47	8.13	8.47	4.80	6.13	4.13	6.99 NS		6.28 NS
	Hawthorn	STRF	8.27	7.33	6.60	5.13	4.60	4.60	3.93	5.78 NS	5.95 B	
		Control	8.27	8.13	5.93	6.33	5.60	3.93	4.60	6.11 NS		Control
	Quince	STRF	8.80	8.80	7.47	7.80	5.47	4.47	2.47	6.47 NS	6.54 A	
		Control	8.80	8.13	7.80	8.13	4.80	4.80	3.80	6.61 NS		6.57 NS
		Mean of SD	8.62 A	8.11 A	7.19 B	7.18 B	5.01C	4.96 C	3.90 D			

content comparison with other fruit species. Similarly, previous studies demonstrated that the high weight losses in loquats were observed due to water loss during storage (Ding et al., 1998; Ding et al., 2002; Ertürk et al., 2005; Park et al., 2005; Cai et al., 2006a; Amoros et al., 2008; Liguoria et al., 2017). Stretch film application clearly decreased the weight loss in loquats during storage (Table 1) as found in previous studies (Ertürk et al., 2005; Çandir et al., 2011).

In this study, in parallel with the increasing storage period, fruit firmness of loquats increased due to the elastic structure of fruit skin as a result of water loss. Talhouk et al. (1999) reported that stretch film treatments increased fruit firmness of loquats during storage. Our results showed that the effect of stretch film treatments on fruit firmness varied depending on rootstocks. Similar to our results, Zhang et al. (2011) indicated that the fruits obtained from different rootstock/scion combinations showed different characteristics. The highest fruit firmness was measured in the combination of Gold Nugget/hawthorn. This can be explained by the differences in the compatibility of rootstock/scion.

It has been reported that different rootstocks have different effects on the formation of taste, dry matter and acidity in fruits (Koyuncu and Çalhan, 2010). The effect of packaging material, storage time and their interactions on SSC during cold storage and shelf life was statistically significant. The SSC value peaked on the 30th day of storage. The higher SSC during shelf life studies can be attributed to the higher water loss from loquat depending on high temperature, as reported by Koyuncu et al. (2019). The SSC of control samples increased proportionally as storage time increased due to higher water loss. Ding et al. (1998) reported that the total acidity of loquat fruits decreased rapidly in the first 5 days of storage and then slowed down. In the present study, there was a similar decrease in TA during storage. Ambient condition increased TA compared to cold storage (Table 1). This increase is thought to be due to an increase in metabolic activity and decay rate. Stretch film treatment had no effect on TA content of loquat. Rootstocks affected TA contents, and the highest one was measured in fruits grown quince rootstock. The MR of fruits obtained from trees on loquat rootstock was significantly higher than those of other rootstocks (Table 1). Rootstocks affect the grafted variety in terms of many characteristics (Bolat and İkinci, 2019). According to results in our study; there is a correlation between ripening rate and SSC and TA value (Table 1). These differences can be attributed to different effects of rootstock and varieties.

While there was no difference between the respiration rates measured at the end of the cold storage and the values determined at the beginning, the respiration rate of fruits increased in room condition (Table 2). It is known that high storage temperature is predominant factor for increasing respiration rate. Ding et al. (1998b) indicated that the respiration rate of loquats was significantly higher at 20ºC in comparison with 1ºC. In the present study, the suppressing effect of low temperature in cold storage on respiration rate of loquat fruits is accordance with the findings of this researcher. The fruits that have higher respiration rate have a shorter post-harvest life (Karaçalı, 2002). Therefore, fruits obtained from Gold nugget and loquat seedlings combination may not be advised for long-term storage when respiration rate is considered only. Wang et al. (2010) have expressed that the ethylene production of loquats, as a non-climacteric fruit, is at a low level during post-harvest ripening. Similar to the findings of Ding et al. (1998a), we determined that ethylene production of loquats decreased with increasing storage period. The ethylene production in cold storage was lower than room condition (Table 2).

Erkan et al. (2005) reported an increase in CO_2% and a decrease in O_2% in different package during storage of loquat. In the present study, the O_2 concentration decreased significantly during storage period, while CO_2 level increased showing similarity to the findings of Erkan et al. (2005). In the present study, O_2 and CO_2 concentrations measured at the end of the cold storage were 6.18% and 2.88%, respectively. In shelf life studies, O_2 concentration of package was relatively higher compared to cold storage (Table 3). This increase is thought to be due to the change in gas permeability of the packaging with temperature. According to our results, it can be said that fruits grown on loquat rootstock provides lower O_2 concentration depending on high respiration rate during cold storage (Table 2 and 3).

Fruit colour is important for the determining of maturity stage at harvest as well as for consumer preference after harvest (Besada et al., 2010). The L*, b* and C* values could be taken into consideration for the evaluation of yellow-coloured fruits. The L* value, represents brightness-darkness changing from 0 to 100, of loquats fluctuated during storage and decreased at the end of cold storage (56.19) compared to initial value (57.49). However, it increased at the end of shelf life in all rootstock combinations (except for loquat-control) and reached to 59.75. The best result for L* value was obtained from quince rootstock (60.79) followed by hawthorn (59.61) and loquat (59.26) (Table 4). The findings of Ding et al. (1998a, 2002) related to colour change are accordance with the present study. The b* values of fruits fluctuated during storage and increased at the end of storage compared to initial values both in cold storage and room condition (Table 4). This change indicates the alteration of skin colour from green to yellow during storage. Our results are similar to those reported by Ertürk et al. (2005), who indicated that b* values of

loquats increased throughout the storage period. In the present study, the best bright yellow color, preferred by consumers, was observed in loquats grown on quince rootstock during storage. Stretch film treatments caused to increase the b* value of fruit skin (Table 4). The C* values (represents vividity of colour) tended to rise with the increasing storage period in all treatments during cold storage as well as shelf life period. Similar trend was also observed by Cao et al. (2011) in loquat fruits throughout cold storage. The highest C* value (52.84) was obtained from loquat fruits grown on quince rootstock followed by loquat seedling (51.40) and hawthorn (51.24). This can be explained by the differences in the compatibility or relationship between scion and rootstock.

Loquat is susceptible to various postharvest diseases after harvest (Pareek, 2014). By keeping the relative humidity high in storage, water loss of fruit can be limited but, if it is too high, the decay rate increases (Gezginç et al., 2005). The result of the present study showed that decay rate increased due to *Phytophthora* spp. infection at the end of storage compared to the beginning. However these changes remained within acceptable limits (2.38%) up to 30th day of storage in cold conditions. Stretch film treatment and room conditions increased decay rate in fruits. While decay rate in boxes covered with stretch film remained within acceptable limits up to 30th day of the storage, it increased rapidly after this period, and was higher at the end of the storage compared to the control (Table 5). Ertürk et al. (2005) reported that the fungal spoilage in loquats started on the 60th day, and there was no decay in control fruits during the storage. Our results related to stretch film are supported by the fact that loquat fruits are susceptible to decay at high humidity conditions. Decay rate in fruits grown on hawthorn rootstock was higher than those of other rootstocks (Table 5). This result can be explained by the effect of rootstocks on the nutrition content and disease resistance of fruit.

According to the sensory analysis results, which are very effective in making decision to terminate the storage period, there was a significant decrease in the external appearance and taste values at the end of the storage compared to the beginning (Table 6). Poor taste can be caused by the accumulation of metabolites (acetic aldehyde, ethanol, ethyl acetate) in fruits (Gerçekçioğlu et al., 2008). Çandır et al. (2011) reported a decrease in taste and aroma values on the 45th day of storage in loquats. On the other hand, Ding et al. (2002) found that loquats could be stored with good quality for 2 months at 5°C. According to the sensory evaluation results, in the present study, loquat fruits grown on quince rootstock can be stored with good quality for 30+2 days at 5°C (Table 6). These results, different from the above mentioned literature findings, are thought to be due to the variety, rootstocks, packaging and storage conditions. Ambient conditions caused a significant decrease in both external appearance and taste scores during storage. Stretch film treatment, widely used in the long-term storage of fruits, did not affect sensory quality of fruits in cold storage. The sensory quality change of loquats in our study is accordance with the findings of Ertürk et al. (2005) up to 30th day of cold storage. The external appearance and taste scores determined in the hawthorn rootstock were generally lower than the other rootstocks. Quince and loquat seedling rootstock, which gave better results during storage, can be recommended for loquat growing. Similar results were also reported by Pio et al. (2007).

5. Conclusion

The findings of the present study showed that quince rootstocks may be more suitable than the others, especially hawthorn rootstock, for some quality parameters during storage. Although loquats grown on three rootstocks gave different results in terms of storage life and quality, the best result for acidity, maturation rate, respiration rate, skin colour, decay rate, and external appearance were obtained from quince during storage. Loquat seedling rootstocks also gave good results for sensory quality and decay rate, showing similarity to quince. While the fruit colour of the fruits grown on hawthorn rootstock was, relatively, pale yellowish-green, quince rootstock gave vivid yellow skin colour. Stretch film application reduced the weight loss in all the combination of scion/rootstock but, increased pathogens development. The disease agent causing decay, especially after 30th day of storage, was *Phytophthora* spp. Fruits grown on quince and loquat seedling rootstocks can be stored with good quality for 30+2 days at 5°C and 90 ± 5 RH%.

Acknowledgements

This paper produced from “Effects of Different Rootstock on Fruit Quality and Storage of Akko XIII and Gold Nugget Loquat Varieties Project” which was funded by Batı Akdeniz Agricultural Research Institute and Suleyman Demirel University. I would like to thank Prof. Dr. M. Ali KOYUNCU, Prof. Dr. Mustafa ERKAN, Dr. Akın TEPE, Dr. Işılay YILDIRIM, Dr. Süleyman BAYRAM, Dr. Derya ERBAŞ, Msc. M. Alper ARSLAN and all those people who made this research possible.

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HortiS 37(2):144-149
http://doi.org/10.16882/HortiS.833488

RESEARCH PAPER

HORTICULTURAL STUDIES

Effect of Submerging *Solanum lycopersicum* Roots in Salicylic Acid (SA) Solution for Different Durations on Nematode Infection and Expressions of *SlPR5* Gene

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Article History
Received 01 November 2020
Accepted 25 November 2020
First Online 30 November 2020

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Keywords
Gene expression
Meloidogyne incognita
PR5
Salicylic acid
Solanum lycopersicum

Abstract

Salicylic acid (SA) stimulates the mechanism of the plant defence and involves in a role in plant pathogen interactions. Plant parasitic nematodes are important biotic stresses causing negative effect on plant growth and development. Treatment of plant roots with SA may increase the plant defence mechanisms against biotic stresses. However, the treated effect of SA on plant defence mechanisms against a root-knot nematode, *Meloidogyne incognita*, has not been fully understood in terms of plant pathogen interactions. Therefore, this study was aimed to determine the most effective SA exposure time on increasing the plant defence and decreasing the nematode parasitism in *Solanum lycopersicum*. In addition, effects of SA treatment on the expression *Pathogenesis Related Gene 5 (PR5)* was evaluated. For this aim, tomato seedlings were exposed within 1000µM SA concentration with distinctive time durations. The expression of *PR5* gene was accomplished using RT-PCR at 1, 3, 7, 14, 21 days post infection (dpi) for each sample. Root galling index, nematode number and reproduction rate were evaluated. Results revealed that nematode reproduction rate was decreased at in longer durations after SA treatment on roots. The highest nematode reproduction rate was determined in nematode+water (non-SA treatment) application compare to SA treatments. The highest increased level of expression of *SlPR5* gene was determined in early (1 dpi) SA treatment + nematode infection. To conclude, SA treatment may increase the plant defence mechanisms and *PR5* gene may involve in nematode-plant parasitism.

1. Introduction

Root-knot nematodes (*Meloidogyne* spp.) are placed on the top among plant parasitic nematodes (Jones et al., 2013) that they destroy crops as giving damage billions of euros on each year. A most polyphagous nematode genus, *Meloidogyne*, has around 100 species. Among them, *M. incognita, M. hapla, M. arenaria* and *M. javanica* are termed as major species of *Meloidogyne* genus and those species are found many countries in the world (Elling, 2013). *Meloidogyne* species are obligate parasite infect most plant species and cause galls in roots including legumes (Bozbuga et al., 2015a; Bozbuga, 2020a). Female nematode deposits eggs within egg mass composed of gelatinous matrix produced from rectal glands (Elling, 2013). Following the embryogenesis of first stage of juveniles (J1s) within egg, hatching occurs subsequent the development of second stage juveniles (J2s). To be an infected stage of *Meloidogyne* species, J2s penetrate plant roots just behind the root tip and migrate intercellularly within cells through the cortex. When they reach to vascular cylinder J2s become sedentary and induces changes in plant tissue. Following the

establishment of the nematode, the modification of cell wall molecular architecture occurs in feeding site of root-knot nematodes (RKN) (Bozbuga et al., 2018). Alteration of cell wall polysaccharides and cell wall thickening are seen in nematode feeding site that these modifications may related to suck up nutrients from plants (Bozbuga, 2017). Nematode induced feeding cells become multinucleated and large called “Giant cells” (Bird and Kaloshian, 2003). Giant cell and nematode sizes increase, and root swelling occurs within 3-4 days (Bartlem et al., 2014). The changes of lateral expansion of giant cells lead to differentiation of sieve elements, xylem vessels and phloem cells occurs (Bozbuga, 2017). During the feeding, J2s undergo several moults and finally become adults and starts produce eggs within the egg masses (Moller et al., 1998).

Some tomato plants have resistance gene (*Mi* gene) against root-knot nematode (Bozbuga et al., 2020). Plant cell wall plays a crucial role against pathogens with several physical barriers, cellulose, hemicellulose, lignin, proteins, and chemical substances (Heredia et al., 1995). Nematode modifies cell wall molecular architecture for feeding to continue its life (Bozbuga et al., 2018). Pathogens can be recognised by cell surface localised pattern recognition receptors by greatly conserved pathogen associated molecular patterns that pathogen triggered immunity involves in inhibiting the pathogen growth and modify pathogen molecules (Jones and Dangl, 2006). Pathogen Related (PR) proteins are stimulated to response to pathogens (van Loon et al., 1994).

As a significant hormone, SA participates the plant defence regulations, plant growth and plant development (Yan et al., 2014). As a transcription co-activator, NPR1 is a fundamental regulator of the plant defence response (Shi et al., 2010). NPR3, NPR4 is involved in SA regulation, and NPR3 and NPR4 bind SA to regulate NPR1 steadiness (Yan et al., 2014; Zhao et al., 2015) and defence responses (Moreau et al., 2012). SA is important component involves in *Mi* mediated defence response against *Meloidogyne* in tomato plant (Branch et al., 2004) and SA methyltransferase gene involves in *Heterodera glycinesis* in soybean (Lin et al., 2013). The changes of plant gene expressions are linked nematode parasitism. Gene expression is achieved a Realtime Polymerase Chain Reaction (RT-PCR) technology. Quantitative reverse transcriptase PCR (qRT-PCR) is used for quantifying mRNA transcription levels (Ginzinger, 2002).

In this study, a root-knot nematode, *M. incognita* was selected due to be a most damaging RKN species in the world. Effect of salicylic acid (SA) on tomato plants to *M. incognita* and expressions of Pathogenesis related *5 (PR5*) gene following the treatment of SA need to be fully understood. Hence, this study was aimed to determine the effect of different exposure time of SA on RKN, *M. incognita* reproduction and plant parameters and determining the *PR5* gene expressions activated by nematode infection using qRT-PCR.

2. Material and Methods

The susceptible tomato (*Solanum lycopersicum* L.) seedlings were grown in pots for inoculation of *M. incognita* used for nematode reproduction to use in this study. *Meloidogyne incognita* pure population was grown to gain sufficient number for nematode inoculation. Nematode induced tomato galled roots were cut into 1 cm length and placed on modified Baermann funnel for extraction in the nematology lab. Second-stage juveniles (J2s) of the nematode were extracted using modified Baermann funnel method and counted under the microscope to optimise under the microscope counting the numbers for setting up the experiment. Tomato seedlings were placed on the 1 kg volume-pots filled with sterilised growing mix for the experiment. Pots were placed on the 25±2°C in the greenhouses. Soil mix was consisted of 80% stream sand + 20% soil at 126°C in autoclave to eradicate pathogens, pests and seeds. Soil mix sterilisation is important for set up experiment. Sterilised soil mix were filled within pots and tomato seedling were gently placed after SA treatment; then, 2000-second stage juveniles (j2s) of *M. incognita*/per plant (2 J2s/gram soil) were inoculated (Bozbuga et al., 2015b). The experiment was set up according to randomised block design with 5 repetitions.

The concentration of SA was achieved as 1000µM. SA concentration was selected based on the previous pre-experimental studies. The roots of 25-day-old tomato seedlings were placed in SA concentration (1000µM) at 1 minute, 5 minutes, 30 minutes, 60 minutes, 120 minutes and 240 minute exposure times. Control treatments nematode+water and non-nematode+water treatments were also set up as controls. SA treated tomato plants were positioned in the 1 kg of pots and 2000 J2s were transferred within the root region in the pot with 5 replications for each treatment. Following the treatment, no watering was applied for seven days. All treatments including controls were set up as five replications. Plants were placed in greenhouses for two months at the 25±2°C with 16 daylight with 8 hours dark conditions. Plant parameters were evaluated after two months following the nematode infection and SA treatment.

Nematodes parameters were assessed to determine the nematode- plant parasitism relationship and nematode reproduction rate is an important indicator for nematode population. Nematode reproduction rate was calculated as final population number dividing the initial inoculation number.

Root gall index were achieved using the 0-5 egg sacs and gall index as 0 = no galls and no egg sacs, 1 = 1-2 egg sacs and galls; 2 = 3-10 egg sacs and galls; 3 = 11-30 egg sacs and galls; 4 = 31-100 egg

sacs and galls and 5 = > 100 egg sacs and galls in each root system (Hartman and Sasser, 1985).

Determining the *PR5* expression in tomato leaves were collected following *M. incognita* infection at 1, 3, 7, 14- and 21-days post infection (dpi) was analysed by using qRT-PCR. Leaves of five tomato plants from each replicate were taken and placed in liquid nitrogen. The GeneJET plant RNA purification mini kit (Thermo Scientific, Lithuania) was used for isolation of RNA from plant tissues and the company protocols were followed for RNA purification. Plant RNA lysis Solution was pipetted (500 µL) and into 1.5 mL micro centrifuge tube. Plant tissue was weighed at 100 mg from frozen tissue and grinding the plant tissues using mortar and pestle into the liquid nitrogen. Incubation was performed for 3 min at 56°C and centrifuged at 14000 rpm for 5 minutes. Supernatant was collected and transferred to the clean micro centrifuge tube and added 250 µL 96% ethanol. Following the transferring of mix to the purification column they were centrifuged. The flow-through solution was discarded and 700 µL of wash buffer 1 were added to the purification column and centrifuged. Flow-through protocol was achieved and 500 µL wash buffer 2 was added to purification column and centrifuged then, flow-through solution was discarded. Re-spinning of the column at 14000 rpm for a 60 sec was achieved, and purification column was transferred to a RNase-free 1.5 mL collection tube, and nuclease-free water was added to elute RNA and centrifuged. Purified RNA was measured in Nanodrop and diluted at 100 ng. Then conversion of cDNA synthesis of RNA was performed by iScript ™ cDNA Sythesis Kit (Bio-Rad) to use solution for two step reverse transcription quantitative PCR (RT-qPCR). Following the cDNA synthesis, SSoAdvanced™ Universal SYBR Green Supermix (Bio-Rad, USA) were used. The reaction set up was achieved using the SSoAdvancedTM Universal SYBR Green Supermix (Bio-Rad, USA), forward and reverse primers, cDNA template and Nuclease free water. Repeated reverse transcription–polymerase chain reaction (RT-PCR) assessment of gene expression was achieved. Nematode and non-nematode infected samples were studied to reveal gene expression during the nematode infection. *Solanum lycopersicum pathogen related gene 5* (*SlPR5*) was taken determine the gene expression. *SlPR5* Forward: 5'-AATTGCAATTTTAATGGTGC-3', Reverse: 5'-TAGCAGACCGTTTAAGATGC-3' (Kavroulakis et al., 2006) was used as pathogenesis related gene expressions. The primers of housekeeping gene, SlActin gene, was selected as Forward: 5'-ATGTATGTTGCCATCCAGGCT-3', Reverse: 5'-TGTGGCTGACACGATCTCCA-3' and it was performed to normalize the expression of gene (Chinnapandi et al., 2017). Cycling conditions were polymerase activation and DNA denaturation 60 sec in 95°C, denaturation at 95°C for 15 sec, amplification annealing/extension and plate read at 55°C for 60 sec with 45 cycles. To check the specificity of the PCR product, the melting curves were analysed for each data point. Repetition was performed for three samples for each treatment. The data of cycle number at which defined florescent threshold was crossed (ct values). The change of relative gene expression was calculated using the $2^{-\triangle\triangle CT}$ method and control uninfected values were subtracted from infected values.

Nematode and plant parameters were designed a complete randomised block design and one way of analysis of variance on pot data of five repetitions to compare results. The data of evaluation parameters were analysed using Duncan's Multiple Range Test at (P = 0.05) in SPSS to observe the significant differences among the values.

3. Result and Discussion

Gene expression was performed to understand the effect of SA exposure time on pathogen related gene expressions on tomato leaves. Tomato leaves was selected to understand the systemic response of plants against nematode and effect the SA treatment after infection of nematode at 1, 3, 7, 14- and 21-days post infection (dpi). For this aim, quantitative reverse transcription–polymerase chain reaction (qRT–PCR) was achieved to determine the gene expression. Following the RNA extraction and cDNA synthesis from tomato leaves in nematode infected, control (non-nematode), 1000 uM SA treated + nematode infected were evaluated using *SlPR5* genes. The expression of *PR5* reached at highest at 1 dpi day in SA treatment+nematode infection (Figure 1).

PCR analysis following the infection of *M. incognita* on SA treated SA+nematode and nematode treatments in tomato plants at 1 days post infection (dpi), 3 dpi, 7 dpi, 14 dpi, 21 dpi. A reference gene (actin) was used to normalise mRNA levels of target genes. Fold change of relative gene expression was calculated with 3 biological replicates using $2^{-\triangle\triangle CT}$ method. Control (uninfected) mean of $^{\triangle CT}$ of three replication value was subtracted from the infected sample mean. Therefore, the value of control group was not showed in the figure. Y axis represents the relative gene expression and X axis indicates *M. incognita* infection at different dpis. Mi, *Meloidogyne incognita*, Error bars indicate the standard error of the means of three replicates.

The relative gene expression of *SlPR5* decreased at 3 and 7 dpi in the treatment of SA+nematode. However, gene expressions were not increased in early dpis but gradually increased until 14 dpi in nematode infected (without SA treatment) samples (Figure 1). This result may reveal that SA involves in gene expression and possibly related to plant resistance against nematode. In general, the relative expressions of *PR5* gene was expressed in high level in

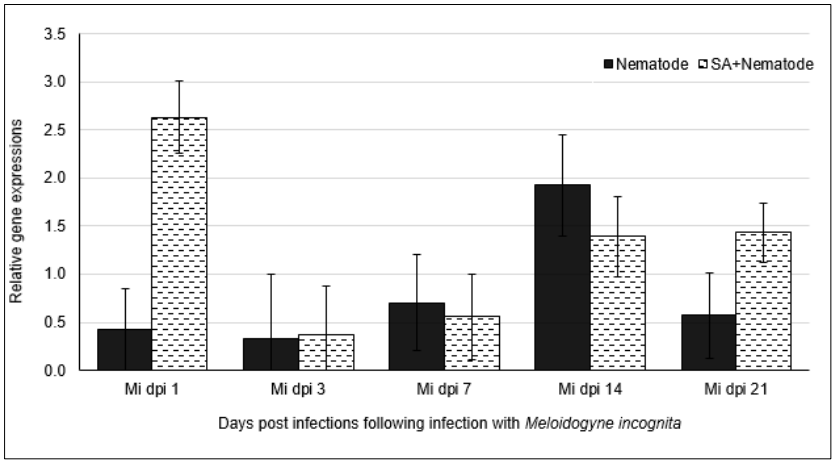

Figure 1. Expression of Pathogenesis-related gene 5 (PR5) (Nematode induced expression of Pathogenesis-related gene 5 (PR5) using RT-PCR analysis following the infection of *M. incognita* on Salicylic acid (SA) treated SA+Nematode and nematode treatments in tomato plants at 1, 3, 7, 14, and 21 dpis (days post infection). A reference gene (actin) was used to normalise mRNA levels of target genes. Fold change of relative gene expression was calculated with 3 biological replicates using $2^{-\triangle\triangle CT}$ method. Control (uninfected) mean of $^{\triangle CT}$ of three replication value was subtracted from the infected sample mean. Therefore, the value of control group was not showed in in the figure. Y axis represents the relative gene expression and X axis indicates *M. incognita* infection at different dpis. Mi, *Meloidogyne incognita*, Error bars indicate the standard error of the means of three replicates).

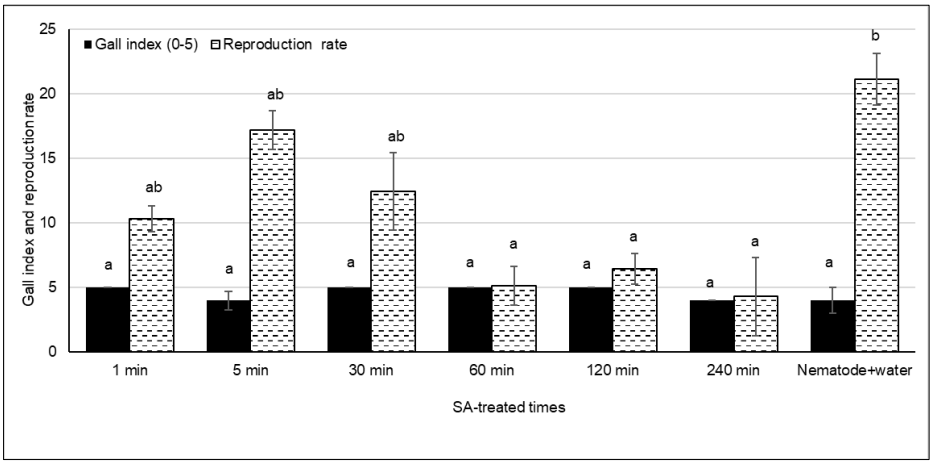

Figure 2. Effects of Salicylic Acid (SA) exposure times on nematode reproduction rate and gall index following the infection by *M. incognita* (Y axis indicates value of 0-5 gall index and nematode reproduction rate. X axis represents control and SA exposure time following the application of different time durations (1 minutes, 5 minutes, 30 minutes, 60 minutes, 120 minutes, 240 minutes. Gall index and reproduction rate were evaluated individually during the statistical evaluation. Error bars represents the standard error of the means of five replicates and letters characterise the statistical differences among different doses. Min, minutes).

SA+nematode treatment compare to non-SA treatment. It means that nematode may suppress the plant defence mechanism in early parasitism, since gene expressions increases following the SA treatment in early nematode parasitism.

Root gall index and nematode reproduction rate important components to determine the SA effect on nematode development and plant resistance against nematode. Several SA exposures time (1 min, 5 min, 30 min, 60 min, 120 min and 240 min) were performed to determine the effect of SA exposure time on nematode reproduction and gall index in plant root. Root gall index was measured using the 0-5 gall index following the SA treatment doses. No significant differences found among the applications in gall index parameter in root system in 1 min, 5 min, 30 min, 60 min, 120 min and 240 min applications. Nematode may enter plant roots then cause gall, however SA teratment may negatively affect the nematode development and reproduction. Therefore, gall index may not be fully show plant resistance. Nematode reproduction rate is an important parameter to show nematode feeding on root and multiplying the population. Highest nematode reproduction rate was determined in the application of nematode+ water treatment (Figure 2). In general, nematode reproduction rate was high at 1 min, 5 min, 30 min and non-SA (control) treatments (Figure 2).

This means that treatment with SA on plant roots at 60 min, 120 min and 240 min plays negative effect on nematode reproduction rate. Salicylic acid involves in plant defence mechanisms (Yan et al., 2014) that may have been produced during the pathogen attack. Similarly treating with SA on plants lead to inhibitory effect of SA on *M. javanica*

reproduction in tomato plants (Moslemi et al., 2016). In this study, nematode number was decreased in SA treated plants that possibly related that SA activated the pathogen related genes. Increased level of *PR5* genes in early infection days (Figure 1) may closely related to the plant defence mechanism.

During the pathogen attack, plant response with multiple layers of defences and triggers resistance to pathogens and SA involves in defence response (Vlot et al., 2009). During the nematode infection, the thickness of nematode induced host cell walls are around 5 times thicker than neighbouring cell walls (Bozbuga, 2017). More than seven hundred of genes are down regulated in *M. incognita* feeding site and few genes are downregulated (Fuller et al., 2007). Similarly, the number of upregulated genes was three times higher than the number of downregulated genes (Li et al., 2009). The SA receptor NPR3 is a negative regulator of the transcriptional defence response during early flower development in Arabidopsis (Shi et al., 2013). The expression of *PR* genes changes important signalling molecules for the development of plant immune response (van Loon et al., 2006). Upregulation of *PR1* gene is seen in early and late days nematode post infection in tomato plants (Bozbuga, 2020b). The expression of some *PR* genes in tomato tissues on SA treated susceptible plants to nematodes is increased and may closely related defence mechanism against nematode (Lavrova et al., 2017).

4. Conclusion

The application of SA reduced the nematode reproduction rate in tomato plants and expression of pathogen related gene may closely related to SA for involving plant defences.

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HortiS 37(2):150-154
http://doi.org/10.16882/HortiS.833769

RESEARCH PAPER

HORTICULTURAL STUDIES

Determination of Pests and Beneficial Species in Avocado Orchards in Antalya Province

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Article History
Received 12 October 2020
Accepted 29 November 2020
First Online 30 November 2020

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Keywords
Avocado
Parasitoid
Pest
Predator

Abstract

This study was conducted to determine the pests and beneficial species found in Avocado orchards in Antalya province, Turkey. Survey studies were carried out between the years of 2018-2020 in Alanya, Aksu, Finike, Gazipaşa, Kemer, Manavgat, Muratpaşa, Serik and Kumluca districts of Antalya that have avocado production. In the surveys, visual examination, counting of the branch, knock down, and trapping methods were used. As a result of the study, 18 pest species belonging to 13 families and 6 orders and 15 beneficial species belonging to 4 orders and 5 families were determined.

1. Introduction

Avocado (*Persea americana* Mill.), is a subtropical plant that spreads over large areas of the world and stands out with its increase in production every year. Avocado, which is in high demand in international markets with its nutritious properties and distinctive taste, entered to Turkey in the early 1970s and spread along the Mediterranean coastline. Mexico ranks first in terms of avocado production in the world, while Indonesia, Peru, the Dominican Republic, and Colombia follow that respectively (FAOSTAT, 2018). In Turkey, it is grown in the coastline of Muğla, Antalya, Adana, Hatay and Mersin provinces (Table 1). The total avocado production area, which was 556 ha in 2018, has almost doubled, reaching 950 ha as of 2019 (TUIK, 2018; 2019). Antalya province in Turkey leads the avocado production at the highest rate. Antalya accounts for 70% of the avocado production area in Turkey. In Antalya, Alanya district constitutes the highest production area with 62% (TUIK, 2019). As avocado production increases over time, it is exported from Antalya province to 25 countries, including Germany, Ukraine, Bulgaria, and Greece (BAİB, 2019). Studies on the adaptation of avocado cultivars in Turkey have been conducted in Batı Akdeniz Agricultural Research Institute (BATEM) in Antalya for many years and it has been determined that Bacon, Fuerte, Hass, Zutano, and Ettinger cultivars are suitable for the region (Bayram et al., 2006). These data clearly show the importance of Antalya province in avocado production. In parallel with the intensive demand day by day, the number of avocado trees is increasing and it is thought that avocado will be as important as citrus and pomegranate in the following years.

It is estimated that pests and beneficial species are intense due to the increase of production areas of Avocado, the suitability of the climate conditions of Antalya province for insect populations, and the lack of chemical control yet. Bayram (2010) reported that the Mediterranean medfly, thrips, scale insects, mealybugs, and lemon rat are among the common pests. However, there is no detailed study on this issue in Turkey. The aim of this study was to identify pests and beneficial species as the first step in the control of avocado pests. Most species obtained as a result of the research will be the first record for the avocado fauna of Turkey.

Table 1. Avocado presence and production in Turkey by provinces (TUİK, 2019)

Province	Number of trees at fruiting age	The number of trees in not fruiting	Total area of orchards (ha)	Production amount (tons)
Adana	-	2180	6.7	-
Antalya	60986	52455	659.5	3409
Hatay	293	-	0.8	23
Mersin	9230	77682	276.9	699
Muğla	2010	1050	5.2	78

Table 2. Number of trees examined according to orchard size (Lazarov and Grigorov, 1961)

Total number of trees in survey orchards	Number of trees examined
1-20	All trees
21-70	10–30
71-150	31–40
151-500	41–80
501-1000	15% of total trees
More than 1000	5% of total trees

In this study, it was aimed to identify pests and beneficial species in avocado orchards by conducting surveys during 2018-2020, spreading Alanya, Aksu, Finike, Gazipaşa, Kemer, Manavgat, Muratpaşa, Serik and Kumluca districts of Antalya province in Turkey. The data obtained from the study, can be used as preliminary information both in the pest control and in the use of biological control factors.

2. Material and Methods

The material of the study consists of avocado orchards in Alanya, Aksu, Finike, Gazipaşa, Kemer, Manavgat, Muratpaşa, Serik, and Kumluca districts in Antalya province, the tools used in the survey studies, culture containers, labels, pests and beneficial species, traps, chemicals and consumables used in preparing insects for diagnosis, and equipment.

2.1. Survey studies

The studies were conducted between March and November in avocado production areas in Alanya, Aksu, Finike, Gazipaşa, Kemer, Manavgat, Muratpaşa, Serik and Kumluca districts in Antalya province between the years of 2018 and 2020. Surveys were carried out at non-periodic intervals and it was noted that no pesticide was applied out in the selected orchards. In the survey studies, 0.01% of the total avocado area was included and studies were carried out in a total of 30 orchards.The number of trees to be examined according to the size of the orchard was determined according to the method of Lazarov and Grigorov (1961) (Table 2).

2.2. Determination of pests and beneficial species

Taking into account the phenology of the plants in the survey areas and labour force, sampling was carried out at non-periodic intervals between March and November by visual inspection, knock down, counting of branch, and trapping method (Anonymous, 2017).

Visual examination method: According to the phenological period of the plant, a total of 100 plant parts, consisting of 10 parts (buds, flowers, leaves, and fruits) from 10 trees, were randomly selected and the pests and beneficial species were collected and recorded.

Knock down method: This method was used with Steiner funnel (Steiner, 1960). The branches, which in the different directions of the trees randomly selected to represent the avocado orchard, were hit twice with a stick with a rubber tube on the end and hit 100 times in total and the pests and beneficial species that fell on the Steiner funnel were collected with an aspirator and recorded.

Branch counting method: 20-25 cm long branches and shoots were collected from different sides of five trees to identify scale insects.

Trapping method: The delta type trap containing the Mediterranean fruit fly pheromone and yellow and blue sticky traps were hung in the orchard in the south direction of the trees and at a height of about 1.5-2.0 m from the ground, and the insects caught in the traps were brought to the laboratory.

2.3. Laboratory studies

Adults were collected and brought to the laboratory in an icebox, prepared for diagnosis and sent to subject experts. Pre-adult periods were cultured in the laboratory and sent to the diagnosis in the same way when they became adult. Furthermore, parasitized individuals were brought to the laboratory and cultured for parasitoid emergence and sent for diagnosis.

3. Results and Discussion

As a result of surveys, 18 pest species belonging to 13 families and 6 orders and 15 beneficial species belonging to 5 families and 4 orders were identified.

Table 3. Pests found in avocado orchards

Order	Family	Species
Hemiptera	Aphididae	*Aphis (Toxoptera) aurantii* (Boyer de Fonscolombe)
		Myzus (Nectarosiphon) persicae (Sulzer)
	Diaspididae	*Chrysomphalus dictyospermi* (Morgan)
		Chrysomphalus aonidum (Linnaeus)
	Coccidae	*Coccus hesperidum* (Linnaeus)
		Ceroplastes floridensis (Comstock)
	Cicadellidae	*Fieberiella oenderi* (Dlabola)
		Balclutha frontalis (Ferrari)
	Issıdae	Agalmatium bilobum (Fieber)
	Margarodidae	*Icerya purchasi* Mask.
	Pseudococcidae	*Pseudococcus viburni* (Signoret)
	Aleyrodidae	*Trialeurodes vaporariorum* (Westwood)
Coleoptera	Cerambycidae	*Batocera rufomaculata* (De Geer)
Thysanoptera	Thripidae	*Thrips pillichi* (Priesner)
		Heliothrips haemorrhoidalis (Bouché)
Diptera	Tephritidae	*Ceratitis capitata* (Wiedemann)
Acarina	Acaridae	*Tyrophagus putrescentiae* (Schrank)
Epulmonata	Helicidae	*Eobania vermiculata* (Müller)

Table 4. Beneficial species found in avocado orchards

Order	Family	Species
Coleoptera	Coccinellidae	*Stethorus punctillum* Weise
		Serangium parcesetosum Sicard
		Scymnus rubromaculatus (Goeze)
		Oenopia conglobata (Linnaeus)
		Scymnus auritus (Thunberg)
		Nephus nigricans (Weise)
		Adalia bipunctata (Linnaeus)
		Chilocorus bipustulatus (L.)
		Hippodamia variegata (Goeze)
		Coccinella septempunctata (Linnaeus)
Neuroptera	Chrysopidae	*Chrysoperla carnea* (Stephens)
	Coniopterygidae	*Conwentzia pineticola* (Enderlein)
Hymenoptera	Braconidae	*Bracon (Habrobracon) hebetor* (Say)
Acarina	Phytoseiidae	*Neoseiulus californicus* (McGregor)
		Phytoseiulus persimilis (Athias Henriot)

Thrips pillichi Priesner, 1924, (Thysanoptera: Thripidae), *Fieberiella oenderi* Dlabola, 1985, *Balclutha frontalis* Ferrari, 1882 (Hemiptera: Cicadellidae), *Agalmatium bilobum* Fieber, 1877 (Hemiptera: Issıdae), *Eobania vermiculata* (Müller) (Eupulmonata: Helicidae) and *Pseudococcus viburni* (Hemiptera: Pseudococcidae) species were recorded as the first record of avocado in the world, while all species except *Ceratitis capitata* in Turkey were recorded as the first record for avocado cultivation.

Pests and beneficial species found in avocado orchards of Antalya province are given in Table 3 and 4. *Myzus persicae* and *Aphis aurantii* species, which are two aphid species determined in avocado orchards in Antalya province, are widely found in many cultivated plants in Turkey (Sarac et al., 2015). Furthermore, they are among the known avocado pests in the world (CABI, 2019).

The most common pest group in avocado orchards are scale insects. *Chrysomphalus dictyospermi* and *Chrysomphalus aonidum* are avocado pests identified as in the world (Kondo and Muñoz, 2016). In Turkey, it has been detected in a large number of hosts in the Mediterranean, Aegean, Marmara, and Black Sea regions (Kaydan et al., 2013; Çalışkan Keçe and Ulusoy, 2017; Yaşar and Erözmen, 2018). *C. hesperidum*, *Ceroplastes floridensis* and *Icerya purchasi* (cottony cushion scale) are known as common citrus pests in Antalya (Göl and Karaca, 2016). In a study conducted in Colombia, it was reported that these pests were identified in avocado areas as well (Kondo and Muñoz, 2016). Moreover, whiteflies are among the important pests that have a wide host range in Turkey. *Trialeurodes vaporariorum* species was found in the study carried out and this species is among the avocado pests known in the world (CABI, 2019; García-Palacios et al., 2020).

Fieberiella oenderi, *B. frontalis* and *A. bilobum* species belong to Cicadellidae and Issidae families were found in Antalya and Turkey fauna (Demir, 2008). In the world, no information has been reached that these species, which are harmful to different hosts and avocados.

Pseudococcus viburni is an important pest species in orchards in the Black Sea Region, Istanbul and Ankara provinces in Turkey (Telli and Yiğit, 2019). However, this species has not been determined in avocado orchards.

Doğanlar and Yiğit (2002) found that black vine thrips, *Retithrips syriacus* (Mayet) (Thysanoptera: Thripidae), a fruit and vineyard pest detected in Hatay, were fed and reproduced in avocado fruits as a result of laboratory studies. In our study, two different thrips species, *T. pillichi* and *Heliothrips haemorrhoidalis*, were found. Moreover, *H. haemorrhoidalis* species is known as an important thrips species in avocado in the world (Stevens et al., 1999; Larral and Lipa, 2007; Denmark and Fasulo, 2010). In Turkey, this species was first recorded as an important kiwi pest in a study conducted in Rize province in 2009-2010 (Ülgentürk et al., 2011). Similarly, *T. pillichi* is found in the fauna of Turkey and is not known as an avocado pest in the world (Nickle, 2008; Tunç and Hastenpflug - Vesmanis, 2016).

Furthermore, *Batocera rufomaculata*, which was detected in avocado orchards in Gazipaşa district in 2020, entered Turkey as a fig pest in 2000 (Tozlu and Özbek, 2000). In the world, it is one of the hosts of avocado trees (Mane and Gaikwad, 2018).

Tiring and Satar (2017) stated that in their study to determine the population fluctuation of the *C. capitata* species in avocado, peach, and fig orchards, *C. capitata* has been identified with the culturing of infected fruits from the avocado orchard. In the present study, *C. capitata* was found in traps in avocado orchards in Serik and Alanya districts. Besides, it is included among avocado pests in the world (De Graaf, 2009; EPPO, 2011).

Tyrophagus putrescentiae mite has been identified in stored products in Turkey, and no information has been found on its detection in avocado areas. Moreover, it was detected in avocado orchards in a study conducted in Mexico in 2017 (Genç and Özar, 1986; Sandoval-Cornejo et al., 2019).

Eobania vermiculata (Müller) (Eupulmonata: Helicidae) has been found to cause damage in peach and nectarine orchards in Adana and Mersin provinces (Hazır and Ulusoy, 2012). This pest is generally found in coastal areas, dry vegetation, vineyards, and agricultural areas in the world (Ronsmans and Van den Neucker, 2016). As for the beneficial species found in avocado orchards during the surveys, all detected species are widely found in the Turkish fauna.

4. Conclusion

Among the pests identified in the surveys, it was observed that the population of most pests is low. Hence, it is believed that the presence of predators and parasitoids found in nature keeps these pests in balance. Considering that there is no licensed plant protection product in avocado, it is thought that many pests will fall below the economic loss threshold if natural enemies are protected. However, for pests that have a high population and require to be controlled, different controlling techniques should be studied within the scope of an integrated pest management (IPM) program. These controlling methods should be the least harmful to the environment and natural enemies.

Acknowledgements

The authors thank to Prof. Dr. Ahmet BEYARSLAN (Trakya University), Prof. Dr. Ekrem ATAKAN (Çukurova University), Assoc. Prof. Emine DEMİR ÖZDEN (Düzce University), Dr. Emine TOPUZ (Bati Akdeniz Agricultural Research Institute), Heval DİLER (Plant Protection Central Research Institute), Dr. Işıl ÖZDEMİR (Plant Protection Central Research Institute), Prof. Dr. Göksel TOZLU (Atatürk University), Dr. Medine BASAR (Aksu District Directorate of Agriculture and Forestry), Prof. Dr. Miktat DOGANLAR (Mustafa Kemal University), Prof. Dr. Nedim UYGUN (Cukurova University), Prof. Dr. Savas CANBULAT (Kastamonu University), Prof. Dr. Selma ULGENTURK (Ankara University), Prof. Dr. Sultan COBANOGLU (Ankara University) and Assoc. Prof. Umit KEBAPCI (Mehmet Akif University) for identification of pests and natural enemies.

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