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Morpho-physiological performance of seven short-day and day-neutral strawberry cultivars in the soilless culture

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Abstract
Strawberry cultivation requires the use of cultivars adapted to the field or greenhouse conditions of the production region. Seven commercial short-day (SD) and day-neutral (DN) strawberry cultivars (Camarosa, Kurdistan, Mrak, Paros, Queen Elisa, Selva, Ventana) were compared using a completely randomized design for different morpho-physiological characters under greenhouse conditions. The cultivars showed variation for all of the studied traits. Days to flowering varied from 53.2 to 94.5 days among the cultivars and Paros followed by Camarosa required minimum days for flowering. The highest total chlorophyll content and fruit volume were obtained in Camarosa and Paros, while the highest fruit weight was found in Paros, Ventana, Camarosa and Kurdistan. The cultivar Camarosa produced the highest flower number (42.0), fruit number (36.3), fruit firmness (4.8 N) and yield (424.7 g per plant). The TSS/TA ratio was maximum in Paros and minimum in Ventana and Mrak. The highest fruit anthocyanin was recorded in Camarosa and Selva. Yield per plant had a positive correlation with total chlorophyll content of leaves, number of flower and fruit, weight and volume of fruit, while negatively correlated to leaf area and crown number. According to stepwise multiple regression analysis, yield had the highest positive relationship with the number of flowers and fruit weight, respectively. Generally, vegetative traits, as well as days to flowering and fruiting, were higher in the DN cultivars (Mrak, Selva). However, the SD cultivars produced higher flower numbers, fruit size and yield than the DN cultivars. The cultivars Camarosa and Paros were most adapted to the greenhouse conditions among the experimental cultivars.

Keywords: Cultivar; *Fragaria* x *ananassa*; Fruit quality; Physicochemical trait; Yield

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Introduction

Strawberry (*Fragaria* x *ananassa* Duch.), which belongs to the family Rosaceae, is a widely grown fruit crop in the world for its fruit organoleptic and nutritional properties (Arias *et al*. 2014). Strawberries are low in calories and have interesting content of niacin, vitamins A, B, C and minerals such as phosphorus, potassium, calcium and iron (Moreno *et al*. 2014; Miri *et al*. 2017). It contains polyphenolic compounds such as anthocyanin and phenolic acids, which display a wide range of biological activities such as antioxidant, cardioprotective effects, anti-inflammatory properties and reduction in the risk of diabetes. Because antioxidant capability is an important anticancer weapon, strawberries can be considered as a good candidate for scavenging free radicals and reducing carcinogenesis (Moreno *et al*. 2014; Pérez *et al*. 2014).

Recently, the greenhouse production of strawberries in Iran is expanding and hydroponic systems are being increasingly used (Eshghi *et al*. 2007). To obtain the highest yield potential, it is necessary to optimize every aspect of the production indicators (Zanin *et al*. 2019). The correct choice of a cultivar is a special aspect for successful strawberry plantation, which must be adapted to the conditions of the growing site (Selamovska, 2014; Zanin *et al*., 2019). The hybrid *F.* x *ananassa* Duch. is the result of natural hybridization between the species *F. chiloensis* and *F. virginiana*, and the large differences between the species that compose the genetic base of *F.* x *ananassa* allow a greater range of adaptation and quality of commercial strawberry cultivars (Antunes *et al*. 2010).

There are two primary types of strawberries now grown commercially in the world, day-neutral (DN) and short-day (SD) plants. The short-day types initiate flower buds under either short-day conditions (less than 14 h of day length) or when temperatures are less than 15 ˚C. Day-neutrals are insensitive to photoperiod and continue to flower as long as temperatures are between 4 and 29 ˚C and produce crowns and flower buds approximately three months after planting, regardless of the day length (Hancock 2000; Ruan *et al*. 2013).

Export has become an important development in the strawberry industry over the last decade in Iran. The requirements of the particular markets being targeted are the major factors involved in the selection of a cultivar to be planted by a grower. These requirements can differ greatly. For processing, they can depend on what the particular processor requires, although there is a general trend toward fruits with bright red flesh. For the local fresh market, cultivars that produce consistently over long periods in the spring, summer and autumn have an advantage. For fresh export, a long shelf-life is important but the requirements for skin color and size depending on the particular market (Carter *et al*. 1988).

The most common cultivars that are grown in Iran are: Kurdistan, Selva, Camarosa, Pajero, Parus, Queen Elisa, Aliso, Gaviota, Fresno, Missionary and Atabaky. Despite growing demands for strawberries in the Iranian market, adapted cultivars for different locations have not been selected (Eshghi *et al*. 2007). So, it is necessary to evaluate the agronomic performance of these cultivars under field and greenhouse conditions (Antunes *et al*. 2010; Moshiur Rahman *et al*. 2013). Hence, studies about these important traits are necessary for the successful cultivation of this crop in Iran. The present study was undertaken to evaluate some SD and DN strawberry cultivars cultivated under greenhouse conditions for vegetative and reproductive characters and to select superior genotypes based on performance and fruit quality traits.

Materials and Methods

The experiment was conducted in a commercial greenhouse which is located at Hashtgerd, Iran (latitude 35˚98'46" N, longitude 50˚72'84" E, altitude 1200 meters). The greenhouse had a metallic structure with a covering polyethylene film and was equipped with a pad and fan cooling system. The temperature and relative humidity during the cropping period were around 15-20 ˚C and 60-80%, respectively.

Healthy and disease free daughter plants of the five SD (Camarosa, Kurdistan, Paros, Queen Elisa, Ventana) and two DN (Mrak, Selva) strawberry cultivars were considered as treatments and transplanted in the 7-liter pots containing substrate mixture of cocopeat and perlite (1:1) in early November. A balanced nutrient solution was supplied by drip irrigation. The strawberry fruits were picked up manually at commercial maturity when at least 80% of the fruit surface turned red, at an interval of 3-4 days during early morning hours while the weather was cool. Fruit harvest started in late February and lasted until early May.

A total of 17 morphological variables representing both reproductive and vegetative characteristics and characters relating to the yield of the plants were measured throughout the growing season as follows: number of leaves, leaf area, total chlorophyll of leaves, number of crowns, days to flowering after planting, number of inflorescences, the total number of flowers, days to fruit set after planting, number of fruits per plant, fruit volume, fruit weight, yield per plant, fruit firmness, fruit anthocyanin, total soluble solids (TSS), titratable acidity (TA) and TSS/TA ratio.

The leaf area was measured by using a leaf area meter. Fruit firmness was recorded using a penetrometer (Wagner, USA) with a probe of 2 mm in diameter and 6 mm in penetration. The TSS of ripe fruit juice was determined with the help of a hand refractometer and expressed in °Brix. Titratable acidity was measured by titration of 10 g crushed pulp + 100 ml distilled water with a standard 0.1 M NaOH solution, obtaining the turning point when the solution reached the pH = 8.2 and expressed in grams of citric acid per 100 g pulp. The anthocyanin content was determined according to Van De Velde *et al*. (2013).

The experiment was laid out as a completely randomized design with three replications. The mean value of each observation was calculated based on four plants for each cultivar in every replication. Data were analyzed using SPSS statistical software, ver. 21 and the means were compared by Duncan's Multiple Range Test ($p \leq 0.05$ and 0.01). To determine the relationship between the traits under study, Pearson correlation coefficients were calculated and stepwise multiple regression analysis was carried out.

Results and Discussion

The F ratios in the analysis of variance were significant for all of the vegetative and reproductive characters (Table 1), which indicated the presence of genetic variability among the studied cultivars. The coefficient of variation (CV) for all traits (except days to flowering) was less than 15% that in accordance with Couto *et al*. (2013), shows good experimental precision.

Table 1. Analysis of variance for vegetative, reproductive and fruit physicochemical traits of seven strawberry cultivars.

Cultivar	df	Mean square																
		LN	LA	TC	CN	DFl	IN	FlN	DFrS	FrN	FrW	FrV	Y	FrF	TSS	TA	TSS/TA	FrA
Cultivar	6	1416**	1330**	1.2*	19.3**	547**	1.7*	137**	528**	80**	27**	18**	36648**	1.6*	14.4*	0.08*	90**	163**
Error	14	41	146	0.02	1.9	257	0.6	13	18	5	2	1	897	0.05	0.7	0.01	1	5
CV (%)		10.9	12.4	2.7	14.1	22.0	12.1	11.9	4.8	8.2	14.2	10.0	11.2	6.3	9.8	8.0	8.5	11.5

Abbreviations: LN: leaf number, LA: leaf area, TC: total chlorophyll, CN: crown number, DFl: days to flowering after planting, IN: inflorescence number, FlN: flower number,
DFrS: days to fruit set after planting, FN: fruit number, FW: fruit weight, FV: fruit volume, Y: yield per plant, FrF: fruit firmness, TSS: total soluble solids, TA: titratable acidity, TSS/TA: TSS/TA ratio, FrA: fruit anthocyanin.
*, **significant at $p \leq 0.05$ and 0.01, respectively.

Leaf number, leaf area and total chlorophyll content

Leaf number differed significantly among cultivars ranging from 23.6 (Queen Elisa) to 87.0 (Mrak). The leaf area was highest in Selva and Mrak, while the maximum of total chlorophyll content was in Camarosa and Paros (Table 2). These traits are important for photosynthesis (Moshiur Rahman *et al*. 2013), as the total chlorophyll content- an indicator of the leaf photosynthesis (Miri *et al*. 2015)- was positively correlated with most of the reproductive variables (days to flowering, number of inflorescences and flowers, number of fruits, fruit weight and volume as well as yield) (Table 3). Moshiur Rahman *et al*. (2013) showed that the number of leaves in different strawberry cultivars varied mainly due to the genetic as well as the environmental effects and obtained from 20.3 to 46.6 leaves per plant in different germplasm. In our results, leaf number presented a positive correlation with some of the reproductive variables and fruit characteristics such as flower number, fruit volume, TSS and anthocyanin (Table 3). So, the incidence of damage in the strawberry leaves negatively affects the number of inflorescences and, ultimately, the yield will be decreased (Grijalba *et al*., 2015). On the other hand, leaf area showed a negative relationship with yield, however, its correlation coefficient was moderate (Table 3). The higher leaf area may cause the leaves to shade over each other and the shaded leaves show a lower photosynthetic efficiency. Also, Mochizuki *et al*. (2013) revealed that lower leaf area index rates may be observed under heavy fruit load.

Table 2. Means of vegetative, reproductive and fruit physicochemical traits of seven strawberry cultivars.

Cultivar	LN	LA (cm^2)	TC (μg/gFW)	CN	DFl	IN	FlN	DFrS	FrN
Camarosa	56.0d**	81.0cd	6.9a	6.7c	63.0d	7.3ab	42.0a	80.5cd	36.3a
Kurdistan	70.6bc	62.6d	5.2d	6.6c	70.0c	6.4b	30.2c	86.1c	28.6b
Mrak	87.0a	112.3ab	6.0c	10.3b	94.5a	7.0ab	28.3cd	113.4a	26.3b
Paros	39.3e	104.0b	6.7a	10.0b	53.2e	7.3ab	35.3b	73.5d	30.6b
Selva	59.6cd	127.6a	6.0c	12.6ab	84.0b	6.4b	25.2d	100.1b	25.2c
Ventana	75.3b	97.6bc	6.3b	9.3b	74.2c	8.1a	24.3d	86.8c	20.4d

Table 2 continued.

Cultivar	FrW (g)	FrV (cm^3)	Y (g/plant)	FrF (N)	TSS	TA	TSS/TA	FrA (μg/gFW)
Camarosa	11.7a	12.7a	424.7a	4.8a	8.7b	0.8b	10.9c	26.6a
Kurdistan	10.6ab	10.5b	306.1bc	2.8d	11.0a	0.9a	11.7c	23.6b
Mrak	8.6bc	6.3c	226.2c	3.1cd	5.6c	0.8b	7.1d	21.3b
Paros	13.2a	13.3a	404.0b	2.8d	10.7a	0.4e	23.3a	6.1d
Selva	7.0cd	10.4b	176.4d	3.7c	7.7b	0.5de	14.0bc	24.0ab
Ventana	12.3a	11.0b	251.0c	4.0b	6.3c	0.7bc	8.5d	22.3b

Symbols as in Table 1.
Mean values followed by the same letters in each column do not differ significantly by Duncan's Multiple Range Test at $p \leq 0.05$ or 0.01, according to Table 1.

Number of crowns

The highest number of crowns was found in Queen Elisa and Selva, whereas the minimum was in Camarosa and Kurdistan (Table 2). Moshiur Rahman *et al*. (2013) also found a significant difference in the number of crowns among the strawberry germplasm in Bangladesh.

The vegetative component of strawberries is important because plants with a high vigor can produce more photoassimilates and, therefore, a higher ability to produce flowers and fruits. However, there is a competition for assimilates between the vegetative and reproductive components (Grijalba *et al*. 2015). Strong vegetative growth expressed through many crowns or high leaf area may weaken yield (Singh *et al*. 2018). Perhaps this is why there was a negative relationship between the number of crowns with the most reproductive traits as well as the physicochemical characteristics of the fruits (Table 3). Lopez-Galarza *et al*. (1997) found that fruit weight decreased linearly with the crown number in Oso Grande and Vilanova, while it was not affected in Chandler or Pajaro.

Table 3. Correlation coefficients among vegetative, reproductive and fruit physicochemical traits in the strawberry cultivars.

Trait	LN	LA	TC	CN	DFl	IN	FlN	DFrS	FrN	FrW	FrV	Y	FrF	TSS	TA	TSS/ TA
LA	-0.02															
TC	0.04	0.19														
CN	-0.37	0.78**	-0.18													
DFl	0.22	0.23	0.51*	0.02												
IN	0.01	-0.38	0.65*	-0.60*	0.20											
FlN	0.63*	0.37	0.46*	-0.57*	0.13	-0.07										
DFrS	-0.03	0.55*	0.07	0.59*	0.98**	0.29	-0.76**									
FrN	-0.36	0.26	0.50*	-0.59*	-0.24	-0.09	0.98**	-0.70**								
FW	0.33	-0.34	0.65*	-0.73**	-0.14	0.68**	0.28	0.03	0.38							
FV	0.86**	0.30	0.67*	-0.47*	0.08	0.25	0.33	0.12	0.46*	0.78**						
Y	0.09	-0.43*	0.70*	-0.78**	0.32	0.38	0.76**	-0.37	0.80**	0.87**	0.77**					
FrF	-0.71**	-0.52*	-0.29	-0.17	-0.68**	-0.57*	0.21	-0.23	0.31	-0.02	0.19	0.19				
TSS	0.58*	-0.70**	-0.24	-0.67**	-0.05	0.21	0.15	-0.63*	0.14	-0.04	-0.23	0.09	-0.12			
TA	-0.80**	0.12	-0.31	0.31	-0.46*	-0.22	0.13	0.23	0.18	0.11	0.40	0.16	0.71**	-0.76**		
TSS/TA	-0.21	-0.04	0.28	-0.01	0.41	0.17	0.11	-0.24	0.13	-0.16	0.04	-0.02	-0.19	0.66**	-0.82**	
FrA	0.68**	0.23	0.01	-0.45*	0.15	0.23	0.09	-0.23	0.13	0.04	-0.03	0.06	-0.49*	0.09	-0.29	0.37

Symbols as in Table 1

*, **significant at $p \leq 0.05$ and 0.01, respectively.

Days to flowering

The maximum number of days (94.5) required for flowering was in Mrak followed by Selva (84.0 days) and the minimum in Paros and Camarosa (53.2 and 63.0 days, respectively) (Table 2). This is because Paros and Camarosa might be early genotypes. Mendonca *et al*. (2017) recorded that the Albion, Camarosa and Ventana cultivars were precocious since they started flowering at 63 days after planting. According to Chowhan *et al.* (2016), the minimum days to flower initiation were observed in Camarosa and Festival. Sonstebya *et al*. (2017) also found a significant variation in days to anthesis, which is also in agreement with the present findings. They found that strawberry cultivar Valentine required a minimum time of anthesis followed by Glima, Zefyr and Camarosa. Days to flower initiation varies mainly due to genotypes, stage of growth, photoperiod as well as temperature, and this explains why the genotype by environment interaction causes distinct phenotypic expressions (Chowhan *et al*. 2016; Mendonca *et al*.

2017). Moshiur Rahman *et al*. (2013) reported that the number of days from transplanting to first blooming among the strawberry germplasm ranged from 48.3 to 102.3.

Number of inflorescences and flowers

Among the cultivars, Ventana produced the maximum number of inflorescences (8.1), followed by Camarosa, Paros and Mrak. During the study period, the highest total number of flowers was observed in Camarosa (42.0) and Paros (35.3) (Table 2). Chowhan *et al.* (2016) also recorded the maximum number of flowers per plant of 23.6 in Camarosa. This result was partially similar to that of Moshiur Rahman *et al*. (2013), who found that the number of flower inflorescences and the number of flowers per plant differed significantly among the germplasm.

The number of flowers showed a positive significant correlation with the number of fruits and yield (Table 3). Singh *et al*. (2018) have also reported a positive correlation between the number of flowers/plant and the number of fruits.

Days to fruit set after planting

The time to fruit set showed the same pattern with the variation of the day to flowering among cultivars. Paros and Camarosa recorded a minimum fruit set duration (73.5 and 80.5 days after planting) and Mrak had a late fruit set (113.4 days after planting) (Table 2). Gaikwad *et al*. (2018) also reported that minimum harvesting duration was obtained in Camarosa.

Fruit number, weight and yield

The highest fruit number per plant was obtained with Camarosa (36.3). However, Paros, Ventana and Camarosa produced the heaviest berries; the bulk of the cultivars had a berry weight of 11.7-13.2 g. Also, Paros and Camarosa had the highest fruit volume, which ranged between 12.3 to 13.2 cm^3. The highest yield was observed in Camarosa (424.7 g fruit per plant), followed by Paros (404.4 g fruit per plant), and the lowest yield was found in Queen Elisa (125.0 g fruit per plant) (Table 2). Data of the number of Camarosa fruits per plant found in this work were higher than those achieved by Chowhan *et al.* (2016), Gaikwad *et al*. (2018) and Zanin *et al*. (2019), which obtained the number of fruits per plant of 19.9, 31.7 and 20.4 fruits/plant, respectively, when grown under open field conditions. Besides, the yield results obtained in the present work for the Camarosa cultivar were greater than those reported by Diel *et al*. (2018) and similar to those found by Gaikwad *et al*. (2018) and Zanin *et al*. (2019). Antunes *et al*. (2010) reported that Camarosa had the greatest accumulated production and fruit weight. Meanwhile, these authors obtained higher values for the strawberry cultivar Camarosa (877.5 g/plant and 20.0 g, respectively). Moshiur Rahman *et al*. (2013) stated that fruit yield in strawberries varied significantly among the germplasm studied.

Productivity, fruit volume, fresh fruit weight and diameter of fruit are polygenic and quantitative characteristics. They are largely defined by the genetics of the cultivar and have high heritability, even though the environment influences on the productive performance of strawberry cultivars (Mishra *et al*. 2015; Zanin *et al*. 2019). Camarosa is a variety with prominent climatological adaptation, exceptional quality and flavor and good tolerance to diseases, and if well managed, has great productive potential and fruits with high mean weight (Ozkaya and Dundar 2009; Van De Velde *et al*. 2013). It even produced superior hybrids in crosses in which it participated as the female genitor for the production and physicochemical characteristics of the strawberry fruit (Barth *et al*. 2019).

Estimates of correlations between variables help in finding out the degree of the interrelationship among various variables and in evolving selection criteria for improvement of the most promising genotypes or adaptability studies (Mishra *et al*. 2015; Zanin *et al*. 2019). The practical utility of selection of a variable as a measure of improving another variable depends on the extent to which they are related and this relation depends not only on genotypic correlation but also on phenotypic correlation and variance (Mishra *et al*. 2015). Yield is the product of a combination of characters, such as number and size of fruit, plant vigor, hardiness and disease resistance of the plant (Hancock *et al*. 2008), of these number of fruits per plant and the fruit weight is the two main components of productivity in the strawberry (Zanin *et al*., 2019). Based on the correlation coefficients in Table 3, the higher yield of Camarosa and Paros was due to the higher total chlorophyll content of leaves, the number of flowers and fruits, weight and volume of fruit and lower crown number. The highest correlation was obtained between yield with fruit weight (0.87) and fruit number (0.80). According to the results of stepwise multiple regression, the number of flowers and fruit weight (positively) and inflorescence number (negatively) were most related to the strawberry yield (Table 4). The final model, together with partial regression coefficients were presented in Table 4.

Similar results were obtained previously by Carp and Ciulca (2016), who found that the number of flowers has a major and significantly distinct contribution to the yield, followed by weight and numbers of fruits. Hortynski *et al*. (1991) stated that the total yield of large fruits correlates closely with the total yield of all fruits and depends mainly on the mean fruit weight of all fruits. On the other

Table 4. The stepwise multiple regression coefficients for the strawberry yield as the dependent variable and flower number, fruit weight and inflorescence number as independent variables.

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-127.40	17.70		-7.20	0.006
Flower number	9.76	0.29	0.60	33.23	0.000
Fruit weight	21.28	0.90	0.57	23.68	0.000
Inflorescence number	-15.48	2.87	-0.11	-5.39	0.012

Model: Y= -127.395 + (9.76 × flower number) + (21.28 × fruit weight) + (-15.43 × inflorescence number) hand, Zanin *et al*. (2019) found that the number of fruits per plant correlated strongly with yield, while the commercial fruit weight did not significantly influence the total production. Besides, due to the significant positive correlations of the number and weight of fruits with yield, they can be used effectively as indirect selection criteria for the plant yield.

Fruit firmness

There was higher fruit firmness in Camarosa, which is good character when taking post-harvest manipulation and transportation into consideration, while the lower fruit firmness was observed in Kurdistan and Paros cultivars, so they should be chosen with a lot of care, mainly when the final destination of the product is to the distant markets (Table 2). Doving and Mage (2002) tested fruit firmness in 18 strawberry cultivars and found considerable differences among them. Although they reported a low correlation between firmness and color but a significant negative correlation between firmness and anthocyanin was found in the present experiment (Table 3). Besides, the fruits with higher TA were softer than the fruits with less TA. As acidity and fruit color (anthocyanin pigmentations) are indicators of ripeness, positive and negative relationships of firmness with TA and anthocyanin, respectively, would be expected. Fruit firmness is an important trait for the quality of strawberries, whose quality is sensitive to the market, and affects the post-harvest shelf life and occurrence of transport damage (Antunes *et al*. 2014: Mora *et al*. 2019).

Biochemical characteristics of the fruit

The maximum TSS was recorded by Kurdistan, Paros and Queen Elisa and the lowest was noticed in Ventana and Mrak. Titrable acidity also varied depending on the cultivar. The highest average of TA was determined in Kurdistan, while Paros had the lowest value. On the other hand, Paros had the maximum average of total soluble solids to acidity ratio (Table 3). Changes in the weight and volume of fruits as well as yield had an insignificant influence on the sugar content and TSS/TA ratio (Table 3). Similar results were also reported by Carp and Ciulca (2016). Appearance, color, size, vitamin C and flavor (TSS, TA and TSS/TA) are very important quality characteristics for consumers (Ozkaya and Dundar, 2009). However, different cultivars may show significant differences in the contents of chemical compounds (Barth *et al*. 2019). The soluble-solids content is composed of some polysaccharides, among which glucose, sucrose and fructose are present in higher concentrations. organic acids, of which citric acid is the most predominant, provide the pulp acidity of strawberry fruits. Strawberry acidity and soluble-solids content are traits inherited quantitatively, controlled by several genes, with variable levels of additive and dominance control (Hancock *et al*. 2008; Zanin *et al*. 2019). The ratio of TSS/TA is a very good indicator of the fruit flavor, and strawberry fruits with the high TSS/TA ratio are more likely to be chosen by consumers, with high acidity being an unfavorable factor in this sense (Ozkaya and Dundar 2009; Antunes *et al*. 2010; Zanin *et al*. 2019). The characteristics considered for acceptable flavor quality of strawberry fruits are as follows: maximum of 0.80 g/100 g of citric acid for titratable acidity, minimum of 7.0% for soluble-solids content, and a minimum of 8.75 for TSS/TA ratio (Kader 2001). Thus, almost all cultivars evaluated in this work, except Mrak and Ventana, presented better fruit quality characters that make them suitable for commercialization.

The Camarosa and Selva cultivars had a high anthocyanin content, whereas Paros had a notably low content (Table 2). The anthocyanin content was found to be approximately in the same range as those obtained by Van De Velde *et al*. (2013), who reported the total anthocyanin concentrations from 22.1 to 38.4 mg/100 g in Selva and Camarosa strawberry cultivars. Color is one of the important quality attributes of strawberries (Ruan *et al*. 2013). Strawberry pericarp pigmentation is primarily caused by anthocyanin accumulation (Wada *et al*. 2010). The consumer market is increasingly interested in foods with good nutritional, higher natural antioxidants and flavor characteristics (Antunes *et al*. 2010; Barth *et al*. 2019).

Comparison of SD and DN cultivars

DN and SD cultivars significantly differed in terms of several vegetative and reproductive characteristics. SD showed lower leaf number, leaf area, crown number, days to flowering and fruiting, while their flower number, fruit weight, fruit volume, yield and TSS were higher than DN cultivars (Table 5). Photoperiod between 8 and 11 h is required for floral induction in SD cultivars, a situation that usually occurs in late summer and the fall and winter (Mendonca *et al*. 2017). Higher flower numbers and lower number of days to flowering and spring fruiting of SD cultivars as compared to the DN cultivars should be attributed to the early initiation of flowers in the SD cultivars. This can explain why SD cultivars produce a higher yield than DN cultivars. Bigger fruit size in SD also resulted in a higher yield per plant in SD than in DN. On the other hand, due to the negative correlation between leaf area and the number of crowns with yield, more vegetative growth resulted in lower flowering in SD than in DN. Since the environmental conditions were the same for all cultivars during the experiment, all these differences could be related primarily to genetic differences. It should be noted that yield-component contributions may depend on the variety, production system and environmental factors (Baumann *et al*. 1993; Hidaka *et al*. 2014). Baumann *et al*. (1993) indicated that varieties under one cultural system could perform differently under other systems. They found that DN varieties produced a higher yield than SD varieties during the summer and fall planting systems. However, Ruan *et al*. (2013) showed that the summer flower of DN cultivars came later compared with ever-bearing cultivars.

Table 5. Means of vegetative, reproductive and fruit physicochemical traits of the short-day (SD) and day-neutral (DN) strawberry cultivars.

Cultivar	LN	LA (cm^2)	TC (µg/gFW)	CN	DFl	IN	FlN	DFrS	FrN	FrW (g)
SD	53.0b	88.3b	6.0a	9.1b	66.0b	6.8a	31.04a	82.4b	27.4a	10.5a
DN	73.3a	120.0a	6.0a	11.5a	89.2a	6.5a	26.75b	106.7a	25.5a	7.8b

Table 5 continued.

Cultivar	FrW (g)	FrV (cm^3)	Y (g/plant)	FrF (N)	TSS	TA	TSS/TA	FrA (µg/gFW)
SD	10.5a	10.6a	294.0a	3.7a	9.4a	0.7a	14.2a	18.2a
DN	7.8b	8.1b	200.2b	3.4a	6.6b	0.6a	10.6a	22.6a

Mean values followed by the same letters in the columns do not differ significantly by Duncan's Multiple Range Test, $p \leq 0.01$. Symbols as in Table 1.

Conclusion

The strawberries cultivars under study showed variation in vegetative, reproductive and fruit physicochemical traits as well as in yield. Yield was positively correlated with the fruit weight, fruit number, fruit volume, flower number and total chlorophyll content of leaves. All characteristics were primarily affected by the genetic background. So, cultivar adaptability is the priority to be considered for a successful production strategy. In general, SD cultivars showed early fruiting and higher spring yield than DN cultivars. The characters of low days to flowering and fruiting as well as high fruit number, fruit size and yield seem to make Camarosa and Paros cultivars suitable for the commercial spring fruit production in the greenhouse. The unique characters of Camarosa were the highest fruit number and fruit firmness as well as high fruit anthocyanin, which make the fruits appealing appearance combined with other good fruit characters. On the other hand, Paros had the highest TSS/TA ratio. Kurdistan, Paros and Queen Elisa also exhibited the highest TSS. Since individual cultivars possessed different characters, cultivar combination utility may be a good strategy to fulfill different customer's requirements and different consumption purposes.

Conflict of Interest

The authors declare that they have no conflict of interest with any organization concerning the subject of the manuscript.

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عملکرد مورفو-فیزیولوژیکی هفت رقم روز کوتاه و روز خنثی توت فرنگی در کشت بدون خاک

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چکیده

کشت توت فرنگی نیاز به استفاده از ارقام متناسب با شرایط مزرعه یا گلخانه در منطقه تولید دارد. هفت رقم تجاری توت فرنگی روز کوتاه (SD) و روز خنثی (DN) Camarosa، Kurdistan، Mrak، Paros، Queen Elisa، Selva و Ventana برای مقایسه صفات کمی و کیفی در شرایط گلخانه مورد بررسی قرار گرفتند. ارقام در تمام صفات مورد مطالعه تنوع نشان دادند. روزهای گلدهی از ۵۳/۲ تا ۹۴/۵ روز در بین ارقام متغیر بود و Paros و سپس Camarosa به حداقل روز برای گلدهی نیاز داشتند. بیشترین میزان کلروفیل و حجم میوه در ارقام Camarosa و Paros به دست آمد، در حالی که بیشترین وزن میوه در Paros، Ventana، Camarosa و Kurdistan مشاهده شد. رقم Camarosa بیشترین تعداد گل (۴۲/۰)، تعداد میوه (۳۶/۳)، استحکام میوه (۴/۸ نیوتن) و عملکرد (۴۲۴/۷ گرم در بوته) را تولید کرد. بالاترین نسبت TSS/TA در Paros و کمترین آن در Ventana و Mrak مشاهده شد. بالاترین میزان آنتوسیانین میوه نیز در Camarosa و Selva ثبت شد. عملکرد هر بوته با کلروفیل کل برگ، تعداد گل و میوه و وزن و حجم میوه همبستگی مثبت ولی با سطح برگ و تعداد تاج همبستگی منفی داشت. بر اساس نتایج رگرسیون چندگانه گام به گام، عملکرد بیشترین ارتباط مثبت را با تعداد گل و وزن میوه داشت. به طور کلی، صفات رویشی و همچنین روزهای تا گلدهی و روزهای تا رسیدن باروری در ارقام روز خنثی (Mrak و Selva) بیشتر بود. با این حال، ارقام SD نسبت به ارقام DN تعداد گل، اندازه میوه و عملکرد بیشتری داشتند. ارقام Camarosa و Paros به عنوان سازگارترین ارقام در شرایط گلخانه‌ای در بین ارقام آزمایشی محسوب شدند.

واژه‌های کلیدی: رقم؛ عملکرد؛ کیفیت میوه؛ ویژگی فیزیکی-شیمیایی، Fragaria x ananassa