EVALUATION OF YIELD AND FRUIT QUALITY OF NEWLY INTRODUCED CHERRY TOMATO CULTIVARS UNDER HIGH TUNNEL CONDITIONS

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ABSTRACT

Nine newly introduced cherry tomato cultivars were evaluated for the yield and yield components and some phytochemical characteristics under high tunnel conditions. The cultivars were Indigo Rose, Oregon II, Indigo Kiwi, Saucy, Oroma, Oregon Cherry, Large German, Gold Nugget, and Indigo Cherry Drops which were developed at Oregon State University breeding programs. A completely randomized block design with three replications was followed in this study. The number of fruits per plant, average fruit weight, plant yield, fruit pH, total soluble solids (TSS) of the fruits, total phenolic content (TPC), and antioxidant activity of the fruits was measured. Gold Nugget showed the highest fruit number per plant (237.89) and yield per plant (2.08 Kg) while Indigo Kiwi expressed the largest fruit weight (50.08 g). In addition, the cultivars showed a wide range of quality characteristics. The fruit pH ranged between (3.73- 4.45) for Gold Nugget and Oroma, respectively whereas the TSS ranged between (3.71- 9.60) for Indigo Rose and Oregon II, respectively. Also, the cultivars showed a wide range in TPC (0.11-0.56 mg GAE g^{-1} E) for Gold Nugget and Oregon Cherry, respectively. Moreover, the results showed that the cultivars varied in ABTS Inhibition percentage (14.04- 44.95%) in Gold Nugget and Saucy, respectively. Regarding repining time, the earliest cultivars were Gold Nugget, Oregon II, and Oregon Cherry which harvested 66 days after transplanting, while the Indigo Rose cultivar, on the other hand, was extremely late which harvested 112 days after transplanting.

Keywords: *Solanum lycopersicum, Yield Components, Phytochemicals, Phenolic Compounds, Antioxidants Activity*

Introduction

The tomato (*Solanum lycopersicum* L.) is a member of the Solanaceae family. It is a vital vegetable crop in terms of nutrition and economic value all over the world [1]. Over the last few decades, global tomato production has steadily increased. It increased by more than 54% between the year of 2000 and 2014 [2]. This crop is considered the world's second most cultivated and consumed vegetable after potato [3, 4]. This vegetable is beneficial to human health due to its essential nutrient diversity and high phytochemical content, which includes lycopene, β-carotene, vitamin C, and phenolic compounds; this composition explains the high antioxidant capacity of both fresh and processed tomatoes [5]. The compounds mentioned above are important for tomato commercial quality and can be influenced by many factors such as variety and environmental, agricultural, and postharvest conditions [6].

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Tomato cultivars are classified into three commercial classes: two for fresh consumption (cherry and fresh market) and one for processing into transformed products. The cherry group is characterized by small fruits (<20 g for standard cherry, 20–50 g for cocktail cherry) [7]. The wild cherry tomato originated in South America's tropical and subtropical regions, then spread to Asia and Africa's tropics [8]. It is a warm-season crop that requires a long growing season to produce more harvests, and it is the most promising crop under protected structures [9]. Cherry tomato cultivars have high consumer acceptance due to their high sweetness, as well as other organoleptic properties superior to traditional tomato fruits. Furthermore, the market value of the cherry tomato is two to three times that of other varieties, which makes it more attractive for greenhouse producers [10].

Yield and yield components such as average fruit weight, number of fruits per plant, and plant yield are quantitative traits that are controlled by several genes with minor effects. Aside from the genetic structure, these traits are influenced by a variety of environmental factors [11]. Many researchers have indicated that the average number of fruits per plant, as well as the average fruit weight, are critical in determining the level of yield performance of various tomato cultivars and hybrids [8, 12].

Besides yield and yield component characteristics, the phytochemical index is an important factor in assessing fruit quality. The pH of tomatoes is determined primarily by the acid content of the fruit. The acidity of the fruit is also important as a contributor to the flavor of the tomato products; furthermore, many studies recommended that the tomato fruits with low pH are more desirable for fresh consumption and industrial processing [13, 14]. In addition, TSS is a critical factor of crop quality and shelf life in both fresh and processed tomatoes. TSS contributes greatly to tomato flavor and consistency and is connected to the number of sugars contained in the fruit, primarily glucose and fructose; TSS also affects sensory qualities such as taste, sweetness, and acidity. Phenolic compounds are essential secondary metabolites that retain various biological activities, the most notable of which is an antioxidant activity linked to a lower risk of cancer [15]. Moreover, antioxidant capacity, or the ability to block the oxidation process, is a significant factor in determining the health benefits of food products. Tomatoes are characterized by high fruit antioxidant capacity, and many literature data indicated that this trait is genotype-specific [16, 17].

The selection of tomato cultivars for specific production areas is a critical factor in increasing productivity and yield quality. The introduction of appropriate cultivars in production based on research will provide much better opportunities for an increase in yields and better quality. Thereby, this study aims to evaluate the yield and fruit quality of newly introduced cherry tomato cultivars under high tunnel conditions in the Sulaymaniyah governorate.

Materials and Methods

Experimental Site and Soil Analysis

The experiment was conducted during the 2021 growing season at the research farm belongs to the Horticulture Department, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaymaniyah, Kurdistan Region-Iraq with a GPS reading of (latitude: 35º 32' 9.6" N, longitude: 45º 21' 54" E, altitude 741 masl). The study was carried out in a high tunnel (30 m length, 11 m width, 3.9 m height) covered with 200µm thick polyethylene plastic film. The climate of the area is classified as a semi-arid region that is hot-dry in summer and cold-moist in winter [18]. The physical and chemical properties of the soil were analyzed (Table 1).

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Table 1. Physical and chemical properties of the experiment soil

Soil Properties	Sand	Silt	Clay	Texture	pH	EC	Organic Matter	Total N	Available P	Soluble K
Unites	%	%	%	----	----	$dS\ m^{-}_{1}$	$g\ kg^{-1}$	$g\ kg^{-1}$	$mg\ kg^{-1}$	$g\ kg^{-1}$
Values	9.8	43.9	46.3	Silty-Clay	7.9	1.04	10.9	13.7	5.6	56.4

Plant Materials

Nine different pure line cultivars of cherry tomatoes were evaluated. All the lines are considered newly introduced cultivars for the Sulaymaniyah governorate. The cultivars were Indigo Rose, Oregon II, Indigo Kiwi, Saucy, Oroma, Oregon Cherry, Large German, Gold Nugget, and Indigo Cherry Drops which were developed by Oregon State University breeding programs.

Seedling Preparation and Planting Method

The seeds were sown on February, 6th 2021 in 36 well seedling trays filled with sterilized peat-moss (TS 1, Klasmann- Deilmann GmbH) under glasshouse conditions. The glasshouse was maintained at 23/18 ± 2°C day/night temperature, 14/10 h light/dark photoperiod, and relative humidity of 65 ± 10%. Seedlings at the four to five true leaves stage were transplanted on 30th, March.

The high tunnel ground was divided into six terraces with a width of 0.9 m and 0.3 m high. The distance between the centers of the two terraces was 1.7 m. Five seedlings per replication from each cultivar were planted on one line in the middle of the terraces with 40 cm between two seedlings. To uniformly distribute water across the experimental units, a drip irrigation system was used. The system included a main pipe with a diameter of 38 mm and lateral pipes with a diameter of 16 mm and an irrigation discharge capacity of 6 L h^{-1}.

Measurements

A variety of parameters were measured to evaluate some of the significant traits that influence yield and fruit quality. The number of fruits per plant, average fruit weight, plant yield, fruit pH, total soluble solid (TSS) of the fruits, total phenolic content (TPC), and antioxidant activity of the fruits were measured. Three plants from the middle of each experimental unit were used to measure all the previously mentioned parameters.

The studied cultivars were harvested six times from June 6th to August 8th, which was very helpful in distinguishing early and late cultivars. The average number of fruits per plant was determined by counting the number of fruits for the selected plants for each experimental unit.

The average weight of a single fruit was calculated by dividing the total yield of the plants in each experimental unit by the total number of fruits for the same plants. In addition, the total weight of the fruits in each experimental unit was measured, and the average was computed to determine the yield per plant in kilograms.

The fruit juice was used to measure the pH value using the pH meter (Model: JENWAY, 3510) after calibration the device by buffer solutions (pH 4 and 7); and the TSS was determined using a digital refractometer (Model: PAL-1, Atago, Tokyo Tech., Japan).

To analyze TPC and antioxidants activity in tomato fruits, the extraction process of the samples was carried out according to [19, 20]. The fruit samples were taken from the field and immediately frozen in liquid nitrogen. Samples were ground into a fine powder, and then 1 g of lyophilized powder was placed in a 15 ml tube with 10ml of 80% methanol. The samples were shaken for 3 hours and centrifuged at 5000 rpm for 10 minutes at 4 ˚C. The supernatants were placed in other tubes and stored at 4˚C as a crude extract solution for TPC and antioxidants activity assay.

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TPC of the fruits was assayed by using the Folin-Ciocalteu method with slight modifications [21]. An aliquot of 50 µl of each sample extract was mixed with 1.3 ml of Folin-Ciocalteu reagent and allowed to react for 7 minutes. Then 1.2 ml of 10% saturated Na_2CO_3 solution was added and left for 50 minutes in the dark at 40℃. The absorbance of the reaction mixture was recorded at 750 nm. The Gallic acid standard curve was used for the calculation of total phenolic content which was expressed as milligrams of gallic acid equivalent (GAE) per gram of the plant extract (mg GAE g^{-1} E) on a dry weight basis.

Furthermore, antioxidant activity was also determined by scavenging of the radical ABTS (2,2'-azino-bis (3-ethylbenzothiazoline)-6-sulfonic acid) as reported by [22] with some modifications. ABTS radical cation (ABTS•+) was prepared by adding 10 ml of 7 mM ABTS to 176 µl of 2.45 mM potassium persulphate. Then, the mixture was incubated under dark conditions and at room temperature for 16 hours. After incubation, the ABTS•+ solution was diluted with ethanol to obtain an absorbance of 0.70 ± 0.02 at 734 nm. An aliquot of 20µl of the plant extracts was added to 3ml of diluted ABTS•+ solution. The mixture was stirred vigorously and then incubated for 7 minutes under dark conditions at room temperature. The absorbance at 734 nm was recorded, and the capability to inhibit the ABTS•+ radical was calculated using the following formula:

$$\text{Inhibition (\%)} = [(\text{A734 of control} - \text{A734 of sample}) / \text{A734 of control}] \times 100$$

Experimental Design and Data Analysis

A completely randomized block design with three replications was followed in this study. The analysis of variance (One -way ANOVA), Duncan's new multiple range test at $P \leq 0.05$, multiple correlation test, and principal component analysis (PCA) were implemented using XLSTAT software.

Results

The cultivars showed broad variations for all the yield traits: number of fruits per plant, average fruit weight, and average plant yield. Gold Nugget produced the highest fruits number per plant (237.89), and Oregon Cherry ranked second with an average of 168.0 fruits per plant. However, the Indigo Rose recorded the lowest fruits number per plant with an average of (9.56) although it was not significantly different with Indigo Cherry Drops, Large German, Oroma, Saucy, and Indigo Kiwi 32.89, 31.78, 25.44, 35.44, and 12.56 fruit per plant, respectively. Despite having a relatively high fruit number per plant (97.22), the OregonII did not differ significantly from Indigo Cherry Drops, Large German, and Saucy (32.89, 31.78, and 35.44 fruits per plant, respectively) (Table 2).

The Indigo Kiwi cultivar produced the largest fruit weight (50.08 g), but it was not statistically superior to Saucy and Oroma (39.44 and 36.40 g, respectively). While the smallest fruit weight was observed in the Oregon Cherry and Gold Nugget cultivars (8.13 and 8.77 g, respectively). In addition, the average fruit weight of the OregonII, Indigo Chery Drops, Indigo Rose, and Large German was in between both categories with an average of 15.02, 17.49, 18.73, and 28.16 g, respectively (Table 2).

Gold Nugget was significantly superior to all the other cultivars in terms of average yield per plant (2.08 kg $plant^{-1}$) except for Saucy which also had a relatively high yield per single plant (1.42 kg $plant^{-1}$). The lowest average yield per plant was recorded by Indigo Rose, Indigo Kiwi, and Indigo Chery Drops (0.21, 0.50, and 0.53 kg $plant^{-1}$, respectively). In comparison to other cultivars, Large German and Oroma produced a moderate yield (0.89 and 0.83 kg $plant^{-1}$, respectively) (Table 2).

For the six distinct harvesting periods, the data revealed a wide range of fruit ripening times among cultivars (Figure 1). The earliest cultivars were Gold Nugget, OregonII, and Oregon Cherry, with the first harvesting date being June 6^{th}, 2021, or 66 days after the transplanting date. The Indigo Rose cultivar,

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on the other hand, was extremely late with the first harvest occurring on July 7th (about 112 days after the transplanting date).

Table 2. Yield and yield components of the studied cherry tomato cultivars

Cultivars	Number of Fruits Plant^{-1}	Average Fruit Weight (g)	Yield (kg plant^{-1})
Indigo Rose	9.56 d	18.73 cd	0.21 c
Oregon II	97.22 c	15.02 cd	1.35 b
Indigo Kiwi	12.56 d	50.08 a	0.50 c
Saucy	35.44 cd	39.44 ab	1.42 ab
Oroma	25.44 d	36.40 ab	0.83 bc
Oregon Cherry	168.00 b	8.13 d	1.36 b
Large German	31.78 cd	28.16 bc	0.89 bc
Gold Nugget	237.89 a	8.77 d	2.08 a
Indigo Chery Drops	32.89 cd	17.49 cd	0.53 c

Different letters in the same column indicate significant differences between means according to Duncan's new multiple range test at P≤ 0.05.

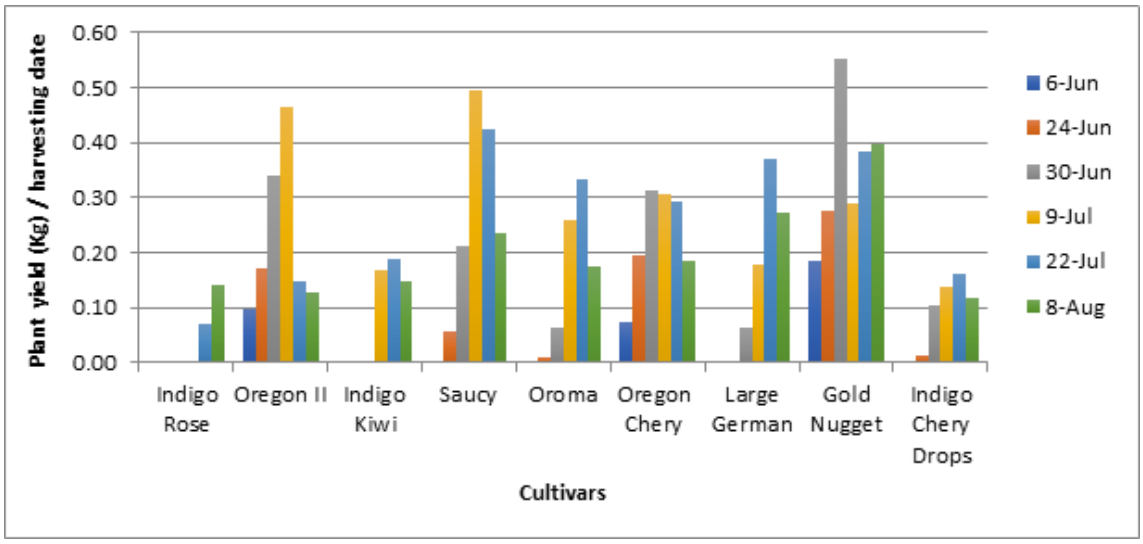

Figure 1. The plant yield (Kg) of each harvesting date for the studied cultivars

Alongside yield and yield component characteristics, various chemical traits of the fruits were measured, such as pH, TSS (%), TPC, and antioxidants activity by ABTS assay. The chemical traits differed significantly between cultivars (Table 3). All the cultivar's pH values ranged between 3.76 to 4.45. Oregon Chery, Gold Nugget, Oregon II, Indigo Chery Drops, and Large German showed significantly low pH (3.78, 3.76, 3.81, 3.9, and 3.9, respectively). However, Oroma and Saucy showed the highest pH values 4.45 and 4.31, respectively. Regarding TSS, the Oregon II cultivar recorded the highest value

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of TSS (9.60%). Whereas, the TSS values for Oregon Chery, Indigo Chery Drops, Oroma, and Large German were also relatively high (7.57, 7.03, 6.70, and 6.60%, respectively). Saucy and Indigo Kiwi had relatively low TSS values (5.47 and 4.90%, respectively), and Indigo Rose showed the lowest TSS value among all the other cultivars (3.71%).

The Indigo Kiwi cultivar was significantly superior to other cultivars in TPC value (0.87 mg GAE g^{-1} E). Whereas, Oregon Cherry showed relatively high contents in TPC (0.56 mg GAE g^{-1} E) in comparison to all other cultivars except the Indigo Kiwi. While, Gold Nugget, Large German, and Oroma showed the lowest value of TPC (0.11, 0.12, and 0.17 mg GAE g^{-1} E, respectively). In terms of antioxidants activity to scavenge ABTS radicals in the fruits, Saucy had the highest percentage of ABTS radical inhibition (44.95%), which was significantly higher than all other cultivars except OregonII, Indigo cherry drops, and Indigo Rose (38.05, 38.92, and 38.05%, respectively). Gold Nugget, on the other hand, had the lowest ABTS radical inhibition capacity (14.04%) (Table 3).

Table 3. Fruit quality of the studied cherry tomato cultivars

Cultivars	pH	TSS (%)	TPC (mg GAE g^{-1} E)	ABTS Inhibition (%)
Indigo Rose	4.13 cd	3.71 f	0.23 d	38.05 a
Oregon II	3.81 a	9.60 a	0.34 c	38.05 a
Indigo Kiwi	4.09 bc	4.90 e	0.87 a	27.96 b
Saucy	4.31 de	5.47 de	0.39 c	44.95 a
Oroma	4.45 e	6.70 bc	0.17 de	24.51 b
Oregon Chery	3.78 a	7.57 b	0.56 b	20.04 bc
Large German	3.90 ab	6.60 bcd	0.12 e	18.35 bc
Gold Nugget	3.76 a	6.17 cd	0.11 e	14.04 c
Indigo Chery Drops	3.90 ab	7.03 bc	0.25 d	38.92 a

Different letters in the same column indicate significant differences between means according to Duncan's new multiple range test at $P \leq 0.05$.

The PCA was conducted to determine the relationship between the cultivars. The first two main components (PC1 and PC2) explained together 72.02% of the observed variation and were thus represented in a two - dimensional space (Figure 2). PC1 plotted on the horizontal axis, illustrated the highest proportion of the variance (58.92%), while PC2, plotted on the vertical axis, accounted for a further 13.10% of the total variation. According to PCA, the cultivars were grouped into four discrete groups relying on all the studied variables. Indigo Kiwi, Oroma, and Saucy clustered in one group. On the other hand, Indigo Rose, Indigo Cherry Drops, and Large German were close to each other. In contrast, Oregon II and Oregon Cherry were grouped in one cluster while Gold Nugget was alone in a distinct cluster.

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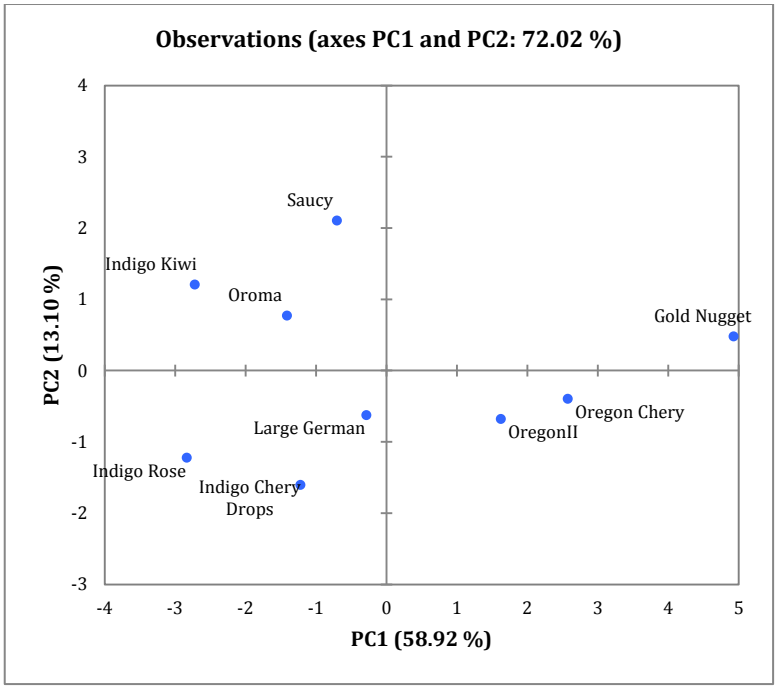

Figure 2. PCA biplot showing the distributions of the studied cherry tomato cultivars based on the studied variables

The multiple correlations analysis showed a significant association between some of the variables (Table 4). The results showed that there is a strong positive correlation between the number of fruits per plant and plant yield with a coefficient of correlation (r^2 = 0.85). Also, a significant positive correlation was observed between fruit pH and average fruit weight (r^2 = 0.73). However, a significant negative correlation was recorded between average fruit weight and the number of fruits per plant (r^2 = -0.70). there is a strong positive correlation between the number of fruits per plant and plant yield with a coefficient of correlation (r^2 = 0.85).

Table 4. Multiple correlations among all the studied traits

Traits	Average Fruit Weight (g)	Yield (kg plant^{-1})	pH	TSS (%)	TPC (mg GAE g^{-1} E)	ABTS Inhibition (%)
Number of Fruits plant^{-1}	-0.70*	0.85**	-0.66	0.37	-0.15	-0.56
Average Fruit Weight (g)		-0.40	0.73*	-0.42	0.44	0.23
Yield (kg plant^{-1})			-0.39	0.43	-0.20	-0.37
pH				-0.46	0.02	0.37
TSS (%)					-0.12	-0.09
TPC (mg GAE g^{-1} E)						0.14

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Discussion

Nine newly introduced cherry tomato cultivars were evaluated to select the most adapted cultivars to the region. For that aim, yield components and several quality parameters were measured. The yield components, particularly the number of fruits per plant and average fruit weight, as well as their balance, are the most significant features that have a direct relationship to the quantity of plant output [8, 12]. In the current study, the Gold Nugget cultivar had the highest fruit number and average yield per plant but it had the lowest average fruit weight. Whereas, the Indigo Kiwi cultivar had the highest average fruit weight but a relatively low number of fruits and yield per plant (Table 2). This might explain the positive correlation between plant yield and the number of fruits per plant among the cultivars (r^2 = 0.85**), and the negative correlation between the plant yield and average fruit weight (r^2 = - 0.40), although it did not reach the significant level (Table 4). As a result, the number of fruits per plant, rather their weight, plays the most important role in increasing plant yield. These results agreed with previous studies that showed that the fruit number per plant is a key factor in determining a plant's economic output in cherry tomatoes [8]. Furthermore, a strong negative association (r^2 = - 0.70*) was discovered between the average fruit weight and the number of fruits per plant (Table 4). It might be due to the limited energy (source) in comparison with a high number of flowers and fruits (sinks) per plant. In a source-limited situation, carbohydrate content in the plants might be low as plants have sufficient sinks to utilize the produced assimilates. Subsequently, a low source/sink ratio negatively correlates with the potential fruit size [23]. Similar results were obtained by [9, 24] who mentioned that increasing fruit number leads to decreasing average fruit weight. The variation in the genetic makeup of the cultivars and their interaction with the environmental factors might explain the variation in yield and yield components characteristics of the studied cultivars [25].

Regarding the fruit quality, The pH value represents the concentration of hydrogen ions in the fruit, which represents the acidity level; the acidity of the fruit is crucial as a contributor to the flavor of tomato products and processing tomato features [13, 26]. According to studies, the pH range in many different cherry tomato cultivars varies between 3.76 to 4.56 [5], which is completely consistent with our finding of a pH range from 3.76 to 4.45 (Table 3).

TSS is a refractometric measure that represents the percentage (%) of dissolved solids in fruit pulp. It is composed of sugars, acids, and other minor components [27, 28]. The TSS is the most important characteristic for tomato fruit sweetness perception and marketing value [29]; which is influenced by several elements such as genetics, growth environment, and management practices [30]. Researches reported that the TSS in cherry tomatoes was ranged between 3.06 to 8.77% [5, 31, 32, 33]; which is relatively close to our finding of a TSS range from 3.71 to 9.60% (Table 3).

Furthermore, tomato is also a source of phenolic compounds which contribute to its antioxidant properties and health benefits [34]. These compounds are important for the detoxification of free radicals [6]. The studied cultivars showed a wide range of total phenol content which ranged from 0.87 to 0.11 mg GAE g^{-1} E. Many studies on the antioxidant properties of foods have focused on phenolic chemicals [35]. The studied cultivars showed clear variation in terms of antioxidants activity to scavenge ABTS radicals in the fruits which were varied from 14.04 - 44.95 ABTS inhibition percentage (Table 3). Our findings agree with the concept of the results of many studies that mentioned that different cherry tomato genotypes show broad variation in antioxidant activity, for instance, [36] reported a wide range of antioxidant activity in eight advanced cherry tomato lines. This variance could be attributable to the genetic background of each cultivar.

Conclusions

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According to the findings of the current study, the studied cultivars showed extraordinary diversity for both yield and yield components and fruit quality characteristics. Gold Nugget produced the most fruit and yield per plant, making it a potential cultivar for the region. Furthermore, the Indigo Kiwi cultivar contained the highest phenolic compounds among all the other cultivars. In addition, the Gold Nugget, OregonII, and Oregon Cherry were the earliest cultivars. In contrast, the Indigo Rose cultivar was extremely late. These genotypes could be used in future breeding programs to boost fruit yield and quality.

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