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# Effect of Plastic Mulching on Strawberry Fruit Yield and Quality

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## Abstract

A field experiment was carried out during the two successive winter seasons of 2017/18 and 2018/19. The aims of the experiment were to investigate the effect of using three different mulch treatments (black polyethylene, clear polyethylene, and bare soil) on strawberry 'Florida' and 'Winterstar' cultivars *(Fragaria X ananassa* Duch*)* regarding the fruit yield, yield attributes, and some fruit quality characteristics (vitamin C, anthocyanin, acidity, TSS, and TSS: acidity), along with the financial aspects of using polyethylene mulching for strawberry productivity. Compared to the un-mulched plants, the total fruit yield of 'Florida' and 'Winterstar' plants was increased by ~40-49% and 17-18%, respectively in the black plastic mulching in the two years. Clear plastic mulching was accompanied by an increased total yield of 'Florida' by 19-34%, while decreased 'Winterstar' fruit yield by 14-24%. Regarding vitamin C content, the main effects of mulching treatment showed that plants grown in black plastic mulching had significantly higher vitamin C content than clear plastic (both seasons) or no mulching (second season). 'Florida' plants in the black plastic mulching achieved significantly the highest vitamin C levels compared to the other treatments. Similarly, 'Florida' plants in the black plastic mulching had higher TSS content than the other mulching treatments. Depending on the cultivar used and the growing season, plastic mulching (whether clear or black) was beneficial in improving the fruits anthocyanin content compared to the un-mulched plants. In conclusion, plastic mulching (especially the black) was helpful in improving fruits contents of vitamin C and anthocyanin compared to the un-mulched plants. Regarding the financial aspect, using black plastic mulching for strawberry production in Assiut governorate was more profitable than the un-mulched farm.

***Keywords:*** *Black Plastic Mulching, Clear Plastic Mulching, Vitamin C, Anthocyanin, TSS, Financial Aspect.*

## Introduction

Mulches are materials applied over the soil surface around the plants to benefit soil and plants as well. Mulches can be made of polyethylene (plastics), straws, leaves, or other materials. Several advantages were reported for using mulches including suppressing weeds, reducing soil evaporations, reducing amounts of fertilizers and pesticides application, and modifying soil temperatures (Chalker-Scott 2007; Kasirajan and Ngouajio 2012; Qin *et al*. 2015; Rajablariani *et al*. 2012; Singh and Kamal 2012). Mulching may also improve the use efficiency of water and nitrogen. Consequently, mulching may improve crop yields (Chalker-Scott 2007; Kasirajan and Ngouajio 2012; Qin *et al*. 2015; Rajablariani *et al*. 2012; Singh and Kamal 2012), particularly in arid and semi-arid regions where soil is

less fertile and water input is limited (Farrag *et al.* 2016; Qin *et al.* 2015). Plastics are the most widely used material in mulching in the modern field production, particularly black polyethylene (Haapala *et al*. 2014).

The world most cultivated desert strawberry species (*Fragaria X ananassa*) is a hybrid of *F. chiloensis* and *F. virginiana* (Hancock *et al*. 2008). The annual world production quantities of this hybrid species have doubled in the last 20 years reaching more than 9 million tons in 2017 (Hancock *et al*. 2008; FAOSTAT 2017). With a production of more than 407 thousand tons in 2017, Egypt is ranking one of the top five strawberry producing countries in the world (FAOSTAT 2017). In Egypt, strawberries are considered one of the profitable horticultural crops that are used for local consumption and for exportation as well (EL-Shal *et al*. 2003).

The delicate fruits of strawberry rest on the ground in direct contact with soil surface which makes the fruits unclean and susceptible to soil-borne pathogen infections, resulting in a reduced fruit quality (Haapala *et al*. 2014; Pandey *et al*. 2015; Poling 1993). This is an additional advantage of using mulches in strawberry production by reducing the number of diseased and dirty berries (Haapala *et al*. 2014; Pandey *et al*. 2015; Poling 1993). Mulching strawberries can also protect plants from frost damage in the winter (Poling *et al*. 1991). Strawberry is among the world's most horticultural crops grown with the use of plastic film whether in greenhouses, soil mulches, tunnels, or row covers (Wittwer 1993). Interestingly, the fruit quality of strawberry was found to differ due to several factors including the environmental factors, the choice of genotypes, and the used cultural systems (Pincemail *et al*. 2012).

In Egypt, Ismalia, Beheira, and Qaluobia are the three main governorates that grow and produce strawberry (Abdelgawad 2019). Ismailia leads strawberry production because of its suitable climate conditions which result in a high strawberry productivity and extended harvest time for about six months around the year (El-Marzoky *et al.* 2018; Essa 2015). The less favorable climate conditions of Assiut governorate has limited its contribution in strawberry production (Mohamed *et al*. 2017). Therefore, *the* aims of the present study were to:1) Investigate the effects of using three different mulch treatments (clear and black polyethylene, in addition to the unmulched soil) on the strawberry fruit yield, yield attributes, and some quality characteristics (Vitamin C, anthocyanins, acidity, and TSS) in 'Florida' and 'Winterstar' cultivars, 2) Investigate the financial aspects of using mulching for strawberry productivity in Assiut governorate.

## Materials and Methods

### Experimental site, soil characteristics, and season of planting

A field experiment was conducted at the Experimental Farm of Vegetable Crops Department, Faculty of Agriculture, Assiut University, Egypt, during two successive winter seasons (from October to April) in 2017/2018 (season 1) and 2018/2019 (season 2). The soil texture of the experimental site was clay with an average pH of 7.65. The experimental site was located at 270 18' latitude and 310 18' longitudes and at an elevation of 70 meters above sea level.

### Experimental design and treatments

The study consisted of two factors: 1) three mulching treatments which included black and clear polyethylene mulches, and bare soil (control), and 2) two cultivars *Fragaria ananassa,* 'Florida' and 'Winterstar'. After preparing the field rows, raised rows were 350 cm X 70 cm, arranged in a randomized complete block with three replications. Mulch films were laid out close to soil

surface one day before planting. Each plot comprised 24 plants in two rows. Strawberry plantlets of the two cultivars used were previously cold stored (Frigo). Plantlets were obtained from the faculty of Agriculture, Ain Shams University, Cairo, Egypt. Before planting, transplants were dipped in a fungicide 0.2% Rizolex solution for 20 minutes. The planting distance was 25 cm and the row distance was 70 cm. All experimental plots and treatments received similar agricultural practices of irrigation, fertilization, and pest and disease control.

**Weather data**

Meteorological data of the mean maximum temperature, mean minimum temperature, average daily temperatures, and minimum field temperatures were collected during the study period from Assiut University Meteorological Station, Assiut, Egypt (Table 1 and Fig.1). Climatic data were recorded at a weather station 200 m away from the experimental site. The mean minimum temperature was recorded 1.5 m above soil surface, whereas minimum field temperature was recorded 5 cm above soil surface. The field area experiences an arid climate where winter season for planting is from October/November to April/May.

**Table 1. The mean values of daily maximum, minimum, average daily temperatures, and air humidity.**

| Month (Mean) | Max. Temp. | | Min. Temp. | | Average daily | | Air Humidity | |
|---|---|---|---|---|---|---|---|---|
| | Season 1 | Season 2 | Season 1 | Season 2 | Season 1 | Season 2 | Season 1 | Season 2 |
| October | 32.9 | 35.0 | 16.6 | 18.5 | 27.1 | 28.6 | 55.2 | 47.7 |
| November | 27.4 | 28.4 | 11.2 | 12.3 | 21.1 | 22.2 | 57.1 | 57.2 |
| December | 24.3 | 22.5 | 8.8 | 7.5 | 17.9 | 17.0 | 61.2 | 62.2 |
| January | 22.2 | 20.9 | 5.6 | 4.9 | 15.6 | 14.9 | 62.1 | 61.2 |
| February | 26.7 | 23.1 | 9.9 | 6.9 | 20.3 | 17.3 | 55.4 | 56.1 |
| March | 31.9 | 26.2 | 13.5 | 9.7 | 25.0 | 20.4 | 42.3 | 52.7 |
| April | 34.4 | 31.4 | 15.7 | 13.9 | 28.0 | 25.9 | 38.5 | 45.8 |

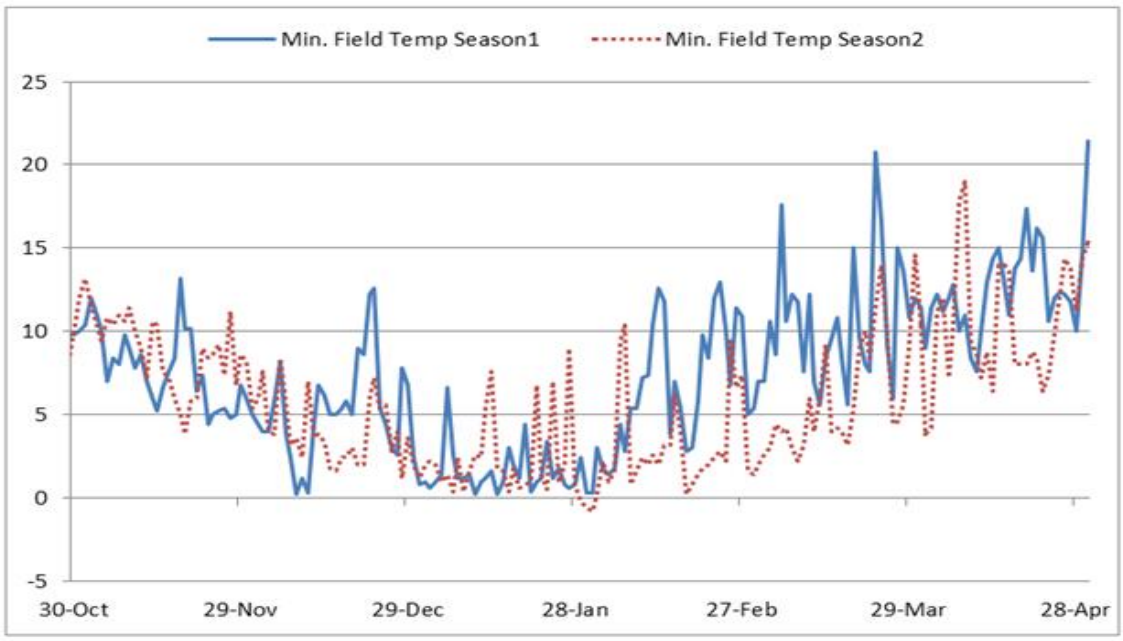


**Fig. 1.** Minimum field temperatures from October, 30th to April, 30th in 2017/18 and 2018/19 growing seasons.

**Fruit yield and quality measurements**

Fruits were harvested from the last week of February until the end of April for a total number of 12 fruit pickings in the experiment. Two midterm pickings from each plot were used for fruit length, width, and weight measurements. Also, two midterm pickings of uniform and well-colored strawberries were used for quality parameters measurements of TSS, acidity, anthocyanin, and vitamin C contents. Measurements were as follows:

**1. Yield and yield components:**

**1.1 Total fruit yield (kg/fed):** from each treatment all over the growing season, harvested fruits were weighed, and total weight was calculated in kg/fed.

**1.2 Early yield (Kg/fed):** the first four fruit harvests were weighed and total weight was calculated in kg/fed.

**1.3 Berry weight (g):** berry weight of single berries of each fruit harvest was recorded and expressed as mean berry weight in grams.

**1.4 Percent increase in fruit yield:** calculated as following:

[(Fruit yield of plants grown over black or clear plastic mulch treatment- fruit yield of the unmulched plants)/fruit yield of unmulched plants]X100.

**1.5 Fruit length (cm):** two midterm pickings were used for fruit length measurement in cm from calyx plug to the apex of the fruit using Vernier caliper.

**1.6 Fruit diameter (cm):** two midterm pickings were used for fruit diameter measurement in cm using Vernier caliper.

**2. Fruit quality measurements:**

**2.1 Total soluble solids percentage (TSS%):** was determined using a hand refractometer.

**2.2 Total titrable acidity**: was determined by titrating pure fruit juice against NaOH 0.1 N and phenolphthalein as an indicator (AOAC. 1984). Acid content was expressed as g citric acid/100ml fruit juice.

**2.3 TSS: acid ratio:** was calculated by dividing the percentage of TSS on the total acidity.

**2.4 Vitamin C content:** was estimated according to the standard method described in AOAC, 1984, and expressed as mg/100 g.

**2.5 Total anthocyanin content:** extract was prepared by the method defined by Rababah *et al*. (2005), and total anthocyanin content was calculated according to Rabino and Mancinelli (1986).

**Financial estimates of the study**

Financial estimates of the experiment are derived from the amounts of the total fruit yield during the first season of the present experiment (Table 4). Measurement of the financial estimates included two aspects, the net profit and the return value of the Egyptian pound. The net profit was calculated by subtracting the total costs from the total revenue. The return value of the Egyptian pound was calculated by dividing total revenue by total costs.

**Statistical analysis**

The experimental data were statistically analyzed using 1998-2004 CoHort Software, CoStat Software, version 6.303 (798 Lighthouse Ave. PMB 320, Monterey, CA, 93940, USA). The experimental data were statistically analyzed using analysis

of variance (ANOVA) and means were compared by Duncan's multiple range tests at 5% probability level.

## Results

### Weather conditions

The mean values for the maximum, minimum, and the average daily temperatures from October to January were comparable between the two seasons (Table 1). Starting from February, the mean maximum, minimum, and average daily temperatures were considerably lower in season two than in season one (Table 1). The minimum field temperature from January to April in season two was consistently lower than the first season (Fig. 1), reaching below 0° for three days in late January of the second season.

### Effect of mulching treatments on fruit yield and yield attributes

The interaction effect of mulch treatment and cultivar on the total fruit yield was not significant. It showed that total fruit yield of 'Florida' plants grown in the black mulch treatment was increased by 49% and 40.6% in season 1 and 2, respectively than the un-mulched plants (Tables 4 and 5; Fig. 2). In 'Winterstar' plants, the total fruit yield was increased by 17% and 18% in season 1 and 2, respectively (Fig. 2).

Plants of 'Florida' grown in the clear plastic mulching treatment had higher yields than the control by 34% and 19% in season 1 and 2, respectively (Fig. 2). But 'Winterstar' was negatively impacted by clear plastic treatment as total fruit yield was decreased by 14% and 24% in seasons 1 and 2, respectively (Fig. 2).

Main effects of mulching showed that early yield of un-mulched plants was significantly lower than clear (season one) or black (season two) plastic mulching treatments (Table 2). Also, 'Florida' plants with clear plastic mulching had higher early fruit yield than the un-mulched plants but it was significant in the first season only (Tables 4 and 5).

Mulching and cultivar interactions had no significant advantages on fruit length or diameter but 'Winterstar' of clear mulch treatment had higher fruit length and diameter than the un-mulched plants in the first season only (Table 4). Berry weight of 'Florida' was significantly the highest in clear plastic treatments in the first season, and was significantly higher than berry weight of the black plastic treatment in the second season (Tables 4 and 5). Main effect of cultivars showed that 'Winterstar' had a higher berry weight than 'Florida' (Table 3).

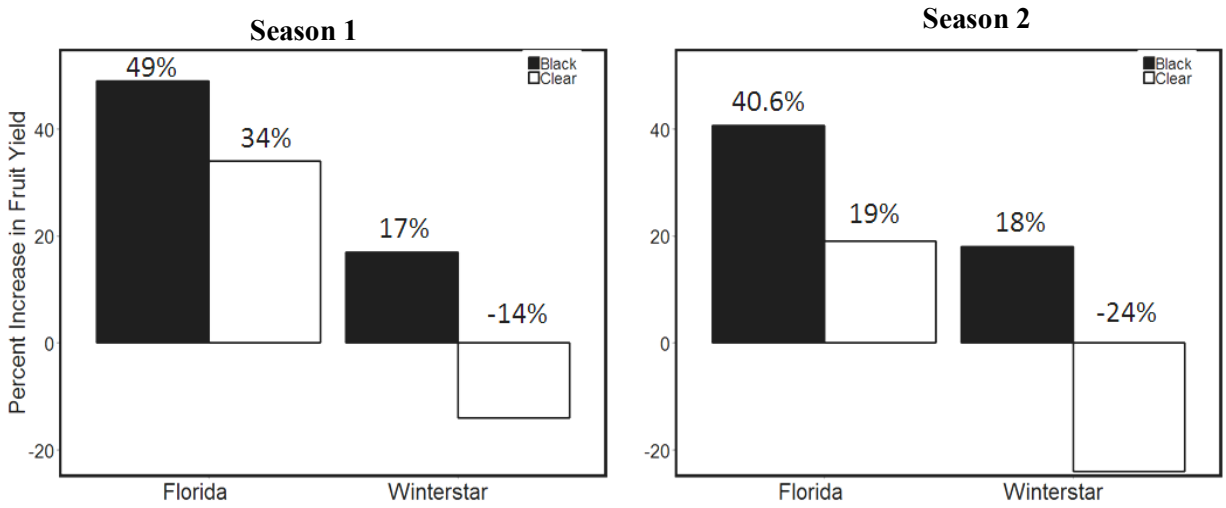


**Fig. 2.** Percent increase in total fruit yield of 'Florida' and 'Winterstar' plants grown in black and clear plastic mulch treatments as compared to the un-mulched treatment.

**Table 2. Main effect of mulching treatments on fruit yield (kg/fed), early yield (kg/fed), berry weight (g), fruit diameter (cm), and fruit length (cm) of 'Florida' and 'Winterstar' strawberry cultivars in the growing seasons of 2017/18 and 2018/19.**

| Season1 | | | |
|---|---|---|---|
| | **Black Plastic** | **Clear Plastic** | **No Mulch** |
| **Fruit yield (kg/fed)** | 3405.62 A | 2769.40 A | 2610.47 A |
| **Early yield (kg/fed)** | 444.7 AB | 485.14 A | 394.1 B |
| **Berry weight (g)** | 9.3 B | 10.85 A | 9.2 B |
| **Fruit diameter (cm)** | 2.9 A | 2.9 A | 2.7 B |
| **Fruit length (cm)** | 3.2 AB | 3.3 A | 3.0 B |
| **Season 2** | | | |
| | **Black Plastic** | **Clear Plastic** | **No Mulch** |
| **Fruit yield (kg/fed)** | 2087.61 A | 1538.52 A | 1645.08 A |
| **Early yield (kg/fed)** | 394.2 A | 352.4 AB | 328.7 B |
| **Berry weight (g)** | 10.3 A | 10.6 A | 10.8 A |
| **Fruit diameter (cm)** | 2.8 A | 2.9 A | 3.0 A |
| **Fruit length (cm)** | 3.6 A | 3.8 A | 3.8 A |

Means within rows denoted by different letters indicate significant difference according to Duncan's test at $P<0.05$.

**Table 3. Main effect of cultivars on fruit yield (kg/fed), early yield (kg/fed), berry weight (g), fruit diameter (cm), and fruit length (cm) of all mulch treatments for 'Florida' and 'Winterstar' strawberry cultivars in the growing seasons of 2017/18 and 2018/19.**

| Season1 | | | |
|---|---|---|---|
| | **Florida** | **Winterstar** | **F test** |
| **Fruit yield (kg/fed)** | 2768.62 | 3088.37 | ns |
| **Early yield (kg/fed)** | 419.9 | 462.8 | ns |
| **Berry weight (g)** | 9.4 | 10.2 | * |
| **Fruit diameter (cm)** | 2.8 | 2.9 | ns |
| **Fruit length (cm)** | 3.1 | 3.2 | ns |
| **Season 2** | | | |
| | **Florida** | **Winterstar** | **F test** |
| **Fruit yield (kg/fed)** | 1579.10 | 1935.04 | ns |
| **Early yield (kg/fed)** | 320.7 | 396.2 | * |
| **Berry weight (g)** | 10.0 | 11.1 | * |
| **Fruit diameter (cm)** | 3.0 | 2.8 | ns |
| **Fruit length (cm)** | 3.7 | 3.7 | ns |

**Table 4. Interaction effect of mulching treatments and cultivars on fruit yield (kg/fed), early yield (kg/fed), berry weight (g), fruit diameter (cm), and fruit length (cm) of 'Florida' and 'Winterstar' strawberry cultivars in the growing season of 2017/18.**

| Parameter | Cultivar | Mulch treatment | | |
|---|---|---|---|---|
| | | **Black** | **Clear** | **No Mulch** |
| | | **Mean** | **Mean** | **Mean** |
| **Fruit yield (kg/fed)** | **Florida** | 3233.25 a | 2906.15 a | 2166.46 a |
| | **Winterstar** | 3577.99 a | 2632.66 a | 3054.47 a |
| **Early yield (kg/fed)** | **Florida** | 404.24 bc | 477.66 ab | 377.69 c |
| | **Winterstar** | 485.22 ab | 492.63 a | 410.57 abc |
| **Fruit diameter (cm)** | **Florida** | 2.8 ab | 2.8 ab | 2.6 b |
| | **Winterstar** | 2.9 ab | 3.0 a | 2.7 b |
| **Fruit length (cm)** | **Florida** | 3.2 ab | 3.2 ab | 2.9 b |
| | **Winterstar** | 3.2 ab | 3.4 a | 3.1 b |
| **Berry weight (g)** | **Florida** | 9.0 c | 10.5 ab | 8.7 c |
| | **Winterstar** | 9.7 bc | 11.2 a | 9.6 bc |

Means combinations denoted by different letters indicate significant difference according to Duncan's test at P<0.05.

**Table 5. Interaction effect of mulching treatments and cultivars on fruit yield (kg/fed), early yield (kg/fed), berry weight (g), fruit diameter (cm), and fruit length (cm) of 'Florida' and 'Winterstar' strawberry cultivars in the growing season of 2018/19.**

| Parameter | Cultivar | Mulch treatment | | |
|---|---|---|---|---|
| | | **Black** | **Clear** | **No Mulch** |
| | | **Mean** | **Mean** | **Mean** |
| **Fruit yield (kg/fed)** | **Florida** | 1850.73 ab | 1569.90 ab | 1316.65 b |
| | **Winterstar** | 2324.48 a | 1507.14 ab | 1973.50 ab |
| **Early yield (kg/fed)** | **Florida** | 345.0 b | 335.5 b | 281.6 b |
| | **Winterstar** | 443.5 a | 369.3 ab | 375.7 ab |
| **Fruit diameter (cm)** | **Florida** | 2.7 b | 3.2 a | 3.1 a |
| | **Winterstar** | 2.9 ab | 2.7 b | 2.9 ab |
| **Fruit length (cm)** | **Florida** | 3.5 a | 3.9 a | 3.7 a |
| | **Winterstar** | 3.7 a | 3.7 a | 3.8 a |
| **Berry weight (g)** | **Florida** | 8.9 b | 10.4 a | 10.6 a |
| | **Winterstar** | 11.7 a | 10.8 a | 11.0 a |

Means combinations denoted by different letters indicate significant difference according to Duncan's test at P<0.05.

**Effect of mulching on fruit quality**

Mulching treatments had significant effects on the anthocyanin content of strawberry fruits ($p \leq 0.05$) in both seasons (Table 6). In 'Florida' cultivar, plants grown in the black plastic mulching had significantly the highest anthocyanin content in the first season, whereas, in the second season, plants from the clear plastic treatment had significantly higher fruit anthocyanin content than the un-mulched treatment (Tables 8 and 9). Also, 'Winterstar' fruits had significantly higher anthocyanin content in plants grown in the black and clear plastic mulching than the un-mulched plants in the first season (Tables 8 and 9).

Regarding vitamin C content, main effects of mulching treatments showed that strawberry fruits grown in the black plastic mulching had higher vitamin C content (85 vs. 63) than those grown in the clear plastic mulch in the first season, and higher than those grown under clear and un-mulched treatments (112 vs. 68 and 48, respectively) in the second season (Table 6). Therefore, values of vitamin C are the highest in plants grown over black mulch treatments in the whole experiment (Table 6).

In both seasons, 'Florida' plants had significantly higher vitamin C content in plants grown with black plastic mulching than those grown with clear or no mulching (Tables 8 and 9). In the present study, vitamin C content was slightly higher than values recorded in 'Florida' cultivar in other studies (Das *et al*. 2007), but it was also lower than what was found under Assiut conditions by Mohamed *et al.,* 2017 (Mohamed *et al.* 2017).

Total soluble solids were significantly affected by the genotype and treatment interactions ($p \leq 0.05$). In both seasons, 'Florida' cultivar fruits from the black plastic mulch treatment had the highest TSS content of all treatments (Tables 8 and 9). On the other hand, in 'Winterstar' cultivar, un-mulched plants had higher fruit TSS than black mulch treatment in both seasons but it was significant in the second season only (Tables 8 and 9). In 'Winterstar', fruits of plants grown un-mulched had the highest acidity levels but it was significant in the second season only. TSS: acidity ratio did not have a specific trend. The main effect showed that fruits from the black plastic mulch treatment had higher TSS: acidity ratio than the clear plastic plants in the first season, but it was higher than the un-mulched plants in the second season.

**Table 6. Main effect of mulching treatments on fruit anthocyanin, vitamin C, TSS, acidity, and TSS: acidity of 'Florida' and 'Winterstar' strawberry cultivars in the growing seasons of 2017/18 and 2018/19.**

| Season1 | | | |
|---|---|---|---|
| | **Black Plastic** | **Clear Plastic** | **No Mulch** |
| **Anthocyanin** | 37.2 A | 30.5 B | 27.9 B |
| **Vitamin C** | 84.8 A | 63.0 B | 77.8 A |
| **TSS** | 7.3 AB | 6.5 B | 7.5 A |
| **Acidity** | 0.67 B | 0.78 A | 0.68 AB |
| **TSS: acidity** | 11.1 A | 8.4 B | 11.4 A |
| **Season 2** | | | |
| | **Black Plastic** | **Clear Plastic** | **No Mulch** |
| **Anthocyanin** | 32.2 AB | 35.9 A | 29 B |
| **Vitamin C** | 111.6 A | 67.5 B | 48 C |
| **TSS** | 7.8 A | 7.5 A | 7.8 A |
| **Acidity** | 0.54 B | 0.65 B | 0.96 A |
| **TSS: acidity** | 14.5 A | 13.4 A | 8.6 B |

Means within rows denoted by different letters indicate significant difference according to Duncan's test at P<0.05.

**Table 7. Main effect of cultivars on fruit anthocyanin, vitamin C, TSS, acidity, and TSS: acidity of 'Florida' and 'Winterstar' strawberry cultivars in the growing seasons of 2017/18 and 2018/19.**

| Season1 | | | |
|---|---|---|---|
| | **Florida** | **Winterstar** | **F test** |
| **Anthocyanin** | 32.8 | 30.9 | ns |
| **Vitamin C** | 87 | 63.4 | *** |
| **TSS** | 7 | 7.2 | ns |
| **Acidity** | 0.65 | 0.77 | ** |
| **TSS: acidity** | 11.1 | 9.4 | ns |
| **Season 2** | | | |
| | **Florida** | **Winterstar** | **F test** |
| **Anthocyanin** | 37.8 | 26.9 | *** |
| **Vitamin C** | 85.4 | 66.0 | * |
| **TSS** | 8.6 | 6.8 | *** |
| **Acidity** | 0.82 | 0.62 | * |
| **TSS: acidity** | 11.3 | 13.1 | ns |

**Table 8. Interaction effect of mulching treatments and cultivars on fruit anthocyanin, vitamin C, TSS, acidity, and TSS: acidity of 'Florida' and 'Winterstar' strawberry cultivars in the growing season of 2017/18.**

| **Parameter** | **Cultivar** | **Mulch treatment** | | |
|---|---|---|---|---|
| | | **Black** | **Clear** | **No Mulch** |
| | | **Mean** | **Mean** | **Mean** |
| **Anthocyanin** | **Florida** | 40.4 a | 26.1 c | 32.0 b |
| | **Winterstar** | 34.0 b | 34.8 ab | 23.9 c |
| **Vitamin C** | **Florida** | 102 a | 76.5 b | 82.5 b |
| | **Winterstar** | 67.5 b | 49.5 c | 73.1 b |
| **TSS** | **Florida** | 8 a | 6 b | 7 ab |
| | **Winterstar** | 6.7 ab | 7 ab | 8 a |
| **Acidity** | **Florida** | 0.64 bc | 0.77 ab | 0.55 c |
| | **Winterstar** | 0.70 ab | 0.79 a | 0.81 a |
| **TSS: acidity** | **Florida** | 12.6 ab | 7.9 c | 13.0 a |
| | **Winterstar** | 9.5 bc | 8.9 c | 9.9 abc |

Means combinations denoted by different letters indicate significant difference according to Duncan's test at P<0.05.

**Table 9. Interaction effect of mulching treatments and cultivars on fruit anthocyanin, vitamin C, TSS, acidity, and TSS: acidity of 'Florida' and 'Winterstar' strawberry cultivars in the growing season of 2018/19.**

| Parameter | Cultivar | Mulch treatment | | |
|---|---|---|---|---|
| | | Black | Clear | No Mulch |
| | | Mean | Mean | Mean |
| Anthocyanin | Florida | 35.3 b | 43.2 a | 34.9 b |
| | Winterstar | 29.1 bc | 28.6 bc | 23.0 c |
| Vitamin C | Florida | 127.2 a | 88.5 b | 40.5 c |
| | Winterstar | 96 b | 46.5 c | 55.5 c |
| TSS | Florida | 9.5 a | 8 bc | 8.3 b |
| | Winterstar | 6 d | 7 cd | 7.3 bc |
| Acidity | Florida | 0.64 ab | 0.87 a | 0.94 a |
| | Winterstar | 0.45 b | 0.43 b | 0.98 a |
| TSS: acidity | Florida | 15.0 ab | 9.4 bc | 9.5 bc |
| | Winterstar | 14.1 ab | 17.4 a | 7.7 c |

Means combinations denoted by different letters indicate significant difference according to Duncan's test at P<0.05.

## The financial aspect of using mulching for strawberry production

Our cost estimates are derived from the amounts of the total fruit yield during the first season of the present experiment (Tables 4 and 10). These estimates show that strawberry production of 'Florida' cultivar in Assiut governorate using the un-mulched cultivation system will result in a net loss of LE 6553 per feddan (Table 10), whereas in 'Winterstar' will result in a net profit of LE 6767 (Table 10). On the other hand, the estimates for the net profit using black plastic mulch for 'Florida' and 'Winterstar' are LE 12499 and LE 17670 per feddan, respectively, while those for the clear plastic are LE 7892 and LE 3790 per feddan, respectively (Tables 10). The return value of the Egyptian pound shows that for every LE 1000 spent in strawberry production of 'Florida' and 'Winterstar' in black plastic mulch system, a profit of LE 1350 and 1490 will be achieved, respectively, whereas, in clear plastic mulching, a profit of LE 1220 and 1110 will be achieved in 'Florida' and 'Winterstar', respectively.

**Table 10. Financial analysis of estimates of strawberry 'Florida' cultivar cultivation systems with or without mulching per feddan.**

| Item cost (LE)/feddan | Black Plastic Mulched field | | Clear Plastic Mulched field | | Un-mulched field | |
|---|---|---|---|---|---|---|
| Plastic | 2500 | | 2200 | | 0 | |
| Seedlings | 20000 | | 20000 | | 20000 | |
| Field Rent | 5000 | | 5000 | | 5000 | |
| Fertilizers | 3400 | | 3400 | | 3400 | |
| Hoeing | 600 | | 600 | | 5400 | |
| Irrigation, fertilization, and harvest | 4500 | | 4500 | | 5250 | |
| | Florida | Winterstar | Florida | Winterstar | Florida | Winterstar |
| Total costs | 36000 | 36000 | 35700 | 35700 | 39050 | 39050 |
| Total revenue | 48499 | 53670 | 43592 | 39490 | 32497 | 45817 |
| Net profit | 12499 | 17670 | 7892 | 3790 | -6553 | 6767 |
| Return value of the Egyptian pound | **1.35** | **1.49** | **1.22** | **1.11** | **0.83** | **1.17** |

**Discussion**

In the present study, black plastic mulching gave the highest fruit yields with 49% (season 1) and 40.6% (season 2) increase in 'Florida' and 17-18% increase (in seasons 1 and 2, respectively) in 'Winterstar' cultivar compared to the un-mulched plants. The effect of black plastic mulching on the fruit yield could be attributed to the increasing soil temperatures and water conservation while facilitating the weed-free environment (Pandey *et al*. 2015; Singh and Kamal 2012; Tarara 2000). This is in agreement with the results of mulching in strawberry and tomato crops (Karhu *et al*. 2007; Singh and Kamal 2012; Soliman *et al*. 2015). Compared to un-mulched plants, the yield of tomato plants was increased by 20.7- 29.8% in black mulch treatment (Singh and Kamal 2012). Differences in yield increments among cultivars with plastic mulching treatments were also noted by other researchers. Soliman *et al*., 2015, found that mulching treatment had no significant effect on strawberry yield of cv. 'Gavuta', whereas in cv. 'Sweet Charlie' plants with black plastic mulch treatment had significantly higher yield than the un-mulched plants (Soliman *et al*. 2015).

Our experiment also showed that the first season yield was better than the second season. This could be the result of the lower minimum field temperatures in the second season, reaching below zero for three consecutive days in late January, compared to the first season. Freezing temperatures could have negatively affected strawberry vegetative growth and flower buds formation, consequently decreasing the total fruit yield. Frosts are a known reason for a reduced yield of strawberry (Shokaeva 2005), and freezing injury to inflorescence and crown buds can be a serious constraint to strawberry production in winter time (Hancock *et al*. 2008).

Seasonal variations in strawberry yield productivity with mulching were found in earlier studies (Karhu *et al*. 2007; Soliman *et al*. 2015). Compared to the un-mulched plants, Soliman *et al*., 2015, reported that 'Festival' fruit yield was significantly higher with black plastic mulch treatment in the first season only. Similarly, Karhu *et al*., 2007, found that black plastic mulching had improved fruit yield in their first growing season only (Karhu *et al*. 2007).

Main effects of mulching showed that early yield of clear (season one) or black (season two) plastic mulching was higher than the un-mulched plants. This is in agreement to the work done by other researchers who found that strawberry plants of three cultivars grown in black and clear plastic mulching had significantly higher early yield than the un-mulched plants (Soliman *et al*. 2015).

Strawberry fruits are known to be rich in anthocyanin content which is responsible for the fruit red color (Dussi *et al*. 1995). Anthocyanins are known for their antioxidant activities (Edirisinghe *et al*. 2011). Therefore, enough intake of anthocyanins is helpful in the control of diabetes, obesity, and cardiovascular diseases (Tsuda 2012). Our results showed that mulched 'Winterstar' plants had significantly higher anthocyanin content than the un-mulched plants in season one. Compared to the control treatment, 'Florida' fruits had significantly higher anthocyanin in the black treatment in the first season while fruits of clear plastic treatment had higher anthocyanins in the second season. So, it seems that plastic mulching in general

(whether black or clear) results in relatively better fruit anthocyanin content than the un-mulched plants. This effect, however, seems to also be dependent on the cultivar used and the seasonal variations. Other researchers also found that plastic mulching improved anthocyanin contents in strawberry (Moor *et al*. 2005; Shiukhy *et al*. 2015). Shiukhy *et al*., 2015, found that 'Camarosa' plants grown over colored plastic mulching (black, white, or red) had higher anthocyanin content than the control un-mulched plants (Shiukhy *et al*. 2015).

The strawberry vitamin C content is considered as a vital fruit quality parameter for many consumers. Vitamin C, for its effective antioxidant functions, is essential for maintaining human health by lowering certain chronic diseases (Jacob 2002; Sapei and Hwa 2014). Another important finding from the present study is the significantly higher vitamin C content in plants grown in the black plastic mulch whether compared to plants in the clear plastic (season one) or plants in the clear plastic or un-mulched plants (season two). Therefore, values of vitamin C are the highest in plants grown in the black mulch treatments in the whole experiment. Vitamin C content in 'Florida' fruits was significantly higher in black mulch treatment than the plants of the clear mulch and the un-mulched plants. Soliman *et al*., 2015, found higher vitamin C content in plants grown over plastic mulching whether clear plastic (with 'Gaviota' and 'Festival') or black plastic (with 'Sweet Charlie')(Soliman *et al*. 2015). In our study, 'Florida' had significantly higher vitamin C values compared to 'Winterstar' values in all mulch treatments. This is in agreement with the results of Mohamed *et al*., 2017, where 'Florida' plants had the highest vitamin C among the five studied cultivars in their research (Mohamed *et al*. 2017).

Flavored strawberry is a complex mix of sweetness, acidity, and aroma volatiles (Kader 1991). The tastiest strawberry fruits are the ones that have high sugars and relatively high acids. A combination of high sugars and low acids results in a weak taste, whereas low sugars and high acids mix will result in a bitter taste of the fruit (Kader 1991). Therefore, the fruit consumers and producers consider soluble solids content as an important quality parameter in strawberry fruits (Moor *et al*. 2004). In the present experiment, the interaction between mulch treatment and cultivar regarding TSS contents was significant. 'Florida' fruits grown over black plastic mulching showed the highest TSS content, whereas fruits of un-mulched 'Winterstar' had highest TSS contents. Similarly, Bakshi *et al*., found higher TSS contents in strawberry fruits (cv. Chandler) in black plastic mulching compared to the control or clear plastic treatments (Bakshi *et al*. 2014). In agreement with our results, Soliman *et al*., 2015, found significant differences in TSS contents among several strawberry cultivars grown in different mulch treatments (Soliman *et al*. 2015). In the first season of their experiment, fruits of 'Festival' and 'Sweet Charlie' cultivars with black and clear mulching, respectively, had higher TSS content than the un-mulched plants. In their second season, mulched (clear or black) 'Sweet Charlie' plants only had higher fruit TSS contents than the un-mulched treatment but 'Festival' was not affected by mulching treatment. In both seasons of our experiment, the high TSS levels in 'Florida' fruits with black plastic

treatment along with the moderate (~0.64) acidity levels resulted in a high TSS: acid ratio.

Our financial analysis showed a substantial difference in strawberry production with or without a mulching system in Assiut governorate ranging from a loss of about LE 6553 per feddan without mulching in 'Florida' compared to a net profit of LE 12499 or LE 7892 per feddan upon using black or clear plastic mulch, respectively. Black plastic mulch increased 'Winterstar' net profit to about LE 17670 per feddan compared to only LE 3790 per feddan without mulching. Our results show that using black plastic mulching is the most profitable for 'Florida' and 'Winterstar' cultivars. Clear plastic mulching was less profitable than black mulch for 'Florida' cultivar while it resulted in a financial harm in 'Winterstar' compared to the un-mulched plants. In strawberry production, the return value of the Egyptian pound was found more profitable when black plastic mulching is used. In the light of these estimates, we recommend using the black polyethylene mulching for its advantages including the increased fruit yield and the improved net profit.

**Conclusions**

Application of black plastic mulching was accompanied by an increased fruit yield by 40-49% and 17-18% (compared to the control) in 'Florida' and 'Winterstar', respectively. We can conclude that plastic mulching was helpful in improving some fruit quality characteristics that are essential to maintain the consumer's health. The contents of vitamin C and TSS in the fruits of 'Florida' cultivar was improved in the black mulch treatments, and plastic mulching (whether clear or black) has improved fruits' anthocyanin content compared to the un-mulched plants in the two cultivars. We can also conclude that the use of black plastic mulching was more profitable for strawberry production.

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# تأثير إستخدام أغطية التربة البلاستكية على محصول و جودة الفراولة

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**الملخص**

أجريت التجربة الحقلية خلال موسمين متتاليين ٢٠١٨/٢٠١٧ و ٢٠١٩/٢٠١٨. وكانت الأهداف من التجارب هو ١) دراسة تأثير إستخدام ثلاثة أنواع من أغطية التربة (الملش) من البوليثيلين الأسود والشفاف والكنترول (التربة الغير مغطاه) على المحصول و الصفات المحصولية وجودة ثمار الفراولة من حيث مكوناتها من الانثوسيانين، فيتامين سي، المواد الصلبة الكلية القابلة للذوبان، والحموضه. ٢) لعمل دراسة جدوى إقتصادية لإستخدام البوليثيلين كغطاء للتربة في إنتاج الفراولة.

**النتائج:** أدى إستخدام غطاء التربة الأسود إلى زيادة المحصول بنسبة ٤٠ إلى ٤٩٪ في صنف فلوريدا و ١٧-١٨٪ في صنف ونترستار. أيضاً أدى إستخدام الغطاء الشفاف إلى زيادة محصول صنف فلوريدا بنسبة ١٩-٣٤٪ في حين أن محصول صنف ونترستار قل بنسبة ١٤-٢٤٪ مع إستخدام غطاء التربة الشفاف. بصفة عامة، أدى إستخدام الغطاء البلاستيكي الاسود إلى زيادة فيتامين سي عن باقي معاملات التجربة. ففي نباتات صنف فلوريدا كانت النباتات المغطاه بغطاء التربة من البوليثيلين الاسود أكثر احتواءًا على فيتامين سي بالمقارنة بباقي المعاملات. أيضاً احتوت ثمار صنف فلوريدا في النباتات المغطاه بغطاء التربة من البوليثيلين الاسود على نسبة أعلى من المواد الصلبة الذائبة الكلية بالمقارنة بباقي المعاملات في صنف فلوريدا. أيضاً محتوى الثمار من الانثوسيانين كان أعلى في النباتات في التربة المغطاه (سواء أسود أو شفاف) عن التربة الغير مغطاه. يمكن إستخلاص أن إستخدام غطاء التربة من البوليثيلين الاسود كان الأفضل لزيادة إنتاجية المحصول ومحتويات الثمار من فيتامين سي والانثوسيانين. من ناحية أخرى، فإن إستخدام غطاء التربة من البوليثيلين الاسود كان أكثر كفاءة في إنتاج الفراولة من حيث زيادة صافي الربح بالمقارنة بباقي معاملات التجربة التي درست.