ORGANIC TOMATO (*Solanum lycopersicum* L.) PRODUCTION UNDER DIFFERENT MULCHES IN GREENHOUSE

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ABSTRACT

Mulching is an important application in greenhouse production. It controls soil moisture, improves soil structure and helps against weeds and diseases. The aim of this study was conducted to determine the effects of different inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE) and organic (S: straw) mulches on earliness, yield and some quality parameters of tomatoes (*Solanum lycopersicum*, L. cv. Sumela F1) grown under greenhouse conditions in Black Sea Region of Turkey during 2009-2010. In this study, leaf stomatal conductance, leaf chlorophyll content, photosynthesis rates, yield, soluble solids content (SSC), titratable acidity (TA), fruit firmness, vitamin C and phenological traits were examined. The highest chlorophyll content (43.9 CCI) and firmness (24.5 N) was obtained from silver gray mulch treatments. PE mulch treatments had higher yields (6256.32 kg da^{-1}) than organic mulch and control treatment (C). On the other hand, while the highest soluble solids content (5.4 %) and vitamin C (40.7 mg 100 g^{-1}) contents were obtained from the control treatment, the highest titratable acidity (0.44 %) was obtained from red PE mulch treatment. Significant differences were not observed between the leaf stomal conductance (128.68 mmol $m^{-2}s^{-1}$) and photosynthesis rates (84.1 µmol O_2 $m^{-2}s^{-1}$) of mulch treatments and control treatment. It was concluded that mulch treatments had significant effects on yield and quality of tomatoes ($P \leq 0.05$).

Key words: Earliness, photosynthesis, stoma, quality, yield.

INTRODUCTION

Mulching is a significant technique commonly used in soil management. Various organic and inorganic mulching materials are used in vegetable culture. Mulch preserves soil moisture, reduces production costs, preserves and develops soil structure and it is highly efficient in controlling weeds, abrupt temperature changes and various diseases and pests (Jordán *et al.*, 2010; Mu *et al.*, 2014).

Beside the other factors, regulation of plant-water relations plays an important role in a successful production. For the regulation of this relationship, stomas from where plants lose water (85-90%) play quite significant roles. Stomas are the micropyles providing gas exchange and regulating transpiration allowing the plants to survive without exposed to excessive water losses (Dickison, 2000). Mulch treatments preserve soil moisture and consequently improve plant resistance against moisture-induced stress conditions (Özer, 2012). Additionally, uncovered soil conditions increase the relative humidity of the greenhouse through evapotranspirative water losses from the soil. Increased relative humidity speeds of the widespread of fungal diseases starting especially from the lower leaves (Ekinci and Dursun, 2009; Özer, 2012; Jodaugiene *et al.*, 2014).

In plant culture, light intensity and quality have various impacts on chlorophyll contents. Natural daylight at different rates certainly effect stoma motions of plant leaves (Taiz and Zeiger, 2008). Beside the effects on soil temperature, different color mulch treatments also affect the light reflected from different mulch materials and have various other impacts on earliness, weeds and pests. Such impacts are related to phytochrome which is a photoreceptor able to sense the radiations at different wave lengths. Phytochrome is known to control the growth and development of various parts of the plants (Özdamar *et al.*, 2006; Zanic *et al.*, 2009).

The present study was conducted to investigate the effects of different inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE) and organic (S: straw) mulching materials on earliness, yield and some quality parameters of tomatoes of the first out of season production under ecological conditions of Samsun Province.

MATERIALS AND METHODS

General characteristics of the research site: The present study was conducted at greenhouses of Ondokuz Mayıs University Agricultural Faculty Horticulture Department (36°C 12' east, 41°C 22' North latitudes and longitudes) during the years 2009/2010. Experimental greenhouses are 6 m wide and 20 m long (120 m^2). The side walls are 3 m high and the greenhouse is covered with anti-fog, antivirus, infrared and ultraviolet supplemented polietilen plastics cover. The greenhouses have natural ventilation from one long side and arc roof.

Research materials: Commonly grown early and pole type tomato (*Solanum lycopersicum*, L. cv. Sumela F1) was used as the plant material of the experiments. The cultivar is suitable for greenhouse and open field culture. Fruits of the cultivar are uniform red colored with 3-4 lumps. The fruits are round, firm, transportation resistant and have long shelf life.

Broad bean (*Vicia faba* L. cv. Seher) seeds were used as green fertilizer to improve soil nutrients organically. Any other supplementary fertilization was not performed throughout the cultivation period.

In this study, 5 different inorganic and organic mulching materials were used to cover the seed beds. These were black PE (1.30 m wide, 0.03 mm thick), silver gray PE (1.30 m wide, 0.03 mm thick, black bottom and silver grey top surface), red PE (1.30 m wide, 0.03 mm thick, both surface are red), ground cover PE (Agroteks ground cover, black and UV-supported) and straw (finely chopped wheat straw).

Soil preparation, seeding and planting: Seeding was performed to peat-filled viols (345 compartments) on 13-15 April of both years. Following the emergence, the seedling with the initial true leaves were transferred to viols (7x5cm, 28 compartments) filled with 2:1 decomposed manure: peat mixture.

Seedling beds were prepared in greenhouse (1m x 17m x 30cm-WxLxH). Seeds of broad bean were sown in the last week of November of both years with 13 cm row spacing and 30 cm on-row plant spacings. Broad beans were than incorporated into soil at full bloom (2 kg m^{-2}). Nutrient content of green fertilizer treatment is provided in Table 1. Following the decomposition of broad bean residues, seed beds were leveled and prepared for planting. Drip lines with 25 cm apart drippers were placed over 1 m wide seed beds between two rows.

Experimental plots of black PE, silver gray PE, red PE, ground cover PE, straw mulch treatments and control treatment (without mulch treatment) were randomly distributed over the seed beds. Planting locations were arranged as to have 45 cm row spacing and 50 cm on-row plant spacing and 90 cm wide row spacing (2962 plant da^{-1}). Tomato seedlings were planted on 21.04.2009 during first year and on 11.04.2010 during second year of experiments. Experiments were conducted in randomized block with 3 replications and 16 plants in each replication. Throughout the experimental periods, measurements and observation were performed over 9 plants of each replication.

Soil samples were taken twice from different sections of the greenhouse. The first sampling was performed at the initial flowering period of the plants and the second sampling was performed just after the harvest. Nutrients and organic matter contents of soil samples (Table 2) were then determined (Kacar and İnal, 2008).

Greenhouse temperature (°C) and lighting intensities (lux) were regularly measured (30 min/day) through data loggers (KT100, Kimo, France). To convert the light intensities measured through data loggers into PAR (Photosynthetic Active Radiation), measurements were taken with Sunscancanopy analyzer (SS1, LI-COR, USA) device tree times in a day (at 07.00, 12.00 and 17.00) at certain intervals. Comparing the values measured with both devices, a conversion coefficient of [2400.16 lux = 1 PAR (MJ m^{-2} d^{-1})] was determined.

Following the planting, soil temperature (in each mulch type and control treatment) was measured three times in a day (at 07:00, 12:00 and 17:00) with a penetrating soil thermometer. Data were recorded as daily averages and provided in Table 3.

Measurements and observations made over the plants and fruits: Following the planting, regular observations were made in this study to determine the initial flowering (appearance of first flowers in cluster) and initial fruit set (appearance of the first fruit in cluster) dates. The number of days to initial and the last harvest was also determined.

Measurements were performed over young, medium-aged and old leaves. Leaf stomal conductance was measured in mmol $m^{-2}s^{-1}$ with a porometer (SC-1, Decogon Devices, USA), leaf chlorophyll content index (CCI) was measured with a chlorophyll meter (CCM-200, Opti-Sciences, USA) and photosynthesis rate was measured in µmol O_2 m^{-2} s^{-1} with a photosynthesis measurement device (PH1LP, Qubit System, USA).

Weights of fruits harvested from the first to last harvest were measured with a precise balance (±0.1 g). Resultant fresh fruits were used to determine the yield per plant. Then, the yield per plant values were multiplied with the number of plants per decare to get the total yield in kg da^{-1}.

For fruit firmness (N) measurements, 1 cm diameter peel was cut shallowly from the chick sections of both sides of the harvested fruits. The resistance against 7.4 mm penetration of 5 mm penetrometer (4301, Instron, ABD) tip from the cut sections of the fruits was taken as the fruit firmness of the fruit.

Soluble solids content (SSC) content was measured in fruit juice of ripened fruits with a hand refractometer (ATC-I, Atago, Japonya) and expressed as %.

Titratable acidity was measured by titration acidity method in fruit juices of ripened fruits. A 5 ml sample was taken from the fruit juice, 45 ml distilled water was added and 2-3 drops of phenol phytaline indicator were dropped over the mixture. Then the mixture titrated with 0.1N NaOH until having an anion skin color.

For vitamin C content of fruits, 5 g fresh fruit samples were taken, 0.4% oxalic acid solution was added to make the final volume of the mixture 50 ml. Then the mixture filtered through a filter paper and resultant assay was read at 520 nm wave length in spectrometer (Kılıç *et al.,* 1991).

Data evaluation: Experiments were conducted in randomized block design. Resultant data were assessed through Microsoft Excel 2010 and SPSS 17.0 software. Means were compared with Duncan's multiple range test at $p<0.05$. Since significant differences were not observed between the years, experimental years were combined and results presented in combined fashion.

RESULTS AND DISCUSSION

Formation and appearance of the first flower bud is a significant issue for yield and earliness of the plants. Phytochrome plays significant roles in germination, shoot development and branching, flowering, leaf development and other various growth and development parameters of the plants (Padem and Özdamar, 2002). The earliest number of days to initial flowering (22.6 days) was observed in silver gray and ground cover mulch treatments with quite high soil temperatures. The latest flowering (27.4 days) was observed in control treatment. The earliest fruit set (30.6 days) was observed in black mulch and the latest fruit set (44 days) was observed in red mulch treatments (Table 4). It was reported in earlier studies that different mulch treatments increased soil temperature and reflected the light through changing color and thus had impacts on phytochrome. Current results also revealed that different mulch treatments increased soil temperature and resulted in early flowering and fruit set. Especially red mulch and organic mulch treatments speeded up the flowering.

The duration passed till harvest is a critical issue in plant culture. In plants like tomato with vegetative and generative stages one within the other, the time to full development decreases with increasing temperatures (Ploeg and Heuvelink, 2005). The shortest initial harvest (79 days) was observed in ground cover mulch treatment with higher soil temperatures and the latest harvest (84.8 days) was observed in red mulch treatment (Table 3; 4).

The longer the growth period, the more the light energy will be intercepted and thus the more yield will be obtained. If the plants start to growth and develop rapidly, their lives (stay green) will be shorter. Together with plant genetics, environmental factors have also various impacts on growth durations (Uzun, 2000). The present results revealed that the treatments with shorter flowering and fruit set periods had short growth periods (time to last harvest) and the red mulch treatment with late flowering and fruit set periods had longer growth period (green period) (142.2 days).

Stomal motions manage the stress factors in plants and balance the photosynthesis capability of the plants. Such motions are highly dependent on various internal and external factors such as light intensity and quality, temperature, relative humidity and cell CO_2 concentrations (Elad *et al.*, 2007; Kılıc *et al.*, 2010). Since silver gray mulch has a bright surface and reflects more light, it had the highest stomal conductance (128.7 mmol $m^{-2}s^{-1}$). The lowest stomal conductance value (72 mmol $m^{-2}s^{-1}$) was observed in red mulch treatment. However, the differences in stomal conductances of mulch treatments and control treatment were not found to be significant ($p<0.05$) (Figure 1).

Stomal conductance influence gas exchange of leaves and higher conductance values positively affect photosynthesis. Stomal opening and closure motions increase the photosynthesis rates and thus increase the yield. For higher photosynthesis rates, amount of chloroplast and chlorophyll should also be higher (Taiz and Zeiger, 2008; Kılıc *et al.,* 2010). In the present study, silver gray mulch treatment had the highest stomal conductance (128.7 mmol $m^{-2}s^{-1}$) and leaf chlorophyll content (43.9 CCI) values, thus the treatment had also the highest photosynthesis rate (84.1 µmol O_2 $m^{-2}s^{-1}$). Parallel to these findings, the lowest chlorophyll content (23.1 CCI), stomal conductance (72 mmol m-²s-1) and photosynthesis rate (81.8 µmol O_2 $m^{-2}s^{-1}$) were observed in red mulch treatment (Figures 1-2).

Mulch treatments control soil moisture levels *(Radics et al., 2004).* Unblanced moisture levels create a stress on plants. Stress exerted on plants then slows down stomal motions (Taiz and Zeiger, 2008). Such slowdowns ultimately reduce photosynthesis rates and yields. In this study, the highest yield (6256.32 kg da^{-1}) was obtained from silver grey mulch treatment with the highest leaf chlorophyll content, photosynthesis rate and leaf stomal conductance. Yield values of inorganic mulch treatment (PE) were significantly different from the yield values of organic mulch and control treatments ($P<0.05$) (Figure 3).

Stomal motions slowdown in plants with water stress and firmness decreases with increasing water holding capacities of the soils (Taiz and Zeiger, 2008; Ünlü and Padem, 2009). The highest fruit flesh firmness of the present study was observed in silver gray mulch (24.5 N) treatment with higher stomal conductance (Figure 4).

While the highest soluble solids content (SSC) content (5.4%) was observed in control treatment, the lowest value (2.5%) was observed in silver gray mulch treatment (Figure 5). In a previous research, decreasing water soluble dry matter contents (3.52-4.18%) were reported in tomatoes with increasing manure treatments (Ünlü and Padem, 2009). Polat *et al.,* (2001) on the other hand indicated that organic fertilizer treatments did not have any significant effects on SSC and vitamin C contents. Organic matter decomposition is largely dependent on soil microorganism activities. Microorganism activities increase until a certain temperature and relative humidity levels (Kutlay *et al.*, 2010). Current findings may also be related to decomposition of organic matter since the highest SSC content (5.4%) was observed in control treatment with the lowest soil temperature (9.69ºC) (Table 3; Figure 5).

Titratable acidity values of tomato plants were reported as between 0.23-0.58% in previous studies (Toor *et al.*, 2006; Ünlü and Padem, 2009). The titratable acidity values of the present study varied between 0.28 - 0.44% (Figure 5) with the highest value (0.44%) observed in red mulch treatment.

Vitamin C content of vegetables and fruits varies based on species, soil texture and ripening level of the seeds and fruits. Green vegetables generally have quite higher vitamin C contents (Kara and Okyay, 2008). Besides, it was reported in previous studies that antioxidant-based compounds in plant metabolism were relatively sensitive to temperature and light-like environmental conditions. However, previous researchers commonly reported that vitamin C content were largely effected by light and indicated increasing vitamin C contents with increasing light intensities in tomatoes (Raffoa *et al.,* 2006). In this study, any significant relationships between ascorbic acid contents and climate parameters were not identified. Vitamin C contents of tomato fruits were previously reported as between 15-23 mg $100g^{-1}$ (Ünlü and Padem, 2009). The value varied between 21-40.7 mg $100g^{-1}$ in this study with the highest vitamin C content observed in control treatment (Figure 5).

Table 1. Nutrient content of broad beans incorporated into soil.

	Broad bean residue	
pH	(1:10)	5.69
EC	(dS m^{-1})	6.9
N	(%)	0.214
Mg	(ppm)	2709.08
Fe	(ppm)	254.93
Cu	(ppm)	8.00
K	(ppm)	32277.05
P	(ppm)	4654.94
Ca	(ppm)	7526.58
Mn	(ppm)	32.85
Zn	(ppm)	35.33

Table 2. Chemical characteristics of soil samples (0-20cm) taken at the first initial flowering and at the end of experiments.

	pH	EC (dS m^{-1})	Ca (meq $100g^{-1}$)	Mg (meq $100g^{-1}$)	K (meq $100g^{-1}$)	P (ppm)	O.M (%)	Na, (meq $100g^{-1}$)
Years	Soil samples taken at initial flowring							
2009	7,63	1,97	46,17	8,67	7,99	42,30	11,94	0,60
2010	7,77	1,17	32,70	14,80	1,27	147,96	6,77	1,07
	Soil samples taken at the end of experiments							
2009	7,84	1,08	39,58	11,17	6,85	45,73	11,88	0,59
2010	8,05	0,89	36,05	11,02	1,65	247,81	11,90	1,03

Table 3. The soil temperature (ºC) at 20 cm depth, indoor air temperature and light (MJ m^{-2} d^{-1}) values in greenhouses.

	Soil Temperature (ºC)						Indoor	
	Black PE	Silver gray PE	Red PE	Ground cover PE	Straw	Control	Temperature (ºC)	Light PAR (MJ m^{-2} d^{-1})
Minimum	10.72	10.36	10.14	10.86	10.19	9.69	9.70	3.1
Maximum	30.98	30.62	30.40	31.12	30.45	29.95	29.70	19.53
Average	22.19	21.83	21.61	22.33	21.65	21.15	20.96	12.22

Table 4. The effects of different mulch types on days to initial flowering, days to initial set and days to initial and the last harvest of tomato (days).

	Mulches					
	Black PE	Silver gray PE	Red PE	Ground cover PE	Straw	Control
Initial Flowering (day)	23	22.6	24.2	22.6	24.2	27.4
Initial Fruit Set (day)	30.6	36.8	44	33	41.4	41.4
Initial Harvest (day)	80.8	83	80.8	79	84.8	83
Last Harvest (day)	135.2	141	142.2	127.6	125.2	138

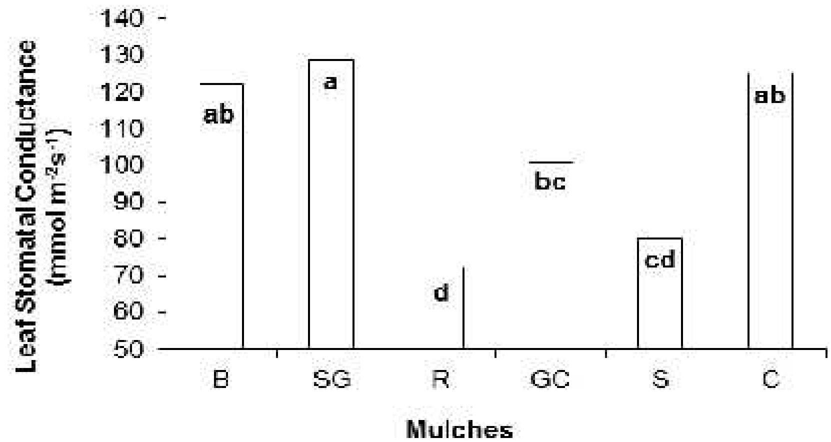


Figure 1. The effects of different mulch treatments on leaf stomatal conductance (mmol $m^{-2}s^{-1}$) of tomato. Different letters above the bars indicate significant differences according to Duncan's Multiple Range test at P<0.05.

Inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE), organic (S: straw) mulch and control treatment (without mulch).

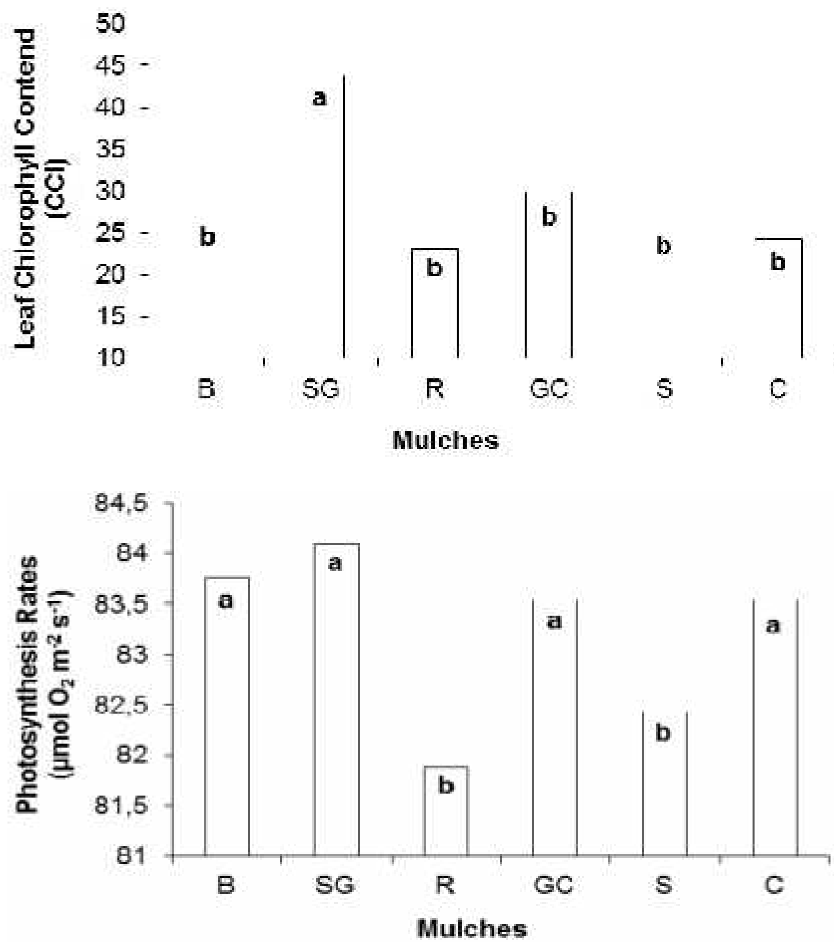


Figure 2. The effects of different mulch treatments on leaf chlorophyll content (CCI) and photosynthesis rates (µmol O_2 m^{-2} s^{-1}). Different letters above the bars indicate significant differences according to Duncan's Multiple Range test at P<0.05.

Inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE), organic (S: straw) mulch and control treatment (without mulch).

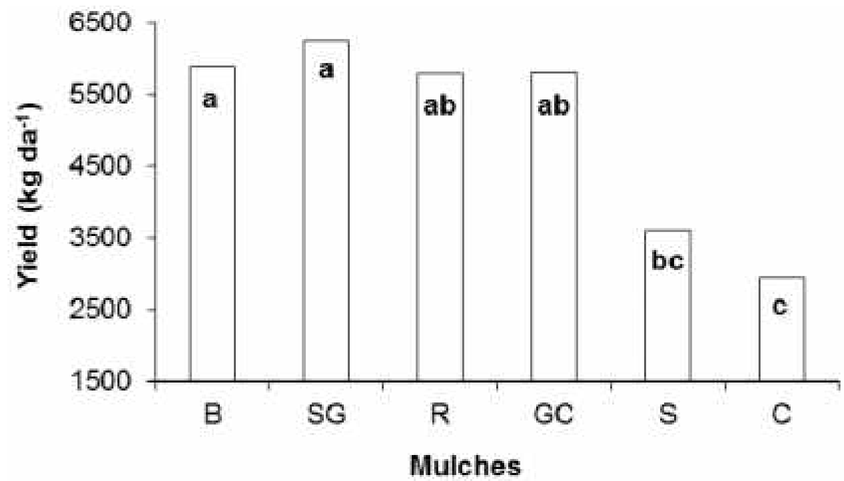


Figure 3. The effects of different mulch treatments on yield of tomato (kg da^{-1}). Different letters above the bars indicate significant differences according to Duncan's Multiple Range test at P<0.05.

Inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE), organic (S: straw) mulch and control treatment (without mulch).

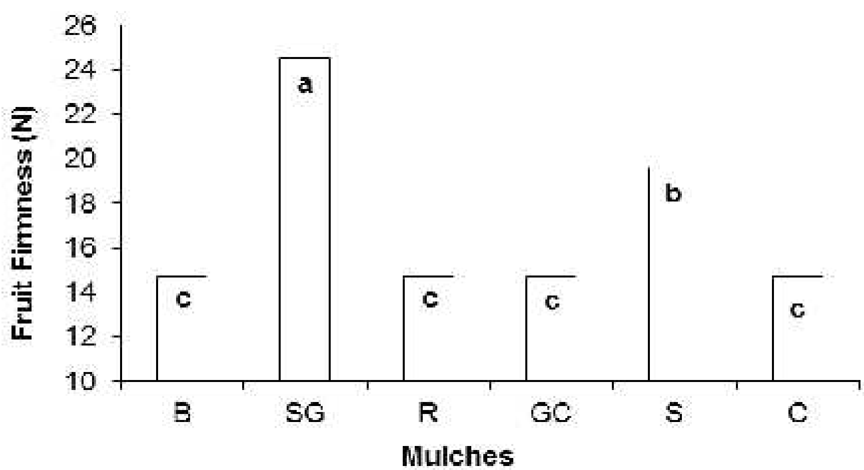
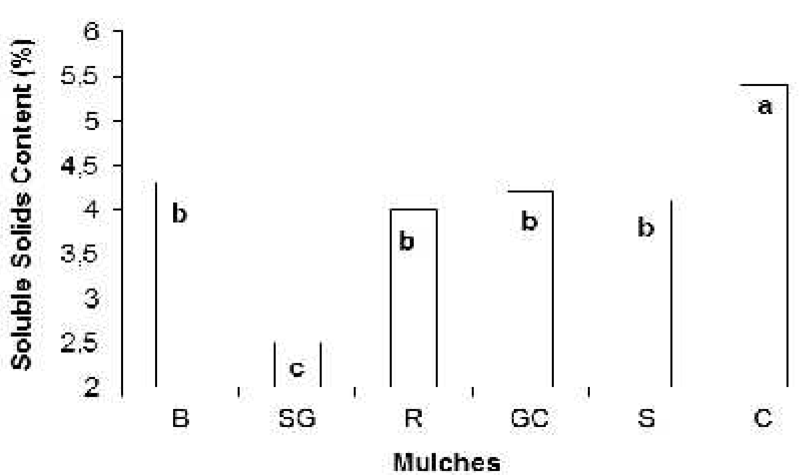


Figure 4. The effects of different mulch treatments on fruit flesh firmness (N) of tomato. Different letters above the bars indicate significant differences according to Duncan's Multiple Range test at P<0.05.

Inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE), organic (S: straw) mulch and control treatment (without mulch).



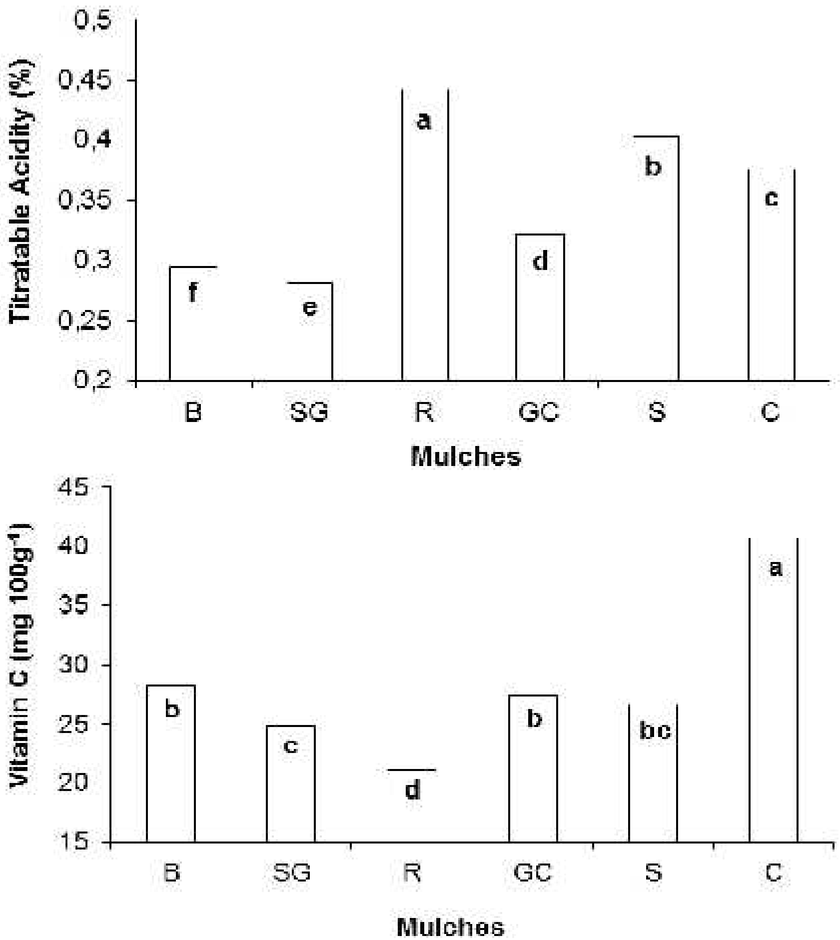


Figure 5. The effects of different mulch treatments on soluble solids content (%), titratable acidity (%) and vitamin C (mg 100 g^{-1}) content of tomato. Different letters above the bars indicate significant differences according to Duncan's Multiple Range test at P<0.05.

Inorganic (B: black, SG: silver gray, R: red and GC: ground cover PE), organic (S: straw) mulch and control treatment (without mulch).

Conclusions: Despite the higher stomal conductance and photosynthesis rates of mulch treatments than the control treatment, the differences between the mulch treatments and the control treatment were not found to be significant. However, silver gray PE mulch treatment with high stomal conductance and chlorophyll content had also high photosynthetic activity levels. Such an increase in photosynthesis rates result in higher yield (6256.32 kg da^{-1}).

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