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Physicochemical attributes of Tomato (*Lycopersicon esculentum* Mill.) varieties under Polyhouse and Mulching Conditions

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Abstract: Tomato is one of the most widely consumed vegetable crops in Ethiopia. However, the yield and quality of this fruit is reduced during rainy season because of many constraints (diseases, climate, nutrition, etc.). Therefore, diverse experiments were conducted to study the effect of mulch on physicochemical attributes of tomato varieties under polyhouse growing condition at Bahir Dar in 2012 and 2013 during the rainy season. Treatments were arranged in 2 x 4 factorial combinations where two varieties viz. Miya and Cochoro were grown under four mulch conditions (black & white plastic, grass mulch and no mulch). Drip irrigation was used to supply plants with water, P_2O_5 and nitrogen were given in the form of DAP and Urea fertilizers.

The variety of mulch influenced significantly ($P \leq 0.05$) and positively almost all physicochemical attributes of Tomato such as the number of fruits per plant, marketability, width, titratable acidity, sugar to acid ratio, fruit juice content and pH. In fact, plants grown under black plastic mulch produced fruits with the highest weight (80.29g), good flavor and a sugar to acid ratio >10. Cochoro was identified as the best variety in terms of physicochemical attributes as compared to Miya.

It is possible to conclude that growing tomato varieties under polyhouse using mulch during rainy season produce fruits with desirable traits that satisfy both the producers and consumers interest and preference. Specifically, we recommend the use of black plastic mulch and Cochoro variety to enhance tomato fruit physicochemical qualities under polyhouse growing condition.

Keywords: Mulch; physicochemical; polyhouse; quality and tomato.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is the most important and major horticultural crop in the world with an estimated global production of over 162 million metric tons [1]. In Ethiopia, tomato is an important cash crop with an expanding production due to its diverse economic benefits [2]. The total area under tomato production in Ethiopia is estimated to 7237 hectares with a total production of 555143 tons [3]. Horticultural crops production in the Amhara Region is at basic stage, however, with the establishment and expansion of small scale irrigation schemes, the production of tomato is showing relative progress yet constrained by various factors. Among the major problems, production of tomatoes during the rainy season is limited by unfavorable conditions due to high disease incidence mainly late blight (*Phytophthora infestans*) and damping off caused by a complex of fungi (*Pythium spp*., *Phytophthora spp*., *Rhizoctonia spp*. and *Fusarium spp*.) reducing tomato yields and quality [4]. Producing tomato in the dry season under irrigation may not be profitable investment unless the availability of tomato is year round [5]. The problem can be overcome through protected cultivation such as the use of plastic shelters and mulch [6]. Therefore, it is necessary to conduct research on protected condition in low cost greenhouses and shelter structures to make tomato production year round in the region. Among the low cost structures, the use of rain shelters with plastic roofing was found as a potential farming technique [7].

Three factors drive consumers preference: physical appearance (color, size, shape, defects, and decay), firmness and flavor [8]. Tomato taste is usually described by sweetness and sourness which is mostly related to the fruit content in reducing sugars and organic acids [9]; [10;[11], and to their ratio [12]. Tomato fruit is primarily composed of sugars and acids, which represent about 60% of the dry matter weight [13]. In mature tomato, glucose

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and fructose constitute the major sugars while citric and malic acids are the major organic acids. Studies showed that tomato acidity is either related to the fruit pH or to the titratable acidity. Sugars and acids contribute to the sweetness and to the overall aroma intensity [14], but sweetness seems to be more influenced by the content in fructose than in glucose, while acidity is mostly due to the citric acid, present in higher amounts than malic acid in mature fruits [9].

Contrasting reports are available about the effect of mulch materials on quality of tomato. Rashidi and Gholami [15] reported that polypropylene row cover yielded larger number of fruits and highest total taste intensity in comparison to plants grown in bare soil. Samaila *et al.* [16] also reported that tomato fruits mulched with polythene were significantly firmer and with less unmarketable fruits yield than control. These authors also reported that fruits produced from straw-mulched rice plants produced bigger fruits than those under polythene mulch. Similarly, Kere *et al*. [17] and Arin and Sozer [18] reported that fruit weighted more in crops grown with straw under greenhouse and tunnel conditions. The juiciness of tomatoes grown in black plastic mulch plus row cover was higher compared to other treatments [19]. On the other hand, Moreno *et al.* [20] concluded that different colored photodegradable and biodegradable film mulches had no significant effect on quality attributes of marketable tomato fruits in respect to shape, total soluble solids, firmness, dry weight and juice content.

The use of plastic shelters and mulch will enable producers to get high year round income with reliable marketability and higher prices. Therefore, it is important to study the effect of mulch materials on quality of tomato varieties. The present study was conducted to determine the effect of different mulching materials on the physical and chemical quality of tomato varieties grown under polyhouse conditions.

Materials and Methods

Description of the Study Area

The experiment was conducted at Woramit Horticultural Crops Trial Site of Adet Agricultural Research Center during the rainy season of 2012 and 2013. Woramit is located in the North-western part of Bahir Dar town on the shore of Lake Tana in Ethiopia. The site is located at 11°38′ N and 37°10′ E with mean altitude of 1,800 m above sea level. It has a warm and humid microclimate with distinct dry and wet seasons. The soil is deep with red-brown color characterized as Nitosol. The mean daily maximum temperature is 29.5 ^{0}C in April and 6.2 ^{0}C in January. The area receives a mean annual rainfall of 800-1250 mm. Generally the agro-ecology is characterized as mid altitude [21].

Experimental Materials

Two tomato varieties, namely, Cochoro and Miya, were used as experimental materials. The variety Cochoro is characterized as processing type tomato having compact and determinate growth habit with strong stem. This variety has oblong fruits shape, fruit weight of 76 g, maturity period of 86 days and a potential yield of 46.3 tons per hectare. The fruit is firm with total soluble solid (TSS %) and pH values of 4.19 and 5.53, respectively. Miya instead, is a fresh market type, strong stem with indeterminate growth habit, having a plum fruit shape and fruit weight of 82g. It has a maturity period of 82 days after transplanting and a potential yield of 47.1 tons per hectare. The fruit is firm with TSS % and pH value of 4.0 and 4.5, respectively [22].

The mulch materials were black and white colored plastic sheets with 0.02 mm thicknesses and dried grass as organic mulch at the rate of four ton per hectare. The treatments were applied in polyhouse (12 m wide and 33 m length with 3 m height at the center). Two-thirds of the four sides of the polyhouse were covered with transparent ultra violet polyethylene sheet starting from the ground and the remaining 1/3 upper portion of the walls was covered with insect proof net for ventilation. Polyhouse was made up of bamboo frame and covered with 0.15 mm clear polyethylene sheet with 80% light transmission capacity.

Treatment and Experimental Design

The experiment consists of eight treatments arranged in a 2 × 4 factorial combinations. The first factor consists of two tomato varieties; Chochoro and Miya. The second factor includes four types of mulch; black plastic mulch (BPM), white plastic mulch (WPM), grass mulch (GM) and no mulch (control). The experiment was laid out as Randomized Complete Block Design (RCBD) with three replications.

Experimental Procedure

Seedlings were raised on a seedbed inside a plastic tunnel. To protect the seedlings from damping off, the fungicide Ridomil® MZ 68 WG was sprayed on the nursery beds every two weeks at the rate of 2.5 kg per hectare. Land inside the naturally ventilated polyhouse was thoroughly plowed to a depth of 20 to 25 cm one month prior to planting. Weeds and stubbles were removed and the soil pulverized through repeated cultivation. Finally raised beds were prepared for each replication with height of 15 cm to facilitate drainage.

One month old seedlings were transplanted on 8.4 m^2 gross plot size (3 × 2.8 m) with spacing of 70 x 40 cm between rows of plants. Data were collected from randomly selected 16 plants per plot from the two central rows.

The plots were watered with drip irrigation system convenient for production under plastic mulch. Phosphorus and Nitrogen were supplied at the rate of 92 kg P_2O_5 and 64 kg N ha^{-1}, respectively, in the form of DAP and Urea as recommended for tomato in Ethiopia. The whole rate of DAP (46% P_2O_5 and 18% N) was supplied at the time of transplanting while Urea (46% N) was supplied in two splits, half at the time of transplanting and half 45 days after. Fungal diseases and worms were controlled by the application of 2.5 kg ha^{-1} Ridomil® MZ 68 WG and 0.75 litters ha^{-1} Selecron® 720 EC, respectively. Other agronomic management practices were applied according to the national recommendation for the crop [23]. The mulch materials were laid before transplanting and a small transplanting hole was made on the plastic mulch for planting each seedling. Trellis structure was prepared from wooden pole and wire to support each plants.

Data Collection and Analysis

Fruit physical quality attributes

Mean fruit length (cm) was recorded by measuring the peduncle end to blossom end of five randomly selected mature fruits at the 2nd, 3rd, 4th and 5th harvest and the mean fruit width (cm) was recorded for the same fruits by measuring the largest diameter of the cross sectioned fruits. Fruit shape index was calculated dividing polar diameter by equatorial diameter of the fruit [24]. Fruit mean pericarp thickness (mm) was recorded from 10 randomly selected fruits at 2nd, 3rd, 4th and 5th harvest by cutting cross section and measuring the pericarp thickness using caliper. The 10 randomly selected fruits used for measuring fruit pericarp thickness were weighted and the mean fruit weight (g) was calculated for each treatment.

Proportion of marketable and unmarketable fruit yield per plant in percent was calculated as follows:

- marketable fruit yield (%) =(marketable fruit yield / total fruit yield) x 100
- unmarketable fruit yield (%) =(unmarketable fruit yield/ total fruit yield) x 100.

Total fruit yield per plant was recorded as average weight (kg/plant). Unmarketable fruit yield (kg/plant) was recorded as average weight of diseased, insect damaged, cracking and blossom end rot fruits whereas fruits free from these defects were considered as marketable fruit yield (kg/plant).

Fruit chemical quality attributes

Total soluble solids (TSS %) as percent (^{0}Brix) was determined following the procedure described in [24]. Aliquot of juice was extracted using High Performance Commercial Blender. Palette digital refractometer ATAGO® PR-32α with a range of ^{o}Brix from 0 to 32% used to determine the TSS by placing two drops of clear juice on the prism. Aliquot of clear juice filtered with cheesecloth was prepared and pH was measured using pH meter (AD1020 pH/mv/ISE model).

Titratable acidity (TA) was measured from extracted tomato juice filtered through cheesecloth that produce decant clear juice. 10 ml of tomato juice sample was titrated gradually with 0.1N NaOH using burette to pink end point (persisted for 15 seconds). Titratable acidity was expressed as percent citric acid using the following formula [24].

$$TA\ (\%) = \frac{\text{Titre x 0.1N NaOH x 0.64}}{1000} \text{ x } 100$$

Where titre is the volume of tomato juice and 0.1N is the amount of NaOH used to neutralize 0.64g of citric acid and 0.64 is the conversion factor. Sugar to acid ratio was calculated by dividing the value of total soluble solids to the value of titratable acidity. Fruit juice content (ml/kg) was extracted from 1 kg of fully ripe fruits using a High Performance Commercial Blender. The juice volume was measured using a graduated cylinder and expressed in milliliter of juice per kilogram of the fruit weight.

Data Analysis

Analysis of variances (ANOVA) were computed using SAS (9.00 version) software. The two years data separately were subjected to analysis of variance and variance homogeneity test (using "t" test) was conducted for each quality attributes. Least significant difference (LSD) at 5% probability level was carried out for means separation.

Results and Discussion

Results

Description of the two year growing seasons in temperature and relative humidity

Tables 1, 2 and 3 show the conditions of humidity, temperature and soil in the polyhouse during the two year growing seasons.

Table 1. Mean monthly day and night time relative humidity inside the polyhouse in 2012 and 2013.

Month	Day time RH (%)		Night time RH(%)	
	2012	2013	2012	2013
July	76.81	77.43	79.58	95.20
August	82.48	74.37	91.41	94.47
September	68.97	65.30	92.53	95.45

Table 2. Mean monthly day and night time air temperature in the polyhouse in 2012 and 2013.

Month	Day time T (°C)		Night time T (°C)	
	2012	2013	2012	2013
July	24.33	24.34	19.84	18.50
August	23.80	26.03	19.31	19.18
September	25.47	26.55	19.87	19.29

Table 3. Mean soil temperature (°C) at 10cm depth under mulching materials in 2012 and 2013.

Type of mulch	July (°C)		August (°C)		September (°C)	
	2012	2013	2012	2013	2012	2013
Black plastic	27.22	27.75	24.31	26.89	24.40	27.61
White plastic	28.17	29.17	24.57	27.31	25.10	28.14
Grass mulch	24.25	25.46	23.11	25.43	23.86	25.01
No mulch (control)	25.39	26.93	23.70	26.38	24.53	26.93

Fruit Physical Quality Attributes

The analysis of variance results revealed that all physical quality attributes viz. fruit weight, width, length, fruit index, pericarp thickness and juice content were significantly influenced by the growing season (year). These traits; except fruit width; were also significantly affected by the variety of tomato; however, only fruit weight, width and juice content were significantly influenced by the main factor mulch.

The mulch, variety and year interacted to influence fruit width and juice content. All possible two way interactions (Mulch x Variety, Mulch x Year and Variety x Year) influenced fruit juice content, while fruit width was significantly affected by the effect of interaction between mulch and variety as well as variety and year (Table 4).

Table 4. Mean squares from combined analysis of variance over two years for tomato fruit physicochemical traits.

Source of variation	DF	Average fruit weight(g)	Average fruit width (cm)	Average fruit length (cm)	Fruit shape index	Fruit pericarp thickness (mm)	Fruit juice content (l/kg)	MFNPP	UMFNPP	TFNPP	% MAK	% UM	TSS (%)	TA	TSS:TA	pH
Replication	2	38.29	0.007	0.016	0.0014	1.01	0.0006	19.96	5.34	41.1	63.72	46.52	0.095	0.035	12.52	0.008
Mulch	3	194.35*	0.109*	0.068	0.0085	0.96	0.0001*	142.72**	0.16	141.26**	34.57	28.94*	0.240*	0.005	0.56	0.023**
Variety	1	1987.26**	0.022	6.690**	0.272**	17.52**	0.0083**	409.16**	6.77*	311.65**	337.09**	345.99**	0.608*	0.053**	32.38**	0.154**
Year	1	2063.65**	2.613**	0.572*	0.048 *	91.30**	0.0066**	1.78	6.93*	2.14	95.13*	84.91*	3.593**	0.001	18.22**	1.003**
Mulch x Variety	3	18.7	0.094*	0.066	0.0025	0.60	0.0014*	7.1	0.87	8.83	6.54	7.10	0.043	0.011*	4.54*	0.013*
Mulch x Year	3	60.23	0.049	0.028	0.0083	0.77	0.0012*	7.94	0.04	7.46	0.60	1.11	0.186	0.002	2.73	0.008
Variety x Year	1	53.03	0.244*	0.141	0.0031	0.07	0.0011*	74.65	4.21*	114.88*	13.85	12.11	0.013	0.000	0.02	0.010
Mulch x Variety x Year	3	56.2	0.173*	0.019	0.0077	0.36	0.0021**	18.29	1.06	25.28	7.61	9.30	0.071	0.002	0.58	0.005
Error	30	46.18	0.030	0.055	0.0036	0.67	0.0002	10.76	0.59	12.38	9.78	9.38	0.058	0.002	1.27	0.003
CV (%)		9	3.7	4.6	5.6	12.8	1.6	14.7	23.1	14.2	3.5	16.3	4.4	8.8	3.7	1.2

*& ** significant at $P<0.05$& $P<0.01$), respectively. DF = degree of freedom, MFNPP=Marketable fruit number per plant, UMFNPP= unmarketable fruit number per plant, TFNPP=Total fruit number per plant, % MAK- marketability and % UM= un marketability, TSS=total soluble solids, TA= titratable acidity, TSS/TA=sugar acid ratio.

Significantly highest fruit weight was obtained by growing Cochoro variety on black plastic mulch in the first year growing season. The weight of Cochoro variety fruit produced in both the first and second year exceeded the weight of Miya variety by 16 and 17% respectively. Fruits grown on black plastic mulch had significantly the highest weight (80.29 g) followed by fruits grown without mulch, then grass mulch compared to fruits grown in white plastic mulch. Growing tomato varieties on black plastic mulch increased fruit weight by about 5, 6, and 12 % over fruits produced without mulch, grass mulch and white plastic mulch, respectively (Table 5).

Table 5. Effect of mulch, fruit variety and year on fruit weight, % un-marketability, TSS, and marketable fruit number per plant.

Mulch	Fruit weight (g)	UM (%)	TSS(%)	Marketable fruit number per plant
BPM	80.29a	9.05b	5.283b	23.44b
WPM	70.49b	11.78a	5.544a	19.64c
GM	75.74ab	9.11b	5.594a	26.64a
No mulch	76.38a	11.76a	5.40ab	19.39c
LSD (5%)	8.01	0.68	0.202	2.74
Variety				
Cochoro	82.16a	13.11a	5.568a	19.36b
Miya	69.29b	7.75b	5.343b	25.20a
LSD (5%)	4.01	0.48	0.143	1.93
Year				
2012	82.28a	11.76a	5.182b	22.08
2013	68.17b	9.10b	5.729a	22.47
LSD (5%)	4.01	0.48	0.143	NS

Means in columns with the same letter in each trait are not significantly different.
BPM= black plastic mulch, WPM= white plastic mulch and GM= grass mulch,
% UM= un-marketability, TSS=total soluble solids.

Fruits length, fruit shape, index and pericarp thickness of Cochoro variety showed significantly higher mean values as compared to Miya. Cochoro produced fruits with higher length shape index and pericarp thickness by 14, 13 and 17%, respectively, over Miya variety (Table 6). The fruit of Cochoro variety grown without mulch in 2012 had highest fruit width (5.13 cm); but this value did not vary statistically over fruit width in both varieties under different mulch types whereas the 2013 values were proportionally very low. On the other hand, Cochoro variety grown on all types of mulch, except white plastic mulch in 2013 produced fruits with high and statistically equivalent juice content whereas for Miya variety, only white plastic mulch and non-mulched treatments in 2012 produced comparable juice contents (Table 7).

Table 6. Effect of variety and year on fruit length, fruit shape index, pericarp and % marketability.

Variety	Average fruit length (cm)	Fruit shape index	Fruit pericarp thickness (mm)	MAK (%)
Cochoro	5.44a	1.158a	7.01a	86.84b
Miya	4.69b	1.007b	5.80b	92.14a
Year				
2012	5.17a	1.114a	7.78a	88.08b
2013	4.95b	1.051b	5.02b	90.90a
LSD (5%)	0.138	0.036	0.482	1.844

Means in columns with the same letter in each trait are not significantly different. MAK (%)= percent marketability.

Table 7. Interaction effect of mulch, variety and year on fruit width and juice content.

Trait		Average fruit width (cm)		Fruit juice content (l/kg)	
	Year	2012	2013	2012	2013
Variety	Mulch				
Cochoro	BPM	5.10ab	4.55def	0.921a	0.907ab
	WPM	5.01abc	4.10g	0.9045ab	0.873cd
	GM	4.83bcd	4.57def	0.921a	0.905ab
	No mulch	5.13a	4.41f	0.898abc	0.901ab
Miya	BPM	4.57def	4.50ef	0.858de	0.884bc
	WPM	4.78cde	4.45f	0.907ab	0.875cd
	GM	5.00abc	4.31fg	0.892bc	0.849e
	No mulch	4.97abc	4.77cde	0.919a	0.835e
LSD (5%)		0.29		0.0242	

Means in columns with the same letter in each trait are not significantly different
BPM= black plastic mulch, WPM= white plastic mulch and GM= grass mulch.

Fruit Yield and Marketability

The two varieties showed significant variation for number of total fruits per plant due to the interaction of variety x year (Table 4). Miya and Cochoro variety produced significantly highest and lowest total fruit number per plant in 2012, respectively, with yield difference of 28%. Similarly, the application of mulch significantly influenced number of total fruits per plant produced by tomato varieties where grass mulch produced significantly highest number of fruits (near to 29) as compared to the rest of mulch treatments. Miya variety in 2013 produced significantly lower unmarketable fruits number per plant while both varieties in both years produced higher (Table 8). On the basis of two years data, the major factors contributing for unmarketable tomato fruit yield were fruit cracking, decay, blossom end rot (BER) and insect damage which accounted 6.64, 3.13, 2.14 and1.24%, respectively, out of the total 13.16% fruits considered as unmarketable (Figure 1).

Table 8. Interaction effect of variety and year on unmarketable fruit number per plant and total fruit number per plant.

Variety	Year	UMFNPP	TFNPP
Cochoro	2012	2.96a	20.92c
	2013	2.79a	23.59bc
Miya	2012	2.80a	29.11a
	2013	1.45b	25.59b
LSD (5%)		0.64	2.93
Mulch	BPM	2.34	25.76b
	WPM	2.52	22.22c
	GM	2.60	29.25a
	No mulch	2.55	21.97c
LSD (5%)		NS	2.93

Means in columns with the same letter in each trait are not significantly different
BPM= black plastic mulch, WPM= white plastic mulch and GM= grass mulch, UMFNPP= unmarketable fruit number per plant, TFNPP=Total fruit number per plant.

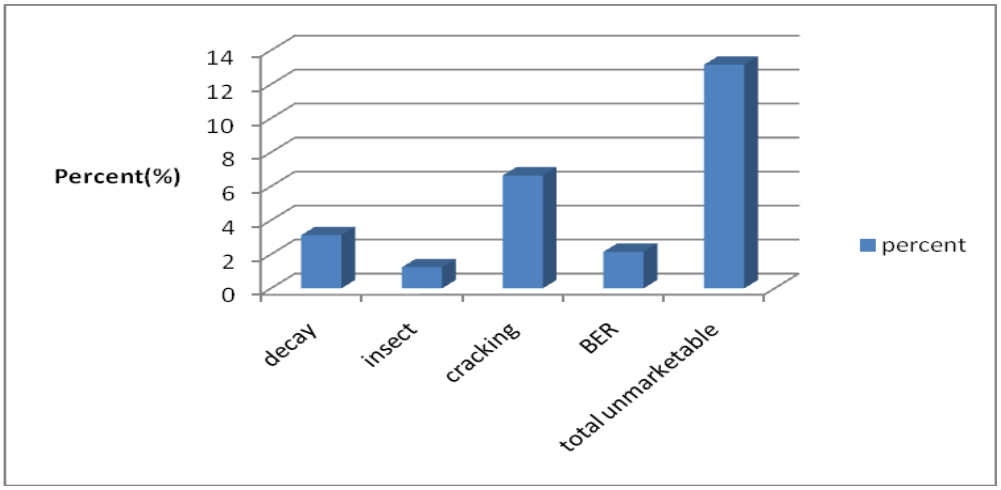

Figure 1. Mean percentage of unmarketable yield

All possible interactions did not influence marketable fruit which was rather significantly influenced by mulch, tomato variety and growing year (Table 4). Grass mulch produced significantly highest marketable fruit number per plant while both white plastic mulch and no mulch produced significantly lowest marketable fruit number per plant. Marketable fruits number per plant produced in both years did not show significant variation. However, plants grown in 2013 showed significant increase of fruit marketability by 3 % as compared to plants grown in 2012 (Table 6).

Fruit Chemical Quality Attributes

The combined analysis of variance over years revealed that variety and growing year significantly influenced all fruit chemical quality attributes (TSS, TA, TSS/TA and pH). Significant difference of traits in the growing season (year) was due to air and soil temperature, and relative humidity difference observed throughout the growing season (Table 1, 2 and 3). The highest TSS value (5.59 %) was recorded for fruits produced under grass mulch followed by white plastic mulch (5.54%). Cochoro variety produced fruits with significantly higher TSS (5.57 %) as compared to fruits produced from Miya variety (5.34 %) (Table 5). Both varieties produced fruits with non-significant TA content under all mulch types (Table 9). In the present study, pH values of tomato fruits ranged from 4.45 to 4.68. Cochoro variety grown on black plastic mulch produced fruits with significantly highest juice pH value (4.68) followed by the same variety fruits grown under grass mulch (4.60). The ratio of TSS/TA ranged from 11.60 to 8.42 for Cochoro variety grown under black and white plastic mulch, respectively. This variety grown without mulch and Miya variety grown under black plastic mulch produced fruits with sugar to acid ratio of 10.94 and 10.29, which have \the highest values (Table 9).

Table 9. Interaction effect of mulch and variety on TA, TSS/TA ratio and pH.

Variety	Mulch	TA(%)	TSS/TA	pH
Cochoro	BPM	0.507b	11.60a	4.687a
	WPM	0.572a	8.42d	4.512cd
	GM	0.582a	9.71bcd	4.608b
	No mulch	0.477b	10.94ab	4.563bc
Miya	BPM	0.622a	10.29abc	4.502cde
	WPM	0.588a	9.31cd	4.485de
	GM	0.600a	9.32cd	4.483de
	No mulch	0.592a	8.92d	4.447e
LSD (5%)		0.059	1.33	0.064

Means in columns with the same letter in each trait are not significantly different
BPM= black plastic mulch, WPM= white plastic mulch and GM= grass mulch.

Table 10. Effect of mulching material on soil temperature (^oC) at 10cm depth combined over years.

Treatment	July(^oC)	August(^oC)	September(^oC)	Mean(^oC)	Minimum(^oC)	Maximum(^oC)
BPM	27.45b	25.59ab	25.99a	26.34b	23.27ab	30.93b
WPM	28.62a	25.93a	26.62a	27.06a	23.60a	32.79a
GM	24.84d	24.27c	24.40b	24.50d	22.08c	27.45d
No mulch	26.14c	25.02b	25.73a	25.63c	22.86b	29.48c
Significance	**	**	**	**	**	**
CV%	2.50	3.03	4.11	2.70	3.23	4.33

* and ** significant at $P \leq 0.05$ and $P \leq 0.01$

BPM= black plastic mulch, WPM= white plastic mulch and GM= grass mulch.

Means in columns with the same letter are non-significant each other at ≤ 0.05

Discussion

Growing tomato varieties on black plastic mulch followed by grass mulch increased fruit weight as compared to fruits produced without mulch and white plastic mulch. Similarly Wahome *et al.*, [25] reported that the superiority of tomato fruits in weight when plants grown under grass and black plastic mulch. Kere *et al*. [17] also observed that dry grass mulch had significantly highest individual fruit weight under greenhouse condition. The superiority of black plastic in producing highest fresh weight of fruit in pepper was also reported (Belel, [26]; Hassandokht *et al*., [27]. This might be probably due to the increase in moisture conservation as a result of reduced evaporation from the surface of the soils. Other authors also reported that heavier fruits of tomato were produced in plants grown with straw under tunnel condition [16]; [18]. This might be due to the beneficial effects of straw mulch which enables retention of soil moisture and prevent soil temperature to raise at the end of vegetative phase enabling the increase in the CO_2 content and thus an increase in photosynthesis [28]. Miya variety gave fruits with significantly highest juice content in 2012 when produced without mulch. The present study result is in agreement with other authors who reported significantly higher juice content of tomato fruits when produced with no mulch as compared to white plastic mulch [29]; [15]; [19].

In the current study, Cochoro variety was found to be superior in terms of fruit length, fruit shape, index and pericarp thickness. The observed quality differences between tested varieties is due to inherent characteristics of the varieties. Similarly Hossain *et al*. [30] found that the highest value of fruit length was observed in TM-13 tomato variety (5.14 cm), whereas the lowest value of fruit length was observed in TM-110 tomato variety (3.35 cm).

Highest total number of fruits were obtained from tomato plants grown under grass mulch followed by those mulched with black polythene sheet in agreement with the result reported by Wahome *et al*. [25]. Tomato fruit yield increment may be further explained by reduction of maximum root zone temperature under grass mulch treatment. During the experiment period grass mulch recorded the lowest mean (24.50 ^oC), minimum (22.08 ^oC) and maximum (27.45 ^oC) soil temperatures compared to the remaining mulch and control treatments (Table 10). On the other hand, high marketable fruit number per plant and consequently marketability of fruits in percent was recorded for plants grown under mulch. Similarly, lowest percentages of unmarketable fruits were obtained in plots covered with mulch than without mulch except for white plastic mulch. The results are in agreement with the findings of Incalcaterra *et al*. [31] who reported that the lowest percentages of unmarketable fruits were obtained in plots covered with no mulch under open field condition. The same author confirmed high un-marketability of fruits produced under no mulch with a direct contact of fruits to the soil and moisture. The observed significant variations between varieties and growing years on the marketability of tomato fruits was reported by Olaniyi, [32] and Titilayo and Folorunso, [33]. This variation in yield may also be due to genetic differences among the varieties since they were grown under the same environmental conditions. Weather condition of the growing season mainly temperature plays a major role in phenological development and productivity of crop plants.

The present result was in agreement with the result reported by Sacco [34] where total soluble solids of the cultivated tomato were comprised between 4 and 7.5 % of its fresh weight. On the other hand, Caliman *et al*. [35] reported the total soluble solids content in tomato fruits between 3.60 % and 3.83 % in different varieties tested under protected condition. In this study, the highest TSS value was recorded for fruits produced from plants grown under grass mulch followed by white plastic mulch. The current result is partially in agreement with the finding of Abdul-Baki and Stommel [36] who reported equal values of TSS from tomato fruits produced on bare soil and hairy vetch mulch. The result obtained in the current experiment is in agreement with Liang *et al*. [37] who suggested that as the soil temperature increased, the sugar content, soluble acid content decreased. In this study, lowest soil temperature was recorded under grass mulch which might have contributed to the highest TSS values. However, the current study result is in contrast with Kere *et al*. [17] finding where clear plastic mulch enhanced tomato fruit total soluble solids.

The present study result showed that tomato fruit pH ranged from 4.44 to 4.61 for the interaction of mulch and variety. The low pH of tomato fruit is associated with high fruit quality. Caliman *et al*. [35] concluded that tomatoes are still classified as an acidic fruit (pH < 5). The authors also reported that fruit pH values ranged between 4.34 and 4.56 in different varieties tested under polyhouse condition. In the current study results of both varieties in all mulch conditions produced fruits with highest TA which was in agreement with Ilić *et al*. [38] finding where tomato fruits produced under black mulch scored higher TA value compared to control in plastic house condition. According to Caliman *et al*. [35] tomato had a good flavor when sugar to acid ratio is greater than 10. In this study, the result obtained for both varieties under black plastic sheet and for Cochoro variety grown without mulch produced fruits with TSS/TA >10 which is considered as having good fruit flavor.

Conclusion and recommendation

Variety and mulch significantly affected almost all fruit yield and fruit quality attributes, namely unmarketability of fruit, fruit width, titratable acidity, sugar to acid ratio, fruit juice content and pH. Based on the research results and considering higher fruit yield particularly marketability of fruits as driving force for producers and high weight (large size) and good flavor for consumers, the production of tomato under polyhouse with the mulch is recommended to increase number of total fruits per plant. Particularly; grass mulch produced significantly highest number of total and marketable fruit number per plant. Although, we have observed variation of fruit weight due to the interaction of variety, year and mulch, fruits obtained from plants grown on black plastic mulch had significantly highest weight. The two varieties of tomato gave different yield with all desirable chemical contents under mulch except total soluble solid. For consumers, the most important trait is fruit good flavor which was attained by growing varieties under black plastic mulch with sugar to acid ratio greater than 10. Therefore, the desirable traits for both producers and consumers were obtained by growing Cochoro variety under polyhouse using black plastic mulch. However, the choice of mulch materials to match the preference of producers and consumers, need to be evaluated by further experiments considering different varieties and estimating cost benefit analysis.

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