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Mitigating Natural Heat Stress for Tomato (*Solanum lycopersicum L*) Production through Management Techniques

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Authors' contributions

This work was carried out in collaboration among all authors. Author TRC designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AKS, MDS, KMT and AS supervised the experiment and amended the final draft. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted to identify suitable production management techniques for tomato (*Solanum lycopersicum* L.) cultivation during late winter-pre monsoon season in plains of Nepal. For this, organic mulches (rice straw, dried grass, and rice husk) were compared with SN (shade net) and no-mulch (bare field) condition for tomato yield in 2018 and 2019. The pooled analysis of all observed morphological and yield traits were performed and they differed significantly. Rice husk significantly affected number of fruits per inflorescence though number of inflorescence per plant and flowers per inflorescence were similar among organic mulches. The highest fruit yield per plant (4.44 kg $plant^{-1}$) was obtained with rice husk, the other mulches and SN were at par but the lowest yield (2.75 kg $plant^{-1}$) was obtained with no-mulch. Similarly, rice husk mulch contributed to the highest number of fruits per inflorescence (5.22), highest fruit weight (46.58 g) and diameter (4.99 cm).Fruit yield positively and significantly associated with fruit per inflorescence(0.78***), fruit diameter (0.65***) and an average fruit weight (0.56***).Organic mulches significantly (p=0.05) contributed to higher yield (86.01 t ha^{-1}) over SN (76.55 t ha^{-1}).Higher values for total soluble solid,

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Vitamin C and fruit firmness were observed under rice husk mulching. The result of the present study found rice husk mulching as better option for tomato production as compared to SN and no-mulch condition.

Keywords: Organic mulch; rich husk; shade net; tomato.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the major commercial vegetable crops widely grown in both the Terai and hills of Nepal [1]. In the Terai, tomato production is restricted to the cooler months of September to March, since its production is constrained by high temperature resulting in low flowering and fruit set as well as diseases such as bacterial wilt (*Ralstonia solanacearum*) in hotter months [2]. Tomato production beyond March is profitable in Nepal [3] but it demands heat tolerant genotypes or modification in growing condition. Because, in the experimental site, the average mean daily temperature exceeds 32^{o}C from March to July [4]. It is established that fruit set in tomato reduced markedly when average maximum day temperature goes above 32^{o}C [5]. However, several researchers have reported the use of heat tolerance genotypes [6], shade net [7] and mulching materials for tomato cultivation in hotter environment [8].

Mulching is a soil covering practice, which helps in better growth and development of the plants by modifying soil temperature, providing better nutrient availability and by better moisture conservation [9,10]. Among mulching material, polyethylene, petroleum derivatives and non-degradable, mulches are the common practices though they creates environment pollution for very long period [11]. As alternatives, we can use biodegradable films, paper mulches or crop residues [12]. Crop residues are easily available, organic sources, biodegradable, and environment friendly.

Organic mulches like straw, rice husk, water hyacinth, and other crop residues are generally utilized in the production of horticultural crops. Additionally, organic mulch keeps soil temperature stable and can contribute organic matter [13].Organic mulching tends to minimize temperature fluctuations to such an extent that mulched areas warms up and cool down more gradually when compared to bare soil which tends to fluctuate rapidly [14].These mulches can reduce ambient soil temperature by 5.6^{o}C to 9.8^{o}C and increase soil moisture content by 4% to 5.6% [15]. Organic mulches reduce heat conduction into the surface of soil by retaining incoming solar radiation [16]. Further, the use of rice husk has been proved effective in tomato production during dry and hot weather in the spring season under the conditions found in Bardiya, Nepal [8]. Besides, these materials are also used in the management of root knot nematodes in tomato [17].

Heat tolerant genotypes are not easily available in Nepal. Shed net could not be afforded by the majority of marginalized farmers due to the higher initial investment [18], although it is being promoted by government and non-governmental sector without research supports [19]. Consequently, the use of organic mulches seemed to be an alternative technology taking advantage that these are easily available in Nepal [20]. From the known references, mulch experiments are mainly focused on making comparisons among plastic mulches or with plastic mulches [18,8] leaving a huge gap to compare organic mulches with shade net for tomato production. Therefore, this study was conducted to compare alternate low cost and eco-friendly mulching technology against shade net for tomato production in hotter months in the plains of Nepal.

2. MATERIALS AND METHODS

2.1 Site Description

The field experiment was conducted at the Department of Horticulture, Agriculture and Forestry University (27°39'23.6"N, 84°21'26.8"E, 220 m), Nepal, from January to June in 2018 and 2019. The area is in subtropical climatic zone. Average annual precipitation is 1372.70 mm, mean annual temperature 24.6°C and mean relative humidity of 84.9%. The soil of the experimental area was sandy loam in texture having good fertility with pH 5.46. The experimental field was solarized with 100 gauge white plastic for two months before transplanting.

2.2 Experimental Materials and Design

There were four levels of mulching treatments- 1.Rice husk (RH), 2. Rice straw (RS), 3. Dried grass (*Imperata spp*., DG), and 4.No-mulch (Bare). The mulch system was also compared with 50% Shade Net without mulch (SN) condition. Each mulching materials manually distributed over the plots maintaining 10 cm thickness [21] before transplanting [12].

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments and four replicates. Seedlings were raised in a peat based substrate (Lithuania), which had a pH of 5.5–6.5 and contains $N:P_2O_5:K_2O$ at the ratio of 14:10:18, respectively. Popular indeterminate hybrid tomato genotype Srijana [22] was used for the experiment. Seeds were sown in plug trays in the first week of January, and trays were put under plastic tunnel. The purpose of the plastic tunnel was to increase potting mix temperature for germination. During the first week of February, a month old seedlings were transplanted at a distance of 0.75 m between rows and 0.60 m within row spacing. Plot size was 10.8 m^2 which consisted six rows with four plants in each row making 24 plants per plot. For SN system, seedlings were transplanted in the plot and covered with 16 x 6 m^2 cladded with silver colored 50% shade net on the top and sides were covered with 40 mesh anti-insect net. The height of the SN was 4.2 m at the center and 3 m at sides.

The recommended dose of farm yard manure (FYM) i.e. 30 tha^{-1} and 150:100:100 $N:P_2O_5:K_2O$ kg ha^{-1} was applied for growing tomato [1]. Half dose N and full dose of P_2O_5 and K_2O along with micronutrient Borax 10 kg ha^{-1} and zinc sulphate 50 kg ha^{-1}, respectively was applied as basal dose [23]. Half of recommended nitrogen was applied in two split doses as top dressing on 30 and 60 days after transplanting. Nitrogen and phosphorous was supplied through Di-Ammonium Phosphate (DAP) containing 18%N and 46%P_2O_5, remaining dose of nitrogen was supplied through urea containing 46%N and potash was applied from Muriate of Potash (MoP) containing 60% potash. Weeding was carried out manually and irrigation was applied through drip irrigation as practiced by local growers. Tomato plants were trained to two stems by continuous removal of auxiliary shoots [24] and tied on vertical ropes those fixed on horizontal iron wire.

2.3 Fruit Quality Traits

Fruits were sampled at light red stage to analyze quality traits. Fruit juice was extracted by crushing tomato fruit pulps and digital refractometer was used for measuring total soluble solids (TSS) and expressed in °Brix. Ascorbic acid was analyzed by volumetric method using 2,6-dichlorophenol-indophenol visual titration as described by Sadasivam and Manickam [25]. The titratable acidity (as anhydrous citric acid) was determined by titrating the sample solution with 0.1 N of NaOH using Phenolphthalein as an indicator. pH of the fruit juice was determined by using pH meter. Diameter and pericarp thickness were measured with digital vernier caliper. Fruit firmness was measured with penetrometer (FACCHINI, FT-011, Italy).

2.4 Data Collection and Analysis

Growth (plant height and number of leaves), floral (Number of inflorescence, flowers and fruits per inflorescence etc.), yield (Marketable fruits per plant, fruit diameter, yield per plant and per hectare etc.) and quality traits (TSS, TA, vitamin C etc.) were recorded. Most of the growth and floral parameters were recorded at the final harvesting stage. Yield attributes were recorded multiple times. Yield t ha^{-1} was calculated from net plot. Analysis of variance for the pooled data of these traits, correlation analysis and t-test were carried out using R Software ("Agricolae" and "Hmisc" packages, Version 1.3.1056 © 2009-2020 RStudio, PBC, Open source). When the treatment effects were found significant, means were separated using least significant difference (LSD). Meteorological information (rainfall, ambient temperature and relative humidity) of experiment site was collected from the Department of Hydrology and Meteorology, Nepal [26].

3. RESULTS AND DISCUSSION

3.1 Climatic Parameters

The climatic parameters (maximum temperature, relative humidity and rainfall) during crop period is presented in Fig. 1. The maximum temperature constantly above 30°C from March to June in both the years. It was low (18.25°C) in the first week of January and the highest (37.61°C) in the third week of June in 2018 and 2019, respectively. From the third week of March, the maximum temperature rose beyond critical temperature point of 32°C. Later, in 3rd week of April onward, it was around 35°C. Thereafter, the natural heat stress condition prevailed in growing area whereas, the optimum temperature for growth and yield in tomato is 21-24°C [27]. Beyond 32°Cfruit set reduced markedly [5]. The main fruiting period suffered by high temperature. Only 415 mm rain occurred during January to June although annual mean rainfall is around 1372.70 mm. It is the dry period in the plains of Nepal. Relative humidity showed similar trend at the beginning and end of the cropping season in both the years. However, in the middle of the season, from 3rd week of March to 2nd week of May, RH was around 65 and 90% in 2018 and 2019, respectively. May 3rd week onward up to second week of June, it remained around 60-80% in both the years. Generally, inverse relationship was observed between temperature and relative humidity. Rainfall and Relative humidity showed well correlated.

3.2 Soil Properties of Experimental Field

Table 1 showed the chemical properties of soil under mulches and SN before experiment in 2018. Soil parameters did not vary significantly among the plots. The range of these parameters were; pH (5.37 to 5.59), TN (0.14 to 16 %), P (32.84 to 47.70 ppm) and K (53.33 to 68.48 ppm). According to soil nutrient categories adapted by SSD [28] organic matter content (2.71%), total nitrogen (0.15%) and exchangeable potassium (60.02 $mgkg^{-1}$) were medium in range whereas the available phosphorus was high (39.79 mg kg^{-1}) in the experimental field.

Soil parameters did not affect the outcome of the experiment because the observed parameters were non-significant. Masfufah et al. [29] stated that vegetables such as tomatoes need suitable soil pH of 5.0 - 7.0 or somewhat acidic to neutral. If the soil pH is too acidic, the soil will lack potassium, so that tomato plants are susceptible to disease [30]. Furthermore, Böhlenius et al. [31] reported that soil pH in between 5.0 to 6.0 is good for the growth of tomato plant. Though it was moderately acidic, soil pH reaction was suitable for tomato cultivation. Likewise, other major nutrients were also in balance form in the experimental soil.

3.3 Growth and Floral Traits

Treatments differed significantly for growth and floral traits (Table 2). SN was significantly different from mulches and no-mulch, and mulches were also significantly different from no-mulch for plant height. The tallest, medium and short plants were under SN (317.58 cm), organic mulches and no-mulch condition (208.34 cm) at final harvest, respectively. Organic mulches did not differ statistically for plant height. Besides significant differences in plant height, number of inflorescence per plant did not show significant

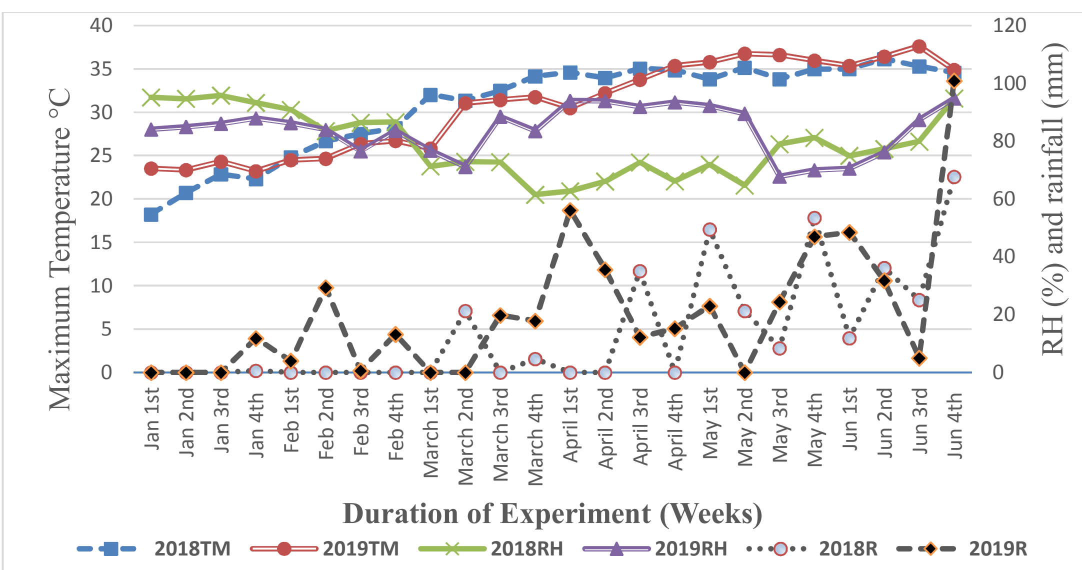

Fig. 1. Mean ambient maximum temperature (°C), relative humidity (%) and precipitation (mm) during field experiment in 2018 and 2019

TM = Maximum temperature, RH = Relative humidity and R = Rainfall

Table 1. Chemical properties of the soil of the experimental plot before experiment

Treatments	Chemical properties of soil				
	pH	OM (%)	TN (%)	P (ppm)	K (ppm)
Shade net	5.37†	2.73	0.16	32.84	53.33
Rice straw	5.59	2.58	0.16	36.42	62.42
Dry grass	5.42	2.71	0.16	42.65	56.36
Rice husk	5.55	2.75	0.15	39.35	59.53
No mulch	5.40	2.78	0.14	47.70	68.48
Mean	5.46	2.71	0.15	39.79	60.02
F–test	NS	NS	NS	NS	NS
CV%	4.95	17.20	12.64	30.05	22.82

† Mean of 4 replications. NS = non-significant. OM = Organic matter %, TN = Total nitrogen%, P = Phosphorus (mg kg^{-1}) and K = Potassium (mg kg^{-1}).

Table 2. Effect of mulching and SN on morphological and floral characteristics of tomato

Treatments	PH	LF	IN	FIPI	UFI	FPI	FS
Shade net	317.58^{a}†	59.97^{a}	23.40^{a}	6.95^{b}	3.52^{a}	3.45^{d}	49.79^{b}
Rice straw	240.43^{b}	56.12^{b}	21.88^{a}	8.03^{a}	3.35^{ab}	4.67^{b}	58.24^{a}
Dry grass	228.92^{b}	56.3b^{c}	21.86^{a}	7.92^{a}	3.32^{ab}	4.59^{b}	58.4^{a}
Rice husk	235.92^{b}	57.85^{ab}	21.95^{a}	8.47^{a}	3.25^{ab}	5.22^{a}	61.7^{a}
No mulch	208.34^{c}	52.87^{c}	19.87^{b}	6.82^{b}	2.83^{b}	3.98^{c}	58.64^{a}
Mean	246.08	56.53	21.79	7.64	3.25	4.38	57.39
F–test	***	***	***	***	*	***	***
LSD(≤0.05)	14.08	2.74	1.53	0.59	0.54	0.4	5.19
CV%	5.58	4.72	6.85	7.61	16.44	9.03	8.82

*† Mean of four replications over two years. In the columns means followed by the same letter are not significantly different (P≤0.05) by LSD. PH=Plant height (cm) at final harvest, LF=Number of leaves per plant, IN = Number of inflorescence per plant, FIPI = Number of flowers per inflorescence, UFI = Unfertilized flowers per inflorescence, FPI = Fruits per inflorescence and FS = Fruit set percentage. Significance level for ANOVA: * P=0.05,*** P= 0.001*

difference among organic mulches and SN. However, organic mulches differed significantly from no mulch and SN for flowers per inflorescence. Irrespective of similarity in flowers per inflorescence among organic mulches, fruits per inflorescence were higher in RH mulch. Organic mulches and no-mulch differed significantly for fruit set percentage. The lowest fruit setting percentage was observed in SN (49.79%). Though, organic mulches did not vary with no-mulch, the highest fruit setting percentage (61.70%) was found under RH mulch. The effect of organic mulches mainly observed in number of flowers and fruits per inflorescence.

Growing environment affects the plant height. The tallest plant in SN condition is due to the low light entered inside the 50% shade net. The increased growth under shade net house is by increasing the rate of plant response to diffused sunlight resulting in longer inter nodal length and increase in the growth variables in terms of plant height [32]. Similarly, Nangare et al. [33] observed the highest plant height under green shade (35-75 %) net house in both the seasons as compared to open field. In similar growing condition, SN with black mulching produced the highest plant height (211.375 cm) as compared to no-mulch (182.79 cm) [18]. Consequently, light retards stem elongation by reducing effective gibberellin supply in growing regions [34].

Significantly low fruit set (49.79 %) under SN could be due to low light and photosynthate partition. Under low solar radiation, photosynthate diverts towards developing fruits scarifying upper inflorescence and roots, root activity decreases causing severe flower abscission or fruit drop [35].The highest number of fruits per inflorescence under RH was attributed to the highest fruit set percentage. The RH demonstrated effectiveness in creating suitable growing environment in natural heat stress condition for tomato.

3.4 Marketable Yield and Yield Characteristics

The observed traits for yield characteristics differed significantly (Table 3). The highest yield per plant (4.44 kg) was obtained from RH mulching. Tomato yield reduced significantly to 2.75 kg per plant without mulching. However, RS and DG mulching did not differ significantly with SN without mulch condition. In contrast, the lowest unmarketable yield per plant (23.23 g) was recorded from SN without mulch condition. RH mulching contributed to higher Number of marketable fruits and average fruit weight. Despite, non-significant differences for total fruit per plant among organic mulches, RH mulching produced the highest yield (95.68 t ha^{-1}).

Rice husk was identified as the most productive mulching through mean separation performing ANOVA. Due to non-significant difference among rice straw, dry grass mulching with SN, it was important to ascertain superiority of organic mulching over SN. t-test was performed to compare organic mulches with SN, and SN with no-mulch condition. Organic mulches differed significantly (*P*=0.02) with SN and SN differed significantly (*P*=0.001) with no-mulch condition. The highest marketable fruit yield (86.01 t ha^{-1}) was obtained from mulch system followed by SN (76.55 t ha^{-1}) and the lowest (57.43 t ha^{-1}) from no-mulch condition.

3.5 Correlation Among Yield Traits

Correlation among the traits calculated and presented in Table 4. Yield per plant had positive correlation with all observed traits. MFP (0.91***), TFP (0.88***), FIPI (0.80***), FPI (0.78***), FD(0.65***) and FW(0.56***) had the most significant positive correlation to yield. FD had positive and significant correlation with FW (0.54***). PH had negative significant correlation with FS (-0.27***) and FPI (-0.54***).

Crop productivity is higher under mulching as compared to bare fields because of the efficiency of mulch in maintaining soil moisture and improving nutrient transformations and availability [36]. Organic mulches has positively contributed to tomato yield. In our study, organic mulches significantly affected the yield and yield attributes. The highest fruit yield in rice husk mulching was attributed to number of marketable fruits, diameter and average weight of the fruit. The result suggested that mulching created favorable environment in root zone. The correlation study revealed that MFP and TFP are two major traits that contributed to the higher marketable yield. The significantly higher FD and FW obtained from RH which made RH significantly high yielder among the organic mulches. These two parameters were significantly correlated with yield t ha^{-1}.The number of fruit per inflorescence, single fruit weight, fruit diameter and pericarp thickness had the highest impact on yield of tomato lines [37]. Likewise, Rajolli et al. [38] found positive correlation of number of fruits per plant, average fruit weight and pericarp thickness with yield per plant. In this study, RH had significantly higher pericarp thickness as compared to the organic mulching that might have contributed to make

Table 3. Effect of mulching and SN on yield characteristics and marketable yield (t ha^{-1})

Treatments	MFP	UMFP	TFP	FW	FD	YP	UMYP	YTH
Shade net	77.99^{b}†	1.00^{b}	79.01^{b}	45.67^{a}	4.75^{b}	3.46^{b}	23.23^{b}	76.55^{b}
Rice straw	87.71^{a}	9.80^{a}	97.57^{a}	42.53^{b}	4.77^{b}	3.86^{b}	185.44^{a}	81.69^{b}
Dry grass	89.47^{a}	8.70^{a}	98.23^{a}	40.76^{b}	4.75^{b}	3.81^{b}	183.4^{a}	80.67^{b}
Rice husk	94.13^{a}	12.45^{a}	105.32^{a}	46.58^{a}	4.99^{a}	4.44^{a}	133.6^{a}	95.68^{a}
No mulch	68.82^{b}	9.60^{a}	78.45^{b}	37.71^{c}	4.55^{c}	2.75^{c}	174.44^{a}	57.43^{c}
Mean	83.62	8.34	91.72	42.9	4.76	3.66	140.01	78.41
F – test	***	***	***	***	***	***	***	***
LSD(≤0.05)	9.38	4.55	11.49	2.05	0.17	0.40	67.17	8.98
CV%	10.93	53.19	12.21	5.43	3.56	10.82	46.76	11.17

† Mean of four replications over two years. MFP = marketable fruit per plant, UMFP = Unmarketable fruit per plant, TFP = total fruits per plant, FW = fruit weight, FD = fruit diameter, YP = yield (kg) per plant, UMYP= Unmarketable yield per plant (g) and YTH = yield ton per hectare

*In the columns means followed by the same letter are not significantly different (P=0.05) by LSD. Significance level for ANOVA: *** P= 0.001*

RH the best yielder. Number of flowers per cluster had positive association with number of fruits per cluster [39]. Shrestha [8] compared organic mulches (Rice straw and husk) with plastic mulches (Black and Red) with no mulch (control) in relatively similar environment as ours and reported that rice husk provided significantly higher yield than control. Further, among organic mulches, the marketable yield was 13% higher in RH as compared to RS from our study. As compared to polythene and no-mulch, organic mulch tomato had more dry matter in fruits [40].

In plain of Chitawan, tomato is mainly produced as winter crop and transplanted during September-October [18]. In winter maximum temperature range between 20^{o}C to 25^{o}C in plains of Nepal [26], within the suitable temperature range [41]. Fruit set reduced markedly when average maximum day temperature goes above 32^{o}C [5]. Due to rise in average day/night temperature (32/26^{o}C) a decrease in the yield of tomato is a common observation [42]. Fruit yield of tomato genotypes Srijana provided 32% less yield from no-mulch treatment as compared to SN with black plastic mulch in same location [18]. Likewise, rice husk mulching provide 31.35 t ha^{-1} as compared to no-mulch (control) 14.68 t ha^{-1} which 213% more as compared to no-mulch in summer season [8]. This result is in accordance with our result. This result has clearly demonstrated that mulching had positive contribution in the yield of tomato. And, it also clarify that organic mulches ameliorate adverse effect of high temperature.

Rice husk, an organic waste, a major by-product of the rice milling and agro-based biomass industry. Rice husk creates favorable environment for tomato by retaining soil moisture and thermal stability in root zone. It absorbs water ranging from 5% to 16% of unit weights [43]. Organic mulch (rice husk) reduce the maximum soil temperature but raise the minimum soil temperature [44]. Zhang et al. [45] recorded a 4^{o}C decrease in soil temperature in the warmer period and a 2^{o}C increase in soil temperature in the colder period at 10 cm soil depth. It might have reduced the soil temperature in the experimental plot because the crop was produced during warmer season. It easily available in Nepal and there will be no issue for sustainability. The milling of paddy rice produced approximately 20% rice husk [46] have potential of producing1.04 million metric tons of rice husk annually [20].

3.6 Quality Characteristics of Tomato Fruit

Growing condition significantly affected all the observed quality traits except titratable acidity (Table 5). The highest total soluble solid was recorded from rice husk mulch (4.17^{o}Brix) which was at par with the other mulches and differ significantly with SN (3.67^{o}Brix). Rice husk contributed to superior values for the most of the quality traits. The lowest TSS, TA (highest) and VitC content were recorded from SN. The highest pericarp thickness (4.72 mm) measured from SN was at par with rice husk mulching (4.41 mm).

3.7 Correlation Among Physico-biochemcial Traits

Correlation among the eight quality traits were computed (Table 6).TSS has positive significant correlation with pH (0.58***), TSS/TA ratio (0.65***) and Vitamin C (0.60***) while it was negatively correlated with fruit firmness (-0.08), pericarp thickness (-0.29), fruit diameter (-0.06) and titratable acidity (-0.04). Fruit firmness had positive significant correlation with pericarp thickness and fruit diameter.

Yield is major concern for grower but the consumer demands quality tomato fruits. Sugars and acids are particularly important taste constituents of tomatoes.TSS was lower inside SN as compared to organic mulches and no-mulch condition those were in open field. Yeshiwas &Tolessa [47] also recorded lower TSS values from four tomato genotypes grown under greenhouse than that of open field condition. Exposure to direct solar irradiation increased the carbohydrate(19%), ascorbic acid (25%), and phenolic compound (20%) and decreased organic acid(6%) and lycopene (21%) content of tomato fruits as compared to shaded fruits [48]. pH and acidity are important parameters for assessing tomato quality. Tomato fruits usually have enough acidity to maintain their pH below 4.6, and for that reason they are considered as acid food [49].pH values obtained in this study were within the optimum ranges (3.7-4.5), reported by Sulieman et al. [50].

Table 4. Correlation coefficients (r values) among morphological and reproductive traits

Traits	LF	IN	FIPI	FPI	FS	TFP	MFP	FW	FD	YP	YTH
PH	0.58**	0.71***	0.12	-0.21**	-0.27***	0.07	0.31	0.57**	0.35	0.28	0.35
LF		0.50**	-0.10	-0.23	0.33	-0.11	0.10	0.59**	0.35	0.17	0.22
IN			-0.02	-0.12	-0.22	0.16	0.40*	0.46**	0.36	0.36*	0.44*
FIPI				0.85***	0.51**	0.79***	0.75***	0.30	0.50*	0.80***	0.74***
FPI					0.65***	0.84***	0.74***	0.16	0.46*	0.78***	0.74**
FS						0.52**	0.35	0.15	0.21	0.52	0.45
TFP							0.94***	0.19	0.52**	0.88***	0.84***
MFP								0.34	0.60**	0.91***	0.89***
FW									0.54**	0.56***	0.60***
FD										0.65***	0.66***
YP											0.98***

*Significance level for correlations: * P= 0.05, ** P= 0.01, *** P= 0.001*

Table 5. Physico-biochemical traits of tomato under different mulching and SN conditions

Treatments	TSS	FF	PT	FD	pH	TA	TSS/TA	VitC
SN without Mulch	3.67^{b}	4.08^{a}	4.72^{a}	4.33^{ab}	4.21^{b}	0.60	6.09^{b}	28.60^{c}
Rice straw	4.02^{a}	2.98^{b}	3.71^{b}	3.92^{c}	4.37^{a}	0.56	7.62^{a}	31.84^{ab}
Dry grass	3.97^{ab}	3.21^{b}	3.95^{b}	4.04^{abc}	4.35^{a}	0.56	7.10^{a}	32.58^{ab}
Rice husk	4.17^{a}	4.51^{a}	4.41^{a}	4.40^{a}	4.34^{a}	0.57	7.27^{a}	33.58^{a}
No mulch	4.00^{a}	2.97^{b}	3.91^{b}	3.99^{ab}	4.36^{a}	0.56	7.74^{a}	29.85^{bc}
Mean	3.97	3.55	4.14	4.13	4.33	0.57	7.20	31.29
F – test	*	***	*	***	**	NS	**	**
LSD(≤0.05)	0.31	0.66	0.31	0.36	0.07	-	0.89	2.84
CV%	5.20	12.10	4.93	5.75	1.06	6.47	8.14	5.89

TSS = total soluble solid, FF = fruit firmness (kg/cm^2), PT = pericarp thickness (mm), FD = fruit diameter, pH, TA = titratable acidity (%), TSS/TA = sugar acid ratio, VitC = vitamin C (Ascorbic acid $mg^{-100\,g}$)

*In the columns means followed by the same letter are not significantly different (P ≤0.05) by LSD. Significance level for ANOVA: *, ** significant at P= 0.05 or P= 0.01, *** P= 0.001, and NS = Non-Significant, respectively*

Table 6. Correlation coefficients (r values) among physico-biochemical traits

Traits	FF	PT	FD	pH	TA	TSS/TA	VitC
TSS	-0.08	-0.29	-0.06	0.58***	-0.04	0.65**	0.60***
FF		0.71**	0.58**	-0.27	0.34	-0.42	0.04
PT			0.57**	-0.61**	0.24	-0.47*	-0.22
FDL				-0.27	0.19	-0.21	0.01
pH					-0.08	0.52**	0.56**
TA						-0.56***	-0.06
TSS/TA							0.32

*Significance level for correlations: * P= 0.05, ** P= 0.01, *** P= 0.001*

Fruit firmness is important quality trait for transportation and shelf life. Pericarp thickness is key to define fruit firmness. Rice husk mulching and SN without mulch condition favored for pericarp thickness. Pericarp thickness is an important fruit quality trait in tomato that needs to be improved so fruit are more attractive to consumers [37].The average pericarp thickness in the present study was comparable to Yesmin et al. [51] and Kouam et al. [52]when they reported 6.33–3.12 mm and 2.2–5.8 mm pericarp thickness, respectively. This variation might be due to the difference of genotypes and growing condition between the studies. It was also found positively associated with fruit diameter. Negative association between TSS and fruit firmness indicates that sugar content increases and fruit firmness decreases with ripening. Our study suggested that fruit with thick pericarp were more firm.Correlation of fruit firmness was found positive and significant with pericarp thickness [38].High pericarp thickness and less number of locules gives high firmed fruit. The high fruit firmness influences the shipping ability and keeping quality. These results were consonance with Bharathkumar et al. [53] for fruit firmness. The RH had highest values for most of the fruit quality and yield traits justified it's superiority among the organic mulches.

In fact, positive correlations were observed between fruit sugar, vitamin C and lycopene content [54].There is an inverse relation between TA and pH, where the higher the total TA, the lower the pH [55] and vice-versa. This result also corroborate to our findings, where the pH increased, TA reduced.The ascorbic acid content peaked in developing fruit at the light-red stage before the full colour was reached [56]. We sampled the fruits at light-red stage for this study.

4. CONCLUSION

Organic mulching was superior to SN for tomato production during late winter to pre-monsoon season in plains of Chitwan, Nepal. Among organic mulches, due to the highest marketable yield, rice husk is recommended as suitable mulching material. Though, the farmers are found attracted towards SN, the structure used in the experiment, cannot be recommended to the farmers for tomato production in pre-monsoon season. This study established the fact that the growing environment created under shade net was better as compared to bare field but inferior to organic mulching. Though earlier studies had identified rice husk as promising mulching material over plastic mulch, it is clear now, rice husk is better to 50% shade net as well.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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