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Black Polyethylene Mulch Doubled Tomato Yield in a Low-input System in Arid Trans-Himalayan Ladakh Region

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ABSTRACT

The influence of black polyethylene mulch (BPM) on growth and yield of tomato was investigated under a low-input cultivation system in arid high altitude (elevation 3344 m) in trans-Himalaya. The mean marketable yield varied from 27.8±2.5 $t.ha^{-1}$ in open-pollinated varieties with no mulch treatment to 81.2±11.9 $t.ha^{-1}$ in hybrid tomatoes with BPM. The yield of hybrid tomatoes with BPM is similar or greater than those reported in high-input systems. With BPM, total marketable yield in hybrid varieties increased by 102 per cent and 107 per cent in 2014 and 2015, respectively. Yield increase due to mulching in open-pollinated varieties was 86 per cent and 80 per cent in 2014 and 2015, respectively. Increase in early fruiting under BPM was observed in all the five varieties studied. Difference in soil temperature between mulch and unmulch was significantly higher at early growth stage than during later stages. BPM reduced 57 per cent weed and save 74 per cent time in manual weeding. Incidence of insect-pest and diseases was minimal, and rotten fruit was less than 2 per cent of marketable yield without staking and pesticide or fungicide application.

Keywords: Crop productivity; Early fruiting; Ladakh; *Lycopersicon esculentum;* Organic farming

1. INTRODUCTION

Modern day vegetable production system depends on high-inputs to maximize yield, improve product quality and reduce production cost. Management practices in these large-acreage production systems depend heavily on use of chemical fertilizers, pesticides, fungicides, weedicides, plastic mulch, staking, trickle irrigation system and farm mechanisation. However, in many parts of the world, such as the trans-Himalayan Ladakh region, the land holding is small and emphasis has been on minimal use of off-farm inputs. Standard cultural practices such as use of pesticide and weedicide, mulching, staking, pruning, raised bed, sink reduction, are not followed. Irrigation is done by flooding and crops are grown more closely than recommended. Vegetables are produced primarily for home consumption and local market. However, with the changing scenario and food habits, there is a growing demand for locally produced vegetables. In past decades, a large number of military troops are being stationed in the region due to the geo strategic nature of the location. Providing essential nutritional support to those operating in high altitude are best taken from resources available locally as timely supply of fresh vegetables from low land is not always possible due to logistics constrains[1]. Increasing acreage is difficult primarily due to water scarcity, and one approach for increasing production could be adoption of selected modern day standard cultural practices. Filling the gap between the required quantity and the quantity locally produce is a difficult task in this region. Importing goods to Ladakh necessitates the shipping of goods by truck across the Himalayas, with passes as high as 5300 m, covering the distance of Manali to Leh (480 km) or Srinagar to Leh (420 km)[2].

Black polyethylene mulch (BPM) has been widely used in production of fresh-market field tomatoes. Polyethylene have excellent mechanical properties, light weight and relatively low price[3]. Beneficial responses of tomatoes to BPM include higher yield, earlier production and better fruit quality. These favorable economic plant responses have been attributed, in part, to greater efficiency of water and fertilizer use[4], reduced competition with weeds[5,6], higher soil temperatures[7,8], reduced soil pathogen, and breakdown of phytotoxic substances[9].

Response of tomato crop to BPM has been widely studied under high-input systems[6,8,10]. However, use of BPM has received limited interest for small acreage, low-input producers especially in arid high altitude regions. Therefore, the objective of the present study was to evaluate BPM for crop productivity enhancement under low-input cultivation system in hybrid and open-pollinated (OP) tomato varieties in cold desert trans-Himalayan Ladakh condition.

2. MATERIALS AND METHODS

2.1 Study Site

Field experiments on tomato (*Lycopersicon esculentum* Mill.) were conducted in 2014 and 2015 on the experimental

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farm of Defence Institute of High Altitude Research in trans-Himalayan Ladakh, India (34°08.3'N; 77°34.3'E, elevation 3344 m). Altitude and location of the experimental site was established using GARMIN *GPS 72*, USA. The mean maximum and minimum temperature in 2015, recorded daily during open field cropping season (May-September), was 21.0±2.6 ºC and 8.3±2.0 ºC, respectively, while the mean maximum and minimum relative humidity was 27.0±1.7% and 22.2±1.1%, respectively. The light intensity measured with Datalogging light meter (HD450, Extech Instruments) at noon in open field was 126870±29072 lux. A preplanting soil test using a soil testing kit (Lamotte Combination Soil Outfit 5010-01, Maryland, USA) revealed pH 7.8, high humus, nitrate nitrogen 170 kg/ha, phosphorus 113 kg per ha, potassium 125 kg/ha, calcium 2800 ppm, chloride 200 ppm, ferric iron 5.7 kg/ha, nitrite nitrogen 1 ppm, sulfate 50 ppm, low magnesium and manganese, and very low ammonia nitrogen.

2.2 Experimental Design and Treatments

Silver black plastic film (30 micron) was used for mulching with black surface facing the sun. The result was compared with plants under non-mulched condition. For determining the effect of BPM on total yield and early production, we used a completely randomised factorial design. The factors were mulch treatment (mulch and unmulch) and cultivars (3 hybrids, and 2 OP varieties). Hybrid varieties studied were Tolstoi, Sultan and BSS-1006, while OP varieties were Roma and Sioux. Plots were flat bed 2.13 m wide and 3 m long. There were five replicates for each treatment. Each replicate consisted of 36 plants spaced at 35 cm within row and 45 cm between rows. Farm yard manure (5 $t.ha^{-1}$), N (18 $kg.ha^{-1}$) and P (8 $kg.ha^{-1}$) were applied at the time of field preparation. Second and third application of N (18 $kg.ha^{-1}$) was done at 30 and 60 DAT. Pesticide, fungicides and weedicide were not used throughout the growing season. Standard cultural practices such as staking, pruning, raised bed and sink reduction were, however, not followed. Irrigation was done by flooding at three days interval during initial plant establishment followed by five days interval at later stages. We made no attempt to determine differences among treatments with regard to evaporative loss of water applied to the plots.

BPM was laid manually and transplant holes of 5 cm diameter were made. Seedlings raised in a passive solar greenhouse were transplanted manually on 24 May in 2014 and 8 June in 2015. Weeding was done twice during the growing season. Weed emergence and time consumed in manual weeding in mulched and unmulched treatments were calculated in terms of fresh weight of weed ($g.m^{-2}$) and time devoted by a single farm worker in weeding ($min.m^{-2}$), respectively. Data were recorded on plant height, number of leaves, number of flower buds, stem diameter and chlorophyll content at 30, 60 and 90 days after transplanting (DAT). Chlorophyll was measured with Chlorophyll Meter SPAD-502 (Konica Minolta Sensing Inc., Japan). Biomass of vegetative part was determined after final harvest. Soil temperature was measured daily at 10 cm depth using a soil thermometer.

Three harvests were made during the growing period extending from August to September. Fruits were harvested at the breaker to pink stages during initial two harvests. Early fruiting was defined as the first harvest during the season. All fruits that attain more than 30 g weight, irrespective of fruit colour, were harvested during the final harvest. Rotten and sunscald fruit at each harvest were determined separately.

2.3 Statistical Analysis

All the experiments were performed in five replicates. The experimental results were expressed as mean ± standard deviation (SD) using statistical analysis with SPSS (Statistical Program for Social Sciences, SPSS Corporation, Chicago, Illinois, USA). One way analysis of variance (ANOVA) and post hoc analysis with 2-sided Tukey's HSD at $p \leq 0.05$ level were performed. A two-way ANOVA was used to test the relationship of mulch and cultivar and their interaction with fruit yield.

3. RESULTS AND DISCUSSION

3.1 Marketable and Early Yield

The mean data on tomato yield under mulch and unmulch is presented in Table 1. The mean marketable yield in different treatments varied from 27.8±2.5 $tonne.ha^{-1}$ ($t.ha^{-1}$) in OP varieties with no mulch treatment to 81.2±11.9 $t.ha^{-1}$ in hybrid tomatoes with BPM in 2015. In comparison the national average is 24.2 $t.ha^{-1}$ in 2016[11]. Increase in marketable yield due to BPM in hybrid varieties was 102% and 107% in 2014 and 2015, respectively. Similarly, the yield increase as a result of mulching in OP varieties was 86% and 80% in 2014 and 2015, respectively. Our result on the effect of BPM on total yield is similar to those reported in high-input systems by Bhella[4] & Baki[8], *et al.* Other published data on increases in total yield varied greatly. In one report[7], no increase in yield under BPM was observed. In other reports, increases in yield under BPM ranged from 13%[12] to 69%[13]. Such yield differences in response

Table 1. Effect of black polyethylene mulch on tomato yield in trans-Himalayan Ladakh

Treatment	Early yield ($t.ha^{-1}$)		Marketable yield ($t.ha^{-1}$)		Non-marketable fruit* ($t.ha^{-1}$)	
	2014	2015	2014	2015	2014	2015
Hybrid varieties + mulch	10.6±4.2^{b}	11.3±6.5^{b}	72.9±8.3^{c}	81.2±11.9^{c}	4.3±5.2^{a}	9.4±6.5^{b}
Hybrid varieties + unmulch	3.0±2.8^{a}	3.5±4.0^{a}	36.1±13.0^{ab}	39.2±14.1^{ab}	3.3±2.5^{a}	4.2±2.7^{a}
Open-pollinated varieties + mulch	10.8±7.9^{b}	13.0±11.7^{b}	45.5±6.9^{b}	50.0±8.8^{b}	4.4±3.2^{a}	6.2±2.2^{ab}
Open-pollinated varieties + unmulch	3.3±1.9^{a}	3.5±2.1^{a}	24.5±2.6^{a}	27.8±2.5^{a}	2.0±1.2^{a}	2.6±0.7^{a}

Values represented as mean ± SD

For each column, different lowercase letters indicate significantly different at $p < 0.05$, as measured by 2-sided Tukey's HSD between treatments

* < $30g.fruit^{-1}$

to BPM have been attributed to environmental factors such as soil temperature and moisture[8]. Marketable yield of hybrid tomatoes (72.9-81.2 $t.ha^{-1}$) under BPM is similar[8,14] or greater[6,10] than previous reports, which followed standard cultural practices. High yield obtained in the present study under low-input system with BPM could be attributed to comparatively closer spacing between plants, and low incidence of insect-pest and diseases. The non-marketable yield (<30 $g.fruit^{-1}$) ranged from 2.0-9.4 $t.ha^{-1}$, which is 8.2-12.4% of the total marketable yield under different experimental conditions.

Greater early yield was observed in crops under BPM (Table 1). Early yield was statistically similar in hybrid and OP varieties. Increase in early fruiting under BPM was observed in all the five varieties studied. However, reports suggested that increase in early fruiting under BPM is not consistent. Sweeney[15], *et al.* reported a 33% increase in early fruiting of tomatoes under BPM. Wein and Minotti[12] found an increase only in 1 of 2 years. Baki[8], *et al.* found that only one of the two tested cultivars responded to BPM.

Incidence of insect-pest and diseases was minimal and remained below the levels that could cause economic losses to the tomato crop (Table 2). Flat bed and close spaced planting are, therefore, recommended in the region. Rotten fruit yield was less than 2% of marketable yield under all the conditions on flat bed without staking and pesticide or fungicide application. In comparison, Monks[16], *et al.* reported 31-72% fruit rot in bare soil and 38-65% fruit rot under BPM in West Virginia when no fungicides or pesticides were applied after planting. Low incidence of insect-pest and diseases could, in part, be attributed to low humidity, extreme cold winter, low cropping intensity and diversified cropping system in trans-Himalayan region. Damage due to sunscald was less than 1% of commercial yield.

3.2 Two Way Analysis of Variance

Two-way ANOVA was carried to visualize the relationship of mulch, cultivar and their interaction with fruit yield. The results showed that both mulch and cultivar had significant effect on early and total yield (Table 3), which is similar to earlier report by Baki[8], *et al.*. Interaction of mulch and cultivar also had significant effect on early and total yield, which is in contrast with earlier report[8]. There was no significant effect of BPM on quantity of rotten and sunscald tomatoes. However, choice of cultivar had significant effect on quantity of sunscald fruit.

3.3 Plant Growth and Flowering

Mulch affected the growth and amount of foliage produced by the plant (Table 4). Tomato plants grown over the BPM had significantly more growth and foliage than those grown without mulch. The increase in growth and foliage due to BPM was significantly greater in hybrid than in OP varieties. Biomass of vegetative parts after final harvest was significantly higher in mulch. Tomato plant grown with BPM had more flowers at an early growth stage. Greater and earlier flowering could contribute to increase early and total yields observed in the present study. Mulch has been shown to influence flowering of tomato[17].

3.4 Weeding

BPM was effective in suppressing weeds. A total of 483±43 $g.m^{-2}$ weed was recorded under BPM as compared to 1134±289 $g.m^{-2}$ in unmulched fields. Therefore, at the same level of cultural practices, BPM reduced 57% weed. In comparison, Shrivastava[6], *et al.* reported 76% weed reduction with plastic mulching. Most of the weed emerged from the ridges of the flat beds, which were not covered with BPM, and thus it was easy to uproot manually. Time consumed in manual weeding was 5±1 $min.m^{-2}$ in mulch as against 19±5 $min.m^{-2}$ in unmulch condition. Therefore, time save due to BPM in manual weeding was 74%.

3.5 Soil Temperature

Increase in growth and yield under BPM could, in part, be attributed to higher soil temperature under BPM. Higher soil temperature under BPM than in unmulched treatments have been reported[7,8]. Difference in soil temperature between mulch and unmulch was significantly higher at early growth stage than during later stages (Table 5), and displayed a direct relationship with DAT (R^2=0.948). Decrease in soil warming by BPM with respect to crop growth stages could be due to increase in foliage of the crop, which reduced direct incidence of sunlight on soil surface. Greater deposition of soil on mulch surface due to flood irrigation may also affect direct incidence of sunlight on soil surface at advanced growth stages. Higher temperature difference between mulch and unmulch was observed at 8 PM, which could be due to retention of soil temperature after sunset by the BPM.

Table 2. Effect of black polyethylene mulch on rotten and damaged tomatoes in trans-Himalayan Ladakh

Treatment	Rotten fruit ($t.ha^{-1}$)		Sunscald fruit ($t.ha^{-1}$)	
	2014	2015	2014	2015
Hybrid varieties + mulch	1.0±1.2^a	1.1±1.0^a	0.7±0.5^b	0.8±0.6^b
Hybrid varieties + unmulch	0.8±0.9^a	0.6±0.9^a	0.2±0.2^a	0.2±0.2^a
Open-pollinated varieties + mulch	0.9±0.6^a	0.8±0.7^a	0.1±0.1^a	0.1±0.1^a
Open-pollinated varieties + unmulch	0.5±0.3^a	0.5±0.5^a	0.2±0.1^a	0.2±0.2^a

Values represented as mean ± SD
For each column, different lowercase letters indicate significantly different at $p < 0.05$, as measured by 2-sided Tukey's HSD between treatments

Table 3. Two-way ANOVA for yield, rotten and sunscald tomatoes with mulch and cultivar as main effects

Source	d.f	Marketable yield		Early yield		Rotten fruit		Sunscald fruit	
		F	Sig	*F*	Sig	*F*	Sig	*F*	Sig
Mulch	1	195.39	***	115.23	***	1.89	NS	0.84	NS
Cultivar	4	30.71	***	32.72	***	0.84	NS	8.47	***
Mulch x Cultivar	4	4.58	**	9.11	***	1.06	NS	4.43	**

The *F* ratio (*F*) is presented for each factor; d.f: Degrees of freedom
*Significant at $p \leq 0.05$, **Significant at $p \leq 0.01$, ***Significant at $p \leq 0.001$

Table 4. Effect of black polyethylene mulch on growth, flowering and chlorophyll content of tomato in trans-Himalayan Ladakh

Parameters	DAT*	Treatments			
		Hybrid + Mulch	Hybrid + Unmulch	Open-pollinated variety + Mulch	Open-pollinated variety + Unmulch
Plant height (cm)	30	17.8±3.8c	9.8±3.4a	13.8±3.4b	9.4±2.2a
	60	71.0±16.4c	48.1±14.0ab	58.1±15.3b	39.6± 13.1a
	90	89.6±23.4b	74.6±24.5b	84.2±20.0b	56.8±15.7a
No. of leaves	30	11.3±2.9c	6.4±2.0a	8.7±2.4b	5.9±1.8a
	60	29.7±8.5bc	24.4±11.3ab	33.7±13.5c	18.6±10.8a
	90	33.8±18.5ab	35.6±7.1ab	48.3±8.4b	24.7±8.2a
Stem diameter (mm)**	30	6.5±1.4b	4.4±1.2a	6.0±1.9b	4.3±1.0a
	60	9.1±1.5b	7.1±1.4a	13.0±1.3c	10.0±1.7b
	90	12.3±4.6ab	11.9±2.5a	14.7±1.4b	12.0±2.5a
No. of branch	60	8.1±2.2b	4.3±2.6a	7.4±3.7b	2.9±1.7a
	90	12.6±3.0b	8.4±3.3a	15.1±7.1b	6.8±2.1a
No. of flower	30	6.4±2.7c	1.6±2.1ab	3.1±3.4b	0.9±2.0a
	60	25.7±6.7b	25.6±16.5b	27.3±9.4b	13.4±6.1a
	90	17.9±9.5a	22.9±10.2ab	28.2±8.8b	19.6±6.1a
No. of fruit	60	15.0±4.6c	8.8±6.8b	10.5±6.9bc	3.7±4.1a
	90	29.6±9.7b	19.9±11.4a	27.0±16.4ab	17.8±8.3a
Chlorophyll (SPAD)	30	45.2±5.0b	43.6±5.1b	37.4±2.3a	37.0±1.8a
	60	43.4±3.5a	45.1±4.0a	55.9±9.8b	51.6±9.9b
	90	43.7±2.3a	44.5±3.9a	52.6±8.4b	53.7±9.4b
Vegetative biomass (g)	110	175.3±53.6b	80.7±22.3a	145.8±54.0b	69.9±23.7a

Values represented as mean ± SD
For each row, different lowercase letters indicate significantly different at $p < 0.05$, as measured by 2-sided Tukey's HSD between treatments
DAT*: days after transplanting; Stem diameter**: 2 cm above ground

Table 5. Effect of black polyethylene mulch on soil temperature in trans-Himalayan Ladakh

Period/ Time	Mulch (ºC)	Unmulch (ºC)	Difference (ºC)
Period (DAT*)			
0-30	20.6±0.5	15.7±0.8	4.9±0.3
31-60	24.2±0.8	20.3±0.4	3.9±0.5
61-90	21.2±0.6	19.2±0.3	2.0±0.3
91-110	18.4±0.7	16.8±0.5	1.6±0.2
Time (h)			
7 AM	16.3±0.6	13.2±0.3	3.1±0.3
10 AM	18.3±0.7	16.0±0.9	2.3±0.3
1PM	23.6±1.0	21.1±0.5	2.5±0.5
4 PM	25.9±0.5	22.6±0.3	3.3±0.2
8 PM	21.4±0.6	17.1±0.6	4.3±0.1

DAT*: Days after transplant
Values represented as mean ± SD

4. CONCLUSION

BPM doubled tomato yield in a low-input system in trans-Himalayan Ladakh. Greater early and marketable yield, in part, could be attributed to higher soil temperature and weed suppression. A major concern for large scale adoption of plastic mulch for crop productivity enhancement in trans-Himalayan region could be the resultant pollution hazards caused by residual plastic film. However, the adverse effect, in part, could be compensated by reducing vehicular pollution during long distance transportation of fresh tomatoes from nearby towns. Survey conducted in 2015 suggested that approximately 21.4 ml diesel is burn in trans-Himalayan condition to transport one kilogram of fresh vegetable by truck from the nearest tomato growing town, which is 450 km away. Future research is needed on the effect of low-cost biodegradable mulching material on crop growth and yield[18].

Conflict of Interest: None

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He designed the experiment and wrote the manuscript.