



Effect of mulching on yield and nutritional quality of organic cucumber (*Cucumis sativus* L.) production at the cold arid high altitude region of Ladakh

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Abstract

This study investigates the impact of black polythene mulch (BPM) on the growth, yield, and mineral composition of cucumber crops in a cold, arid, high-altitude region of Ladakh, India. The research was conducted under open-field conditions at the Defence Institute of High Altitude Research, Leh, India, during 2022 and 2023. Two cucumber cultivars, Japanese Long Green (JLG) and BSS 647, were used in both mulched and non-mulched conditions. Mulching significantly improved plant height (JLG: 150.01 cm and BSS-647: 144.29 cm), leaf area (JLG: 166.73 cm² and BSS-647: 164.91 cm²), stem diameter (JLG: 10.20 mm and BSS-647: 10.00 mm), leaf chlorophyll content (JLG: 29.9 and BSS-647: 30.32 CCI) and yield (JLG: 690.37 q/ha and BSS-647: 737.06 q/ha). The total soluble solid (4.73 °B), titratable acidity (1.00 %), sulphate (97.28 mg/kg), Mg (370.77 mg/100g) and Mn (8.04 mg/100g) content were found in BSS-647 cultivar whereas crude protein (14.83 g/100g), phosphate (650.35 mg/kg), N (2373.56 mg/100g), Zn (4.59 mg/100g) and K (3713.59 mg/100g) content were found in JLG cultivar. As per this study, mulching significantly enhances cucumber yield and improves the levels of health-promoting nutritional compounds compared to non-mulched cultivation in the Ladakh region.

Key words: *Cucumis sativus*; high-altitude; Ladakh; mulching; yield; mineral content

Introduction

Cucumber (*Cucumis sativus* L.) is one of the most prevalent members of the Cucurbitaceae family cherished for its excellent flavor, versatile uses, crisp texture, and medicinal properties (Mukherjee *et al.*, 2013; Acharya *et al.*, 2024). This nutrient-dense vegetable is low in calories while being rich in vitamins and potassium. Including cucumbers in your diet can aid in weight loss, promote healthy hydration levels, support digestive regularity, and assist in detoxification (Keerthika *et al.*, 2016). It is rich in polyphenolics and phytochemicals with diverse biological activities such as antioxidant, anticancer, anti-inflammatory, and antimicrobial effects (Uthpala *et al.*, 2020).

Its cultivation in high-altitude regions like Leh-Ladakh faces numerous challenges. The high mountain region of Ladakh, with an average altitude of over 3500 m, is characterised by extreme temperature variations, low precipitation, high wind velocity, and a fragile ecosystem (Stobdan *et al.*, 2018; Shukla *et al.*, 2024a). These conditions limit the cropping season and affect crop growth and yield. These challenges can be mitigated through proper cultivation techniques. Mulching is increasingly adopted by farmers; with black polythene mulch (BPM) proving especially effective in creating a favorable microclimate to overcome cultivation challenges and enhances plant growth (Awodoyin *et al.*, 2010).

Mulching is the practice of placing a layer of organic or synthetic material over the soil surrounding plants. The primary goals of mulching are to suppress weed growth, modify soil temperature, conserve soil moisture, and improve overall soil health (Karki *et al.*, 2017; Jabran, 2019). Additionally, mulching can reduce the need for frequent watering and prevent soil erosion. Black polythene mulch modifies the microclimate by warming the soil, enabling higher yields and a longer growing season. Selecting the right mulch is essential for enhancing soil conditions and crop performance (Kader *et al.*, 2017). Black mulch significantly improved yield, heat use efficiency, and profitability in broccoli grown under abiotic stresses in the mid-hills of Himachal Pradesh by optimizing soil moisture and temperature conditions (Meena *et al.*, 2025). Similarly, in onion and pineapple cultivation, mulching positively influenced growth, yield, and quality by enhancing soil moisture retention, weed control, and nutrient use efficiency (Patnaik *et al.*, 2024). These studies collectively suggest that mulching could effectively enhance cucumber production in harsh environments by mitigating stress and improving resource use efficiency.

The novelty of this research lies in its comprehensive evaluation of black polythene mulch (BPM) as a tool to enhance the yield, growth performance, and nutritional quality of organically grown cucumber (*Cucumis sativus* L.) under the unique cold arid and high-altitude agro-climatic conditions of Ladakh.

This region presents extreme environmental challenges such as low atmospheric pressure, high solar radiation, large diurnal temperature fluctuations, limited precipitation, and a very short growing season, all of which severely restrict vegetable cultivation and productivity. While mulching has been widely studied in temperate and tropical climates, its application and effectiveness in high-altitude cold arid regions like Ladakh remain largely unexplored. This study fills a critical knowledge gap by generating region-specific data on how BPM influences soil microclimate, plant development, yield attributes, and mineral composition of cucumber under organic farming conditions. Additionally, by analysing these factors under both mulching and non-mulching conditions, the study provides evidence-based insights into how mulching can mitigate climatic stress, extend the effective growing period, and enhance nutrient uptake.

Materials and methods

Experimental site: The research was conducted during 2022 and 2023 under open field conditions experimental fields at Defence Institute of High Altitude Research (DIHAR), Leh-Ladakh, India; located at an altitude of 3340 m above sea level, at latitude 34°08.2 North and longitude 77°34.3'E with a mean minimum and maximum temperature of 6.50 ± 2.42 and 29.6 ± 3.41 °C while mean minimum and maximum relative humidity was $22.1 \pm 2.16\%$ and $28.42 \pm 2.86\%$ respectively during cropping season (May-September). The soil was loamy sand (81 % sand, 13.4%, silt and 5.6% clay) with pH (7.81 ± 0.14), EC (0.97 ± 0.08 ms/cm), organic carbon (0.874 ± 0.01 %), N (41.41 ± 1.73 kg/ha), P (16.07 ± 0.18 kg/ha), K (212.44 ± 6.87 kg/ha), S (122.43 ± 3.8 kg/ha), Zn (2.017 ± 0.75 kg/ha), Fe (3.35 ± 0.83 kg/ha), Cu (5.75 ± 2.07 kg/ha) and Mn (2.16 ± 1.07 kg/ha).

Experimental Design: Cucumber (*Cucumis sativus* L.) cultivar Japanese Long Green (JLG) and BSS 647 was used under mulched and non-mulched conditions with three replications per treatment and per cultivar of a randomized block experimental design. Black polythene mulch (30 micron) was used in this experiment. A total number of plots are 12 and the size of experimental plot was 2.3 m × 1.4 m. Each plot consisted of three rows, with two seeds sown per hole in the plastic mulch. The Row-to-row and plant-to-plant spacing was uniformly maintained at 45 cm × 45 cm and total number of plant per plot is 15 and per treatment is 45. Farmyard manure (150 q/ha) was incorporated into the soil during field preparation under both conditions. In the initial stages of plant establishment, surface irrigation was carried out every three days, which was later extended to seven days interval. No chemical fertilizers or pesticides were applied at either location. Weeding was conducted twice throughout the growing season.

Vegetative growth and yield attributes: We collected data from five representative plants, randomly selected from each plot and tagging of the selected plants was done for further measurement. Growth and flowering parameters *i.e.* vine length (cm), number of leaves, leaf area (cm²), stem diameter (mm), number of tendril, tendril length (cm), leaf chlorophyll content (CCI), leaf anthocyanin content (aci), number of branches, number of male flower and number of female flower were recorded at 30, 45, 60, 75 and 90 days after sowing (DAS). Leaf chlorophyll content was measured using a portable chlorophyll meter (CCM-200 Plus, ADC Bioscientific, UK), while leaf anthocyanin content (ACI) was assessed with a portable anthocyanin meter (ACM-200 Plus, ADC Bioscientific, UK) (Singh *et al.*, 2009). Yield parameters

like number of fruits per plant, length of fruit, diameter of fruit (mm), average fruit weight (g) and fruit yield (q/ha) was measured after harvesting. Diameter of fruit was measured by Vernier callipers (Eifediyi and Remison, 2010).

The moisture content (%) was estimated using an oven drying method with following equation (Bhardwaj *et al.*, 2019). About 12 g fresh fruit was blended and the juice was extracted to measure the total soluble solids by using Hand-held refractometer (ATAGO, Tokyo) and values corrected at 20 °C. Titratable acidity (TA) was determined by titrating fresh fruit juice with 0.1 N NaOH and was expressed as percentage of malic acid (Shukla *et al.*, 2024b)

Estimation of Anions (Nitrate, Phosphate and Sulphate): Anions (Nitrate, Phosphate and Sulphate) of fresh fruit samples were determined by using ion exchange chromatography (Cataldi *et al.*, 2003; Shukla *et al.* 2025). For this process, fresh fruit samples (1200 mg) were homogenized at 12,000 rpm using a homogenizer with Milli-Q water for 1.5 minutes. This was followed by sonication in an ultrasonic bath (Ultrasonic Cleaner YJ5120-1, India) at 48°C for 30 minutes. The supernatant was then diluted with distilled water and filtered through a 0.22 µm syringe filter. An injection volume of 20 µL was used in column (Metrosep A Supp 5- 250/4.0) with a flow rate of 0.6 mL/min (930 Compact IC flex Metrom; Switzerland) and mobile phase, consisting of 3.2 mM sodium carbonate and 1 mM sodium bicarbonate. The detection was carried out using a conductivity detector, and the results were reported in mg per 100 g of fresh weight (FW).

Estimation of Kjeldahl Nitrogen and crude protein: The kjeldahl nitrogen and crude protein in cucumber samples was determined according to the modified method of Kjeldahl instrument (K-355, Buchi Labortechnik, Switzerland) (AOAC, 2006). For this, oven dried onion sample (200 mg) was digested through concentrated H₂SO₄ and digestion tablets. After digestion, distillation was done with 32% NaOH. The released ammonium gas was absorbed in a 4% boric acid solution containing methyl red and bromo cresol green as indicators. The resulting distillate was then titrated with 0.25M H₂SO₄ until a light pink color appeared. The volume consumed was recorded, and the results were expressed in grams per 100 grams of dry weight (DW). The crude protein in the dried sample was estimated by multiplying nitrogen with correction factor (6.25) (Wang *et al.*, 2016).

Estimation of macro and micro elements: Potassium and sodium contents were determined by flame photometer (Jenway PFP7, Bibby scientific Ltd, UK) (AOAC, 2006; Shukla *et al.*, 2024c) while Zn, Cu, Fe, Mn and Mg were determined by an atomic absorption spectrophotometer (AAS ZEE nit 700 plus, analytik Jena AG, Germany) (AOAC, 2006; Lee, *et al.*, 2010). For this, dry fruit powder (200 mg) was digested with a micro digester (Analytik Jena AG, Germany) using nitric acid and hydrochloric acid at 3:1 ratio. The supernatant was diluted with distilled water to a final volume of 50 mL and filtered using Whatman Grade 1 filter paper. The results were expressed in mg per 100 g of dry weight (DW).

Statistical analysis: All experiments were carried out in triplicate as mean ± standard deviation (SD). One-way ANOVA (Analysis of Variance) followed by Duncan's Multiple Range Test at $P \leq 0.05$ was used to assess differences between growing periods. Independent t-tests were conducted to compare mulching vs.

non-mulching treatments at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ by using in SPSS 16.0 (Statistical Program for Social Sciences, SPSS Corporation, Chicago, IL) to determine the significance of the results. Principal component analysis (PCA) was analyzed by using SRPLOT software.

Results and discussion

Growth attributes: A study was carried out to assess the impact of mulching and non-mulching conditions on the growth characteristics of two cucumber varieties, Japanese Long Green (JLG) and BSS-647. The parameters assessed included plant height, number of leaves, leaf area, stem diameter, number of tendrils, tendril length, number of branches, number of male and female flowers, as well as leaf chlorophyll and anthocyanin content. The data in Table 1 revealed that all variables differed significantly ($P \leq 0.05$). Plant height increased consistently with maturity under both mulched and non-mulched conditions. At 90 days after sowing (DAS), the highest plant height was recorded in the JLG cultivar under mulched conditions (150.01±1.93 cm), followed by BSS-647 (144.29±1.87 cm). In comparison, plant heights under non-mulched conditions were significantly lower at 113.00±5.22 cm for JLG and 104.92±1.75 cm for BSS-647.

Significant differences ($P \leq 0.05$) in the number of leaves, leaf area, stem diameter, tendril length, and number of branches were observed throughout the growing period under both mulched and non-mulched conditions, although no significant differences were noted between the two cultivars. At 90 DAS under mulched conditions, the JLG and BSS-647 cultivars demonstrated superior performance, with higher values for the number of leaves (59.89±0.51 and 55.89±1.02, respectively), leaf area (166.73±5.77 cm² and 164.91±8.4 cm²), stem diameter (10.20±0.07 mm and 10.00±0.08 mm), tendril length (25.21±0.46 cm and 24.44±0.75 cm), and number of branches (9.07±0.12 and 10.67±0.50) compared to non-mulched conditions. During the growth period (30–90 DAS), plants grown under non-mulched conditions exhibited relatively suppressed growth in terms of plant height, number of leaves, leaf area, stem diameter, tendril length, and number of branches. The improved growth observed under mulching conditions can be linked to the effectiveness of black polyethylene mulch in retaining heat, preserving soil moisture around the root zone, minimizing evaporation, and extending water availability. These factors likely improve nutrient uptake by promoting cell division and elongation, leading to the development of longer vines, more leaves, and thicker stems (Karki *et al.*, 2020; Bharati *et al.*, 2020). These findings align with previous studies on cucumbers by Acharya *et al.* (2024), Hallidri (2021), Awasthi *et al.*, 2022; Bhandari *et al.* (2021), and Parmar *et al.* (2013).

In present study, mulching tends to result in higher chlorophyll and anthocyanin content in leaves of cucumber plants compared to non-mulching for both cultivars throughout the experiment. At 90 DAS, maximum leaf chlorophyll content (JLG; 29.9±1.29 and BSS-647; 30.32±0.14 CCI) and anthocyanin content (JLG; 9.12±0.36 and BSS-647; 9.16±0.14 aci) was found in mulching condition as compared

Table 1. Effect of mulching and non-mulching on growth parameters of cucumber (*Cucumis sativus* L.) cv. JLG and BSS-647

Trait	DAS Cucumber cultivar JLG		Cucumber cultivar BSS-647		
	Mulching	Non mulching	Mulching	Non mulching	
Plant height (cm)	30	23.14±1.28 ^{aC}	8.63±0.51 ^{aA}	18.45±0.93 ^{aB}	7.71±0.46 ^{aA}
	45	52.69±1.07 ^{bC}	13.85±0.66 ^{bA}	36.35±1.77 ^{bB}	12.08±0.61 ^{bA}
	60	125.31±0.43 ^{cB}	41.32±1.78 ^{cA}	125.31±0.43 ^{cB}	39.59±1.52 ^{cA}
	75	134.57±1.49 ^{dC}	60.55±0.96 ^{dA}	134.57±1.49 ^{dC}	64.44±1.22 ^{dB}
	90	150.01±1.93 ^{cC}	113.00±5.22 ^{eB}	144.29±1.87 ^{cC}	104.92±1.75 ^{eA}
Number of leaves	30	04.00±0.00 ^{aC}	2.22±0.19 ^{aB}	4.00±0.00 ^{aC}	2.00±0.00 ^{aA}
	45	13.78±0.77 ^{bB}	4.78±0.19 ^{aA}	17.11±0.51 ^{bC}	4.44±0.20 ^{aA}
	60	38.67±1.20 ^{dD}	11.67±0.34 ^{bA}	51.11±1.54 ^{cC}	15.56±2.78 ^{bB}
	75	56.67±0.34 ^{dB}	18.45±1.07 ^{cA}	57.00±1.46 ^{dB}	20.55±1.35 ^{cA}
	90	59.89±0.51 ^{cC}	42.67±4.18 ^{dB}	55.89±1.02 ^{dC}	30.67±1.53 ^{dA}
Leaf area (cm ²)	30	64.83±3.93 ^{aC}	16.25±1.01 ^{aA}	54.02±2.16 ^{aB}	14.14±0.79 ^{aA}
	45	150.41±11.76 ^{bC}	42.27±1.48 ^{bA}	131.71±6.65 ^{bB}	34.96±1.46 ^{bA}
	60	159.69±6.37 ^{bcB}	104.84±1.76 ^{cA}	184.53±0.77 ^{dC}	110.64±10.57 ^{cA}
	75	174.98±6.83 ^{dB}	147.47±11.14 ^{dA}	176.00±8.72 ^{cdB}	157.21±0.39 ^{eA}
	90	166.73±5.77 ^{cdB}	141.35±1.89 ^{dA}	164.91±8.4 ^{cBA}	144.46±4.73 ^{dA}
Stem diameter (mm)	30	6.08±0.18 ^{aB}	3.50±0.16 ^{aA}	6.05±0.35 ^{aB}	3.48±0.02 ^{aA}
	45	8.37±0.45 ^{bB}	5.03±0.20 ^{bA}	8.24±0.16 ^{bB}	5.31±0.11 ^{bA}
	60	9.71±1.43 ^{bcA}	7.49±0.86 ^{cA}	9.71±1.43 ^{cA}	7.79±0.38 ^{cA}
	75	9.66±0.54 ^{bcB}	7.79±0.62 ^{cA}	9.62±0.68 ^{cbB}	9.81±0.23 ^{dB}
	90	10.20±0.07 ^{cA}	9.58±0.93 ^{dA}	10.00±0.08 ^{cA}	9.69±0.21 ^{dA}
Number of tendril	30	00.80±0.00 ^{aB}	0.00±0.00 ^{aA}	NG	NG
	45	6.27±0.42 ^{bC}	0.00±0.00 ^{aA}	2.73±0.31 ^{aB}	0.00±0.00 ^{aA}
	60	22.53±0.42 ^{cB}	3.47±0.50 ^{bA}	24.80±1.40 ^{bC}	2.67±0.58 ^{bA}
	75	26.53±1.14 ^{dC}	7.53±0.12 ^{cA}	25.80±0.35 ^{bcB}	12.33±0.99 ^{cB}
	90	27.87±0.58 ^{cC}	21.73±3.25 ^{dA}	27.27±0.31 ^{cBC}	24.13±1.03 ^{dAB}
Tendril length (cm)	30	2.13±0.04 ^{aB}	0.00±0.00 ^{aA}	NG	NG
	45	19.65±0.94 ^{bC}	0.00±0.00 ^{aA}	11.82±0.66 ^{aB}	0.00±0.00 ^{aA}
	60	23.75±0.66 ^{cC}	19.61±1.02 ^{bB}	23.75±0.66 ^{bC}	13.37±1.07 ^{bA}
	75	25.77±0.62 ^{dC}	20.41±1.56 ^{bB}	25.77±0.62 ^{cC}	14.55±0.75 ^{bA}
	90	25.21±0.46 ^{dC}	19.66±0.38 ^{bB}	24.44±0.75 ^{bC}	14.61±0.27 ^{bA}
Leaf chlorophyll content (CCI)	30	22.95±0.79 ^{aB}	13.72±0.54 ^{aA}	24.36±0.43 ^{aC}	14.80±0.70 ^{aA}
	45	27.41±0.19 ^{bC}	14.97±0.33 ^{bA}	27.82±0.52 ^{bC}	21.67±0.53 ^{bB}
	60	28.06±0.89 ^{bcB}	19.57±0.3 ^{cA}	28.74±0.22 ^{cC}	24.95±1.41 ^{cB}
	75	29.13±1.19 ^{bcC}	23.01±0.4 ^{dA}	29.33±0.25 ^{cC}	25.19±1.27 ^{cB}
	90	29.9±1.29 ^{cC}	23.73±0.54 ^{dA}	30.32±0.14 ^{dC}	26.14±1.55 ^{cB}
Leaf anthocyanin content (aci)	30	5.97±0.21 ^{aB}	4.13±0.32 ^{aA}	6.30±0.07 ^{aB}	4.26±0.18 ^{aA}
	45	8.18±0.44 ^{bC}	5.47±0.14 ^{bA}	8.03±0.14 ^{bC}	6.07±0.24 ^{bB}
	60	8.37±0.45 ^{bcB}	6.18±0.38 ^{cA}	8.53±0.21 ^{cC}	7.72±0.07 ^{cB}
	75	8.91±0.40 ^{cdB}	6.72±0.22 ^{dA}	9.02±0.37 ^{dB}	8.55±0.26 ^{dB}
	90	9.12±0.36 ^{dB}	6.87±0.19 ^{dA}	9.16±0.14 ^{dB}	8.81±0.16 ^{dB}
Number of branches	45	1.67±0.23 ^{aB}	0.00±0.00 ^{aA}	1.67±0.12 ^{aB}	0.00±0.00 ^{aA}
	60	7.40±0.35 ^{bC}	0.80±0.2 ^{aA}	7.40±0.35 ^{bC}	1.80±0.20 ^{bB}
	75	9.00±0.20 ^{cB}	3.40±0.69 ^{bA}	9.00±0.20 ^{cB}	4.00±0.60 ^{cA}
	90	9.07±0.12 ^{cB}	4.67±0.83 ^{cA}	10.67±0.50 ^{dC}	5.27±0.61 ^{dA}
	Number of male flower	60	23.33±1.17 ^{aD}	2.40±0.20 ^{aA}	20.00±1.44 ^{aC}
75		50.67±2.23 ^{bD}	15.27±0.61 ^{bA}	40.93±4.41 ^{bC}	28.93±2.42 ^{bB}
90		70.6±2.12 ^{cD}	34.2±3.64 ^{cbB}	48.13±2.05 ^{cC}	28.67±1.33 ^{bA}
Number of female flower	60	5.67±0.58 ^{aB}	0.40±0.20 ^{aA}	6.40±0.72 ^{aB}	0.20±0.20 ^{aA}
	75	9.67±0.31 ^{bC}	7.20±0.72 ^{bB}	7.60±0.72 ^{aB}	5.20±0.69 ^{bA}
	90	13.13±0.76 ^{cC}	6.60±0.80 ^{bB}	6.26±0.46 ^{Ab}	5.10±0.30 ^{Ba}

Values presented as means ± SD, DAS=Days after sowing.

For each column, different superscript (Small alphabet) letters indicate significantly different at $p \leq 0.05$, as measured by Duncan's test between growing period and within a row different superscript (capital alphabet) letter indicate significantly different at $p \leq 0.05$, between cultivar and condition.

to non-mulching conditions. The increased chlorophyll and anthocyanin content in cucumber leaves under mulching conditions could be attributed to enhanced plant growth exposed to higher light intensity and ultraviolet (UV) radiation. These factors likely boosted photosynthetic

efficiency and pigment production. Shukla *et al.* (2024c) similarly reported that higher light intensity improved photosynthetic efficiency and chlorophyll content in onion leaves. Additionally, the elevated levels of UV radiation at high altitudes may have contributed to the higher anthocyanin content observed in cucumbers grown under these conditions. These findings align with those of Shukla *et al.* (2024b), who demonstrated that UV-B and UV-C exposure increased anthocyanin concentration in the leaves of *Brassica oleracea* var. *gongyloides*.

Mulching appears to positively influence the number of male and female flowers in cucumber plants for both cultivars, with higher numbers recorded under mulched conditions compared to non-mulched conditions. Under mulching, the JLG cultivar exhibited the highest number of male and female flowers (70.6±2.12 and 13.13±0.76, respectively), followed by the BSS-647 cultivar (48.23±2.05 male flowers and 6.26±0.46 female flowers). This variation could be influenced by cultivar-specific traits and environmental factors associated with the growing conditions. These findings are consistent with the results of Karki *et al.* (2020) and Bhujbal *et al.* (2015).

Yield attributes: The use of black polyethylene mulch and different cucumber cultivars had a significant impact ($P \leq 0.05$) on yield-related traits, including the number of fruits per plant, fruit length (cm), fruit diameter (mm), average fruit weight (g), fruit yield per plant (kg), and overall yield (q/ha) (Table 2). The highest number of fruits per plant was recorded for the BSS-647 cultivar (7.07±0.50) followed by JLG (6.67±0.12) under mulch condition. The higher fruit length was observed in JLG (30.73±0.76 cm) followed by BSS-647 (20.05±0.44 cm) under mulch condition. Whereas, maximum fruit diameter was observed in BSS-647 (46.63±1.26 mm) followed by JLG (36.97±2.48 mm) as compared to non-mulch condition. No significant differences were observed in average fruit weight, fruit yield per plant and yield (q/ha) between cultivars under mulch condition. However, the maximum average fruit weight (JLG; 294.33±14.52 g and BSS-647; 289.33±12.85 g), fruit yield per plant (JLG; 1.96±0.12 kg and BSS-647; 2.04±0.06 kg) and yield (JLG; 690.37±28.45 q/ha and BSS-647; 737.06±31.04 q/ha) were observed under mulch condition as compared to non-mulch condition. The increased yield of cucumber plants under black polythene mulch can be attributed to reduced weed competition for nutrients and improved water availability, leading to greater fruit numbers, larger size, heavier weight, and overall higher yields. Mulching enhances cucumber growth and fruit production by modifying the growing environment, including suppressing weed growth, conserving soil moisture, and regulating soil temperature (T. Yaghi *et al.*, 2013), (Iqbal *et al.*, 2020) and (Bharati *et al.*, 2020). Similar findings have been reported by Hutabarat *et al.* (2021) in cucumber; Aruna *et al.* (2007) in tomato; and Suresh & Kumar (2006) in pointed gourd. Singh *et al.*, 2012 further noted that mulching enhances leaf photosynthesis and boosts metabolic activities during growth and reproduction. This results in increased carbohydrate production, which promotes cell division, thereby supporting both vegetative and reproductive growth and ultimately leading to higher crop yields.

Total soluble solid (°B), titratable acidity (%) and crude protein (g/100g): Higher soluble solid content is often associated with improved flavor perception (Rahman

et al., 2021). The cucumber fruits cultivated at mulch and non-mulch condition shown a significant difference ($p \leq 0.05$) in total soluble solid and titratable acidity (Table 2). Under mulched condition, highest total soluble solid and titratable acidity was found in BSS-647 (4.73±0.12 °B and 1.00±0.17 %) followed by JLG (4.1±0.1 °B and 0.64±0.05 %) as compared to non-mulch condition. This effect may be attributed to the high photosynthetic rates and efficiency facilitated by mulching and the high-altitude environment. Shukla *et al.* (2024c) similarly observed that at higher elevations, increased photosynthetic activity significantly enhanced the total soluble solids (TSS) and titratable acidity in cucumber fruit. These findings are consistent with Ansary and Roy (2005) in watermelon, Sharma and Agrawal (2004); Aruna *et al.*, (2007) in tomato.

This study found significant differences ($P \leq 0.05$) in crude protein content between cultivars grown with and without mulch (Table 2). The highest crude protein content was recorded in the JLG cultivar under mulched conditions (14.83±0.4 g/100g), followed by BSS-647 (13.15±0.11 g/100g), and compared to non-mulched conditions. The increase in protein content under mulching may be attributed to nitrogen-rich compounds, particularly nitrate (NO_3^-), in the soil, which promotes protein synthesis in plants. These findings are consistent with those of Bhandari *et al.* (2021) and Parmar *et al.* (2013) on cucumber.

Mulching effect on anions content of cucumber fruits: Ion exchange chromatography was utilized to analyze the concentrations of essential anions, including nitrate, phosphate, and sulfate (Table 3 and Fig. 1).

Under mulched conditions, the BSS-647 cultivar exhibited significantly higher ($P \leq 0.05$) nitrate and sulfate levels *i.e.*, 470.98±6.73mg/kg FW and 97.28±5.57 mg/kg FW followed by JLG (390.26±4.03 mg/kg FW and 37.48±5.36mg/kg FW) respectively, as compared to non-mulch condition. However, maximum phosphate content (650.35±13.99 mg/kg FW) was recorded in JLG followed by BSS-647 (491.84±8.07 mg/kg FW). The increased nutrient content in the BSS-647 cultivar could be attributed to the enhanced absorption of nitrate and sulphate facilitated by black polythene mulch. Mulching promotes the growth of microorganisms, which in turn increases the availability of nitrogen and sulfur in the soil, benefiting plant nutrient

Table 2 Effect of mulching and non-mulching on yield parameters of cucumber (*Cucumis sativus* L.) cv. JLG and BSS-647

Parameters	Cucumber cultivar JLG		Cucumber cultivar BSS-647	
	Mulching	Non mulching	Mulching	Non mulching
Avg fruit weight (g)	294.33±14.52 ^B	213.93±10.37 ^{AB}	289.33±12.85 ^B	207.00±10.13 ^A
Fruit yield per plant (kg)	1.96±0.12 ^B	0.85±0.06 ^A	2.04±0.06 ^B	0.95±0.13 ^A
Yield (q/ha)	690.37±28.45 ^B	329.71±22.23 ^A	737.06±31.04 ^B	349.9±16.34 ^A
Moisture (%)	95.17±0.15 ^B	95.53±0.25 ^B	95.43±0.35 ^B	94.13±0.15 ^A
TSS (°B)	4.10±0.1 ^B	3.83±0.06 ^A	4.73±0.12 ^C	4.27±0.15 ^B
Titratable acidity (%)	0.64±0.05 ^B	0.51±0.01 ^{AB}	1.00±0.17 ^C	0.44±0.1 ^A
Crude protein (g/100g)	14.83±0.4 ^C	13.05±0.33 ^B	13.15±0.11 ^B	10.71±0.22 ^A

Values presented as means ± SD.

For each row, different superscript (Large alphabet) letters indicate significantly different at $p \leq 0.05$, as measured by Duncan's test between cultivar and condition

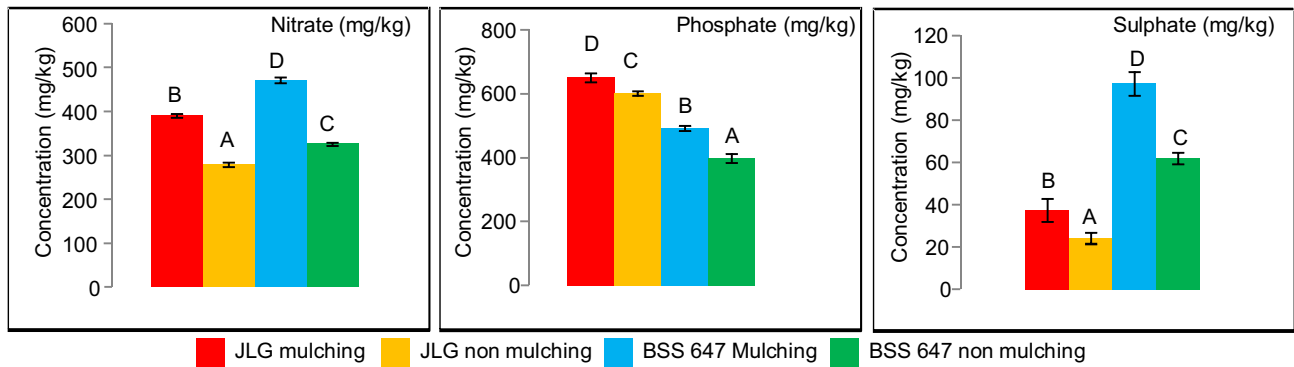


Fig. 1. Anions (nitrate, phosphate and sulphate) content of cucumber cultivar JLG and BSS-647 under mulching and non-mulching condition

uptake. These findings align with the work of Agegnehu and Amede (2017). Additionally, the highest phosphate content was observed under mulched conditions, likely due to the improved availability of phosphorus in the soil. As noted by Shukla *et al.* (2024c), plants are able to absorb minerals more efficiently when they are readily available in the soil.

Mulching effect on minerals content of cucumber fruits: Macro and micronutrients are essential for plant survival under stress conditions, as they contribute to the synthesis of secondary metabolites that help plants cope with environmental challenges (Bhat *et al.*, 2020). Under stress conditions such as drought, salinity, and cold, there is often an increased production of anthocyanins, which is linked to higher levels of calcium (Tuteja and Mahajan, 2007). Nutrients like nitrogen, potassium, sulfur, and manganese are crucial in the synthesis of secondary metabolites, including lignin, phenols, flavonoids, carotenoids, phytochelatins, and phytoalexins, all of which play significant roles in plant defense and adaptation (Luciano *et al.*, 2017).

The result of cucumber fruit N, Mg, Zn, Mn and K concentration were significantly affected by black polythene mulch ($P \leq 0.05$) and cultivar while Fe and Na exhibited no significant effects between cultivars (Table 3). Under mulch condition, the highest concentration of N (2373.56 ± 63.32 mg/100g), Zn (4.59 ± 0.25 mg/100g) and K (3713.59 ± 40.18 mg/100g) was found in JLG cultivar followed by BSS-647 (N: 2103.94 ± 17.73 mg/100g, Zn: 3.91 ± 0.36 and K: 3119.84 ± 77.23 mg/100g) respectively, as compared to non-mulching condition. Whereas, maximum Mg (370.77 ± 10.48 mg/100g) and Mn (8.04 ± 0.06 mg/100g) was recorded BSS-647 cultivar followed by JLG (Mg: 350.89 ± 2.15 mg/100g and Mn: 7.49 ± 0.16 mg/100g), respectively.

Table 3. Effect of mulching and non-mulching on anion and mineral parameters of cucumber (*Cucumis sativus* L.) cv. JLG and BSS-647

Parameters	Cucumber cultivar JLG		Cucumber cultivar BSS-647	
	Mulching	Non mulching	Mulching	Non mulching
Nitrate (mg/kg)	390.26±4.03 ^B	279.27±5.18 ^A	470.98±6.73 ^D	325.88±3.45 ^C
Phosphate(mg/kg)	650.35±13.99 ^D	600.93±7.04 ^C	491.84±8.07 ^B	398.6±13.99 ^A
Sulphate(mg/kg)	37.48±5.36 ^B	24.27±2.69 ^A	97.28±5.57 ^D	61.94±2.75 ^C
N (mg/100)	2373.56±63.32 ^C	2088.33±53.46 ^B	2103.94±17.73 ^B	1713.85±34.12 ^A
Mg (mg/100g)	350.89±2.15 ^B	335.15±1.34 ^A	370.77±10.48 ^C	353.45±12.74 ^B
Zn(mg/100g)	4.59±0.25 ^C	4.12±0.09 ^B	3.91±0.36 ^B	2.83±0.05 ^A
Fe(mg/100g)	8.14±0.33 ^C	7.51±0.05 ^B	7.88±0.44 ^{BC}	6.69±0.31 ^A
Mn(mg/100g)	7.49±0.16 ^B	7.17±0.07 ^A	8.04±0.06 ^C	7.95±0.15 ^C
Na(mg/100g)	217.31±6.48 ^B	199.8±5 ^A	223.79±1.23 ^B	214.64±9.07 ^B
K(mg/100g)	3713.59±40.18 ^D	3379.95±76.3 ^C	3119.84±77.23 ^B	2745.44±51.29 ^A

Values presented as means ± SD.

For each row, different superscript (Large alphabet) letters indicate significantly different at $p \leq 0.05$, as measured by Duncan's test between cultivar and condition

The nutritional composition of cucumber fruit in the present study varied in response to the chemical properties of the soil and the use of black polythene mulch (Torres-Oliver *et al.*, 2016). The higher nitrogen concentration under mulched conditions may account for the increased chlorophyll content observed. The lower magnesium concentration in the JLG cultivar could be attributed to its antagonistic relationship with potassium, as potassium, a monovalent cation, is absorbed more readily by plants than divalent ions like magnesium (Demidchik *et al.*, 2002).

Correlation between morphological and biochemical traits:

The correlation studies conducted on various Yield and biochemical traits have offered valuable insights into the interrelationships among these parameters (Fig. 2). Yield showed a strong positively correlation with important biochemical traits like TSS (0.633), titratable acidity (0.843) crude protein (0.659), N (0.659), Mg (0.720) and Fe (0.793). Similarly, TSS was positively correlated with important biochemical traits like titratable acidity (0.793), nitrate (0.874), sulphate (0.989), Mg (0.987), Fe (0.097), Mn (0.909) and Na content (0.884), while displaying negative correlations with traits such as crude protein (-0.143), phosphate (-0.535), N (-0.143), Zn (-0.255) and K content (-0.425). Similar studies conducted on vegetable crops *viz.*, cucumber (Acharya *et al.*, 2024; Akter *et al.*, 2020) and Potato (Bharati *et al.*, 2020).

Principal Component Analysis (PCA):

In the present study, Principal Component Analysis (PCA) was performed on 20 cucumber traits to identify potential clustering patterns within the dataset (Table 4 and Fig. 3). PCA serves as an effective statistical tool for reducing a large set of interrelated variables into a smaller number of principal components. Based on eigenvalue criteria, five principal components (varifactors) were extracted, collectively explaining 98.52% of the total variance. The first and second principal components (PC1 and PC2) accounted for 46.70% and 42.50% of the variation in plant quality parameters, respectively. PC1 exhibited high loadings for fruit yield (9.77), fruit weight (9.63), and number of fruits (8.23),

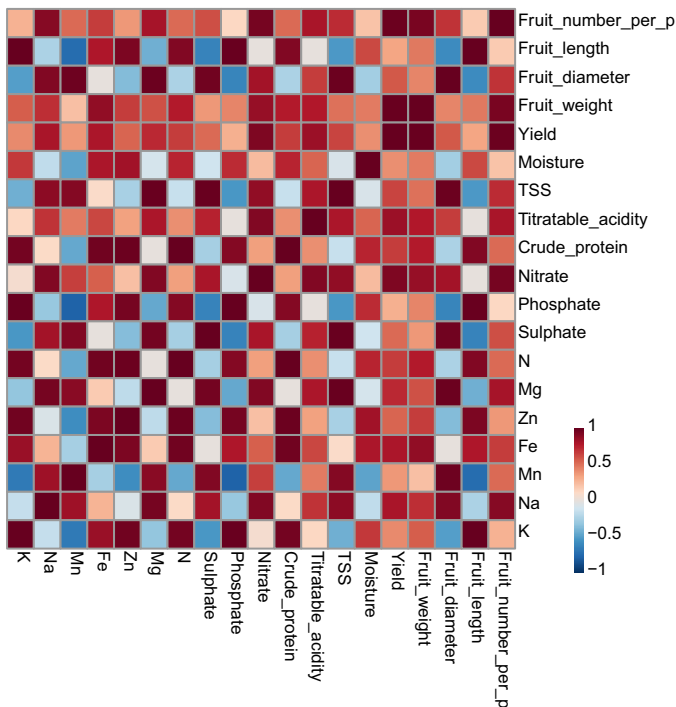


Fig. 2. Heat-map correlation for physico-chemical traits of cucumber cultivar JLG and BSS-647 under mulching and non-mulching condition

Table 4. Principal component analysis (PCA) with the eigen value, variance and cumulative variance of cucumber

Component	PC1	PC2	PC3	PC4	PC5
Eigenvalues	9.34	8.50	0.93	0.63	0.31
Variance (%)	46.70	42.51	4.64	3.14	1.54
Cumulative (%)	46.70	89.21	93.85	96.98	98.52
Contribution per PC					
No of fruit	8.23	1.80	3.98	0.63	10.16
Length of fruit	3.02	8.00	2.82	0.05	0.16
Diameter of fruit	1.25	9.52	0.15	7.03	1.17
Avg. fruit weight	8.08	0.43	0.40	30.25	0.17
Fruit weight/plant	9.63	0.67	2.15	1.28	4.55
Fruit yield	9.77	0.70	1.40	0.55	1.70
Moisture	3.60	2.48	41.98	5.64	1.05
Total soluble solid	2.08	8.72	2.50	4.15	0.86
Titrateable Acidity	6.33	1.84	19.98	3.95	0.00
Crude protein	7.12	3.66	0.94	0.02	0.04
Nitrate	7.05	3.77	0.03	0.10	0.15
Phosphate	2.77	8.53	0.23	1.45	0.66
Sulphate	1.14	9.87	3.37	1.22	3.04
Nitrogen	7.12	3.66	0.95	0.02	0.04
Magnesium	2.44	6.87	0.84	22.92	4.13
Zinc	5.29	5.06	1.57	6.32	4.90
Iron	7.70	1.09	0.50	0.26	54.76
Manganese	0.16	11.13	1.98	0.00	2.25
Sodium	3.14	5.40	13.12	12.23	9.41
Potassium	4.08	6.79	1.09	1.93	0.81

whereas it showed low loadings for manganese (0.16) and sulphate (1.14). PC2 had strong associations with manganese (11.13) and sulphate (9.87), but minimal contribution from fruit weight per plant (0.67) and fruit yield (0.70). The third principal component showed significant loadings for moisture content (41.98) and titrateable acidity (19.98). These results suggest that the number of fruits per plant, fruit weight, manganese, sulphate, and titrateable acidity are key contributors to the enhancement of

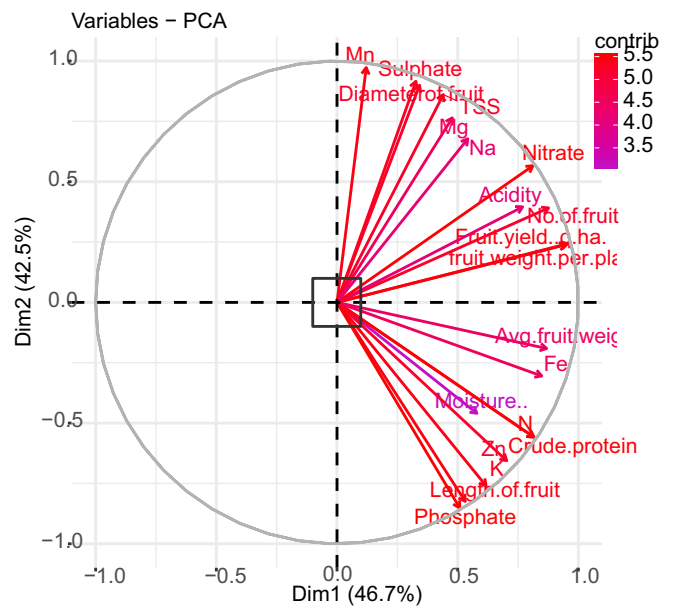


Fig. 3. Biplot of measured morpho-biochemical parameters on the basis of principal component analysis. Abbreviation: TSS Total soluble solid, N Nitrogen, K Potassium, Fe Iron, Zn Zinc, Mn Manganese, Cu Copper, Mg Magnesium, Na Sodium.

cucumber quality traits in the treatment field. Similar patterns were observed in related studies by Dhiman *et al.*, (2024) on cucumber and Gonzalez *et al.*, (2025) on lettuce.

According to the results presented, it is concluded that cucumber plant under mulching condition both cultivars increased growth and yield parameters *i.e.*, plant height, number of leaves, leaf area, tendril length, number of branches, and the number of male and female flowers, leaf chlorophyll and leaf anthocyanin content, number of fruit per plant, length and diameter of fruit and yield as compared to non-mulching condition. The study revealed that mulching led to a 2.11-fold increase in fruit yield compared to non-mulching. Additionally, the nutritional quality of cucumber fruit, in terms of total soluble solids (TSS), titrateable acidity, crude protein, and major mineral components, was significantly higher in the JLG cultivar, followed by BSS-647, under mulching conditions. Therefore, to ensure optimal food and nutritional security, growers are encouraged to use black polythene mulch to produce high-yield, nutrient-rich cucumber crops at higher elevations. This initial study lays the groundwork for future research to assess the effectiveness of various mulching materials and cucumber cultivars in producing nutrient-rich crops at high altitudes.

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