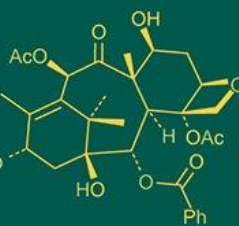
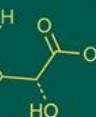
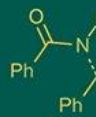


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Influence of mulching and fertigation levels on growth, yield, fruit quality and economics of tomato (*Solanum lycopersicum* L.) cv. 'Heem Sohna' under naturally ventilated polyhouse

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Abstract

A field experiment was conducted during Kharif 2021 in a naturally ventilated polyhouse at the Experimental Research Farm, Chhapang, Eternal University, Baru Sahib, Himachal Pradesh, to evaluate the influence of three mulch types (saw dust, straw and black polythene) and three fertigation levels (100, 150 and 200 kg NPK ha⁻¹ through Polyfeed 19:19:19) on the growth, yield, fruit quality and economics of tomato cultivar 'Heem Sohna'. The experiment was laid out in a Randomized Block Design with nine treatment combinations replicated thrice. Black polythene mulch combined with fertigation at 200 kg NPK ha⁻¹ (M3F3) consistently produced the most favourable microclimate and nutrient regime, resulting in earliest flower initiation (27.67 days), tallest plants (216.90 cm), maximum leaf area (64.50 cm²), highest fruit yield per hectare (1715.25 q) and superior fruit quality, including ascorbic acid (26.44 mg 100g⁻¹), total soluble solids (5.77 °Brix) and lycopene content (4.65 g mol⁻¹). The same treatment combination also recorded the highest benefit-cost ratio (2.21), followed by straw mulch with 200 kg NPK ha⁻¹ (2.15). Saw dust mulch, although comparatively inferior for yield, conserved the highest residual soil nitrogen (340.95 kg ha⁻¹) after final harvest. The results demonstrate that black polythene mulching integrated with fertigation at 200 kg NPK ha⁻¹ is agronomically and economically the most rewarding practice for protected tomato cultivation under mid-hill polyhouse conditions, and can be recommended to growers seeking higher productivity, superior fruit quality and better returns.

Keywords: Tomato, mulching, fertigation, polyhouse, fruit quality, lycopene, benefit-cost ratio

Introduction

Tomato (*Solanum lycopersicum* L., 2n = 2x = 24) is among the most widely cultivated and consumed vegetable crops in the world, ranking second only to potato in terms of area and production (Ram, 1991) [27]. Native to Peru in Latin America (Villareal, 1979) [44], the crop was introduced into India during the seventeenth century, most likely by Portuguese traders (Kalloo, 1991) [16], and has since become integral to Indian diets, both as a fresh vegetable and in processed forms such as puree, ketchup and sauce. Nearly two-thirds of the global tomato harvest is consumed fresh, with the remainder directed towards processing (Ugonna *et al.*, 2015) [42]. India currently cultivates tomato over roughly 814 thousand hectares, producing about 2,515 thousand tonnes annually, with Himachal Pradesh contributing close to 482 thousand tonnes from about 11.24 thousand hectares (NHB, 2018-19) [23].

Beyond its culinary versatility, tomato is valued as a 'protective food' owing to its rich content of vitamins A and C, dietary fibre and minerals such as potassium, calcium, iron and manganese (Kaur and Kapoor, 2008; Naika *et al.*, 2005) [17, 22]. Lycopene, the principal carotenoid responsible for the fruit's characteristic red colour, is widely regarded as one of the most potent naturally occurring antioxidants and has been associated with reduced risk of cardiovascular disease, osteoporosis and certain cancers (Tigist *et al.*, 2013) [38].

Open-field tomato cultivation remains highly susceptible to biotic and abiotic stresses that constrain both yield and quality. Protected cultivation, by moderating the crop microclimate, offers a dependable route to year-round production of high-value, superior-quality fruit (Sirohi, 2002) [35] while enabling more efficient use of shrinking landholdings (Sanwal *et al.*, 2004) [30].

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Within protected systems, mulching and fertigation are two agronomic levers of particular importance. Mulches, whether organic (saw dust, straw) or inorganic (black polythene), moderate soil temperature, conserve moisture, suppress weeds and improve soil structure (Hochmuth *et al.*, 2001; Patil *et al.*, 2013) ^[13, 26], while black polythene in particular restricts outgoing radiation and thereby enhances moisture retention and weed control relative to organic alternatives (Patil *et al.*, 2013) ^[26]. Fertigation, the delivery of water-soluble fertilizer through the irrigation system, permits frequent, precise and uniform nutrient application, improving nutrient-use efficiency under protected conditions (Vasanthi *et al.*, 2017) ^[43]. The rate and scheduling of fertigation is known to strongly influence nutrient uptake and, consequently, crop performance. Despite considerable independent evidence on the benefits of mulching and fertigation, information on their combined or interactive effects on growth, yield, fruit quality and economics of tomato hybrids under mid-hill naturally ventilated polyhouse conditions remains limited. The present investigation was therefore undertaken with the following objectives: (i) to evaluate the effect of different mulch materials on growth, yield and quality of tomato under protected conditions; (ii) to assess the influence of varying fertigation levels on these parameters; (iii) to examine the interaction effects of mulching and fertigation; and (iv) to work out the benefit-cost ratio of the different treatment combinations.

2. Materials and Methods

2.1 Experimental site and climate

The experiment was conducted during Kharif 2021 in a naturally ventilated polyhouse (25 m × 20 m × 15 m) at the Experimental Research Farm, Chhapang, Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib (173101), Himachal Pradesh, India, situated at 30.73°N, 77.31°E and 898 m above mean sea level, within the sub-temperate, sub-humid mid-hill agro-climatic zone. The site receives an average annual rainfall of 985.8 mm, most of which is received during the south-west monsoon (June-September). The initial soil at 0-15 cm depth was sandy loam in texture, normal in electrical conductivity and pH, high in organic carbon and medium in available nitrogen, phosphorus and potassium.

2.2 Experimental design and treatments

The trial was laid out in a Randomized Block Design (RBD) with nine treatment combinations replicated thrice (27 plots; plot size 2 × 1 m; ten plants plot⁻¹ at 60 × 45 cm spacing). Three mulch materials saw dust (M1), straw (M2) and black polythene (M3) were factorially combined with three fertigation levels of water-soluble fertilizer (Polyfeed 19:19:19) 100 kg NPK ha⁻¹ (F1), 150 kg NPK ha⁻¹ (F2) and 200 kg NPK ha⁻¹ (F3) to give nine treatments (T1-T9: M1F1 through M3F3). Nursery seed of the indeterminate hybrid 'Heem Sohna' (Syngenta) was sown on 18 January 2021, and 4-6 leaf-stage seedlings, pre-treated with 0.2% Bavistin, were transplanted onto raised beds on 28 February 2021. Fertigation commenced 15 days after transplanting through drip, and mulches were applied according to treatment; plots were kept weed-free by hand weeding throughout the season.

2.3 Observations recorded

Five randomly tagged plants per plot were used to record vegetative parameters (days to flower initiation, plant height, plant spread, leaf area, leaflets per leaf, nodes per plant and internodal distance), yield-attributing and yield parameters (harvest duration, fruit length and breadth, fruit weight, fruits per plant, and fruit yield per plant, per plot and per hectare) and fruit-quality parameters (pericarp thickness, ascorbic acid content estimated by the 2,6-dichlorophenol indophenol dye method, total soluble solids by hand refractometer, and lycopene content by petroleum-ether extraction and spectrophotometry at 503 nm, following Rangana, 1997) ^[28]. Soil samples were analysed for available N, P and K before planting and after final harvest using standard procedures (Subbiah and Asija, 1956; Olsen *et al.*, 1954; Jackson, 1973) ^[36, 14]. Cost of cultivation, gross and net returns and benefit-cost (B:C) ratio were computed for each treatment on a per-unit-area basis, and incidence of pest and disease was monitored throughout the crop period.

2.4 Statistical analysis

Data were subjected to analysis of variance appropriate for a two-factor RBD, following Gomez and Gomez (1984) ^[11]. Treatment means were compared using critical difference (CD) at the 5% level of significance wherever the F-test was significant.

3. Results and Discussion

3.1 Vegetative growth parameters

Mulching and fertigation level exerted a significant independent influence on all recorded vegetative traits (Table 1). Black polythene mulch (M3) advanced flowering, and produced the tallest, most spreading plants with the greatest leaf area and leaflet number, while saw dust (M1) consistently trailed. Among fertigation levels, the highest dose of 200 kg NPK ha⁻¹ (F3) was significantly superior to the lower levels for every vegetative character measured. Interaction effects were significant for plant spread and leaflet number, where the combination of black polythene mulch with 200 kg NPK ha⁻¹ (M3F3) recorded the best performance (plant spread 87.64 cm; leaflets per leaf 15.67), generally at par with straw mulch at the same fertigation level (M2F3).

The superiority of black polythene mulch for early flowering and vigorous vegetative growth can be attributed to the elevated soil and canopy-level temperature it sustains relative to organic mulches, which improves the soil hydrothermal regime and accelerates photosynthate production and floral primordia initiation (Kavitha *et al.*, 2020; Singh *et al.*, 2017; Gudugi *et al.*, 2012) ^[18, 33, 12]. The response to increasing fertigation level reflects the well-established role of nitrogen in stimulating protein synthesis, chlorophyll formation and carbohydrate accumulation, coupled with the contribution of phosphorus to reproductive development (Agrawal *et al.*, 2018; Tegen *et al.*, 2016; Dhiman *et al.*, 2018) ^[1, 37, 9]. Enhanced leaf area and plant height under black polythene combined with the highest fertigation level are further consistent with improved nutrient and moisture availability at the root zone through drip-based delivery, which sustains higher rates of cell division and net assimilation (Devi *et al.*, 2020; Wankhede *et al.*, 2018; Kosterna, 2014) ^[7, 45, 20].

Table 1: Effect of mulching and fertigation levels on vegetative growth parameters of tomato cv. 'Heem Sohna'

Parameter	M1	M2	M3	CD (M)	F1	F2	F3	CD (F)
Days to flower initiation	36.78	33.22	29.00	1.646	35.22	33.22	30.56	1.646
Plant height (cm)	185.20	199.97	206.45	4.849	189.36	196.78	205.48	4.849
Plant spread (cm)	69.63	80.26	82.16	1.658	71.70	77.55	82.82	1.658
Leaf area (cm ²)	42.66	56.68	60.31	3.551	47.80	52.39	59.46	3.551
Leaflets per leaf (no.)	11.96	13.98	14.60	0.505	12.11	13.67	14.76	0.505

M1 = saw dust; M2 = straw mulch; M3 = black polythene mulch; F1 = 100 kg NPK ha⁻¹; F2 = 150 kg NPK ha⁻¹; F3 = 200 kg NPK ha⁻¹; CD = critical difference at 5% level of significance.

3.2 Yield and yield-attributing traits

Harvest duration, fruit length and breadth, fruit weight, number of fruits per plant and fruit yield (per plant, per plot and per hectare) were all significantly influenced by mulch type and fertigation level as independent factors, with black polythene mulch and 200 kg NPK ha⁻¹ fertigation producing the best results throughout (Table 2). The interaction of mulch and fertigation level was significant for fruit length, number of fruits per plant, and all three yield expressions, with M3F3 emerging as the single best treatment combination (fruit yield 1715.25 q ha⁻¹), generally at par with straw mulch under the same fertigation level (M2F3, 1549.35 q ha⁻¹).

The yield advantage under black polythene mulch is best explained through its cascading effect on component traits: moisture conservation and a more favourable root-zone microclimate promote greater nutrient influx into developing fruit, translating into longer, broader and heavier

fruit with a higher fruit count per plant (Shukla *et al.*, 2009; Kundu *et al.*, 2019; El-Moulla *et al.*, 2018) [32, 21, 10]. A weed-free environment and reduced nutrient loss through leaching under the impermeable mulch further support a higher number of fruit-bearing nodes (Ogundare *et al.*, 2015; Tipu *et al.*, 2014) [24, 39]. The corresponding response to increasing fertigation level is consistent with more efficient translocation of photosynthates from source to sink under a regime of frequent, split nutrient supply, which favours fruit set, fruit size and, ultimately, total yield per unit area (Kavitha *et al.*, 2020; Vasanthi *et al.*, 2017; Ughade *et al.*, 2016) [18, 43, 41]. The significant mulch × fertigation interaction for yield traits underscores that the full yield benefit of intensive fertigation is best realised only when paired with a mulch, such as black polythene, capable of sustaining the associated microclimatic and moisture advantages (Selvamurugan *et al.*, 2018; Aruna *et al.*, 2007) [31, 4].

Table 2: Effect of mulching and fertigation levels on yield and yield-attributing traits of tomato cv. 'Heem Sohna'

Parameter	M1	M2	M3	CD (M)	F1	F2	F3	CD (F)
Fruit length (cm)	4.58	5.01	5.22	0.117	4.60	4.96	5.26	0.117
Fruit weight (g)	91.80	95.29	100.42	2.790	93.83	95.67	98.01	2.790
Fruits per plant (no.)	35.07	39.53	43.78	1.044	36.61	39.57	42.20	1.044
Fruit yield per plant (kg)	3.22	3.77	4.40	0.168	3.44	3.80	4.15	0.168
Fruit yield per hectare (q)	1159.09	1358.80	1585.61	60.702	1238.78	1369.16	1495.55	60.702

M1 = saw dust; M2 = straw mulch; M3 = black polythene mulch; F1 = 100 kg NPK ha⁻¹; F2 = 150 kg NPK ha⁻¹; F3 = 200 kg NPK ha⁻¹; CD = critical difference at 5% level of significance.

3.3 Fruit quality parameters

All four quality attributes examined pericarp thickness, ascorbic acid content, total soluble solids (TSS) and lycopene content responded significantly and positively to black polythene mulch and to the highest fertigation level (Table 3). Interaction effects were significant only for ascorbic acid content, where M3F3 again recorded the highest value (26.44 mg 100 g⁻¹), statistically at par with M3F2 and M2F3.

Improved pericarp thickness under black polythene mulch parallels the gains already observed in fruit length, breadth and weight, and reflects more efficient nutrient translocation into the pericarp tissue during fruit development (Samui *et al.*, 2020; Dharmatti *et al.*, 1989) [29, 8]. The elevated ascorbic acid, TSS and lycopene content under black polythene mulch is consistent with an accentuated metabolic and photosynthetic environment beneath the mulch, including greater canopy-level carbon dioxide concentration, both of which favour sugar translocation to the fruit and support carotenoid biosynthesis during ripening (Samui *et al.*, 2020; Ayyar, 2019; El-Moulla *et al.*, 2018) [29, 5, 10]. The parallel improvement in these traits with increasing fertigation level is attributable, in particular, to enhanced potassium availability, which plays a central role in sugar translocation, ascorbate metabolism and chloroplast

development the very site of lycopene synthesis (Kalanjiyam and Manickam, 2015; Anac and Colcoglu, 1995; Singh *et al.*, 2019) [15, 2, 34].

Table 3: Effect of mulching and fertigation levels on fruit quality parameters of tomato cv. 'Heem Sohna'

Parameter	M1	M2	M3	CD (M)	F1	F2	F3	CD (F)
Pericarp thickness (mm)	4.61	5.01	5.24	0.381	4.62	5.00	5.25	0.381
Ascorbic acid (mg 100g ⁻¹)	20.35	23.37	25.33	0.595	20.55	23.87	24.62	0.595
TSS (°Brix)	5.03	5.31	5.55	0.107	4.92	5.38	5.59	0.107
Lycopene (g mol ⁻¹)	3.85	4.24	4.38	0.131	3.75	4.25	4.47	0.131

M1 = saw dust; M2 = straw mulch; M3 = black polythene mulch; F1 = 100 kg NPK ha⁻¹; F2 = 150 kg NPK ha⁻¹; F3 = 200 kg NPK ha⁻¹; CD = critical difference at 5% level of significance.

3.4 Economics of cultivation

The cost of cultivation was highest under black polythene mulch (Rs 166.86 m⁻²) owing to the higher material cost of the plastic sheet, and lowest under saw dust mulch (Rs 133.34 m⁻²). Despite its higher input cost, black polythene mulch combined with 200 kg NPK ha⁻¹ (T9) returned the highest net return (Rs 369.14 m⁻²) and the highest benefit-

cost ratio (2.21), driven by its markedly superior yield (21.44 kg m⁻²). Straw mulch with 200 kg NPK ha⁻¹ (T6) was the next most profitable option, with a B:C ratio of 2.15 at a considerably lower cost of cultivation, making it an attractive alternative where the initial investment in plastic mulch is a constraint. These findings align with the economic gains reported for combined mulching and fertigation practices in tomato by Kundu *et al.* (2019)^[21], Agrawal *et al.* (2018)^[1] and Vasanthi *et al.* (2017)^[43], although they contrast with reports of comparatively higher returns from organic mulches under different agro-climatic settings (Tegen *et al.*, 2016; Biswas *et al.*, 2015; Khan *et al.*, 2005)^[37, 6, 19], reflecting the influence of local input costs and market price on the final B:C outcome.

3.5 Soil fertility status after final harvest

Residual soil nitrogen was significantly highest under saw dust mulch (340.95 kg ha⁻¹), most likely reflecting the immobilisation and gradual release of nitrogen associated with the decomposition of a high carbon-to-nitrogen organic residue and comparatively lower plant offtake (Ogundare *et al.*, 2015)^[24]. Available phosphorus was highest under straw mulch (38.28 kg ha⁻¹), consistent with the relatively high phosphorus content of decomposing wheat straw (Khan *et al.*, 2005)^[19], while available potassium, though numerically highest under straw mulch, did not differ significantly among mulch treatments. Across all three nutrients, residual availability increased significantly with fertigation level, being highest under 200 kg NPK ha⁻¹, reflecting a greater unutilised fraction of applied nutrient at the higher dose (Ughade *et al.*, 2016; Tumbare *et al.*, 2004)^[41, 40].

3.6 Incidence of pest and disease

No disease incidence was recorded throughout the cropping season, and fruit borer infestation remained well below the economic threshold level in all treatments, consistent with the generally favourable and better-regulated microclimate and improved field sanitation associated with protected cultivation.

4. Conclusion

Under naturally ventilated polyhouse conditions in the mid-hills of Himachal Pradesh, black polythene mulch combined with fertigation at 200 kg NPK ha⁻¹ consistently outperformed the other treatment combinations for vegetative growth, yield and fruit quality of tomato cv. 'Heem Sohna', and also returned the highest benefit-cost ratio (2.21). Straw mulch at the same fertigation level offered a comparable, more economical alternative (B:C ratio 2.15) where the cost of plastic mulch is limiting. Saw dust mulch, while agronomically inferior for yield, conserved the greatest residual soil nitrogen and may hold value in nutrient-management rotations. On the basis of overall growth, yield, quality and economic performance, black polythene mulching integrated with fertigation at 200 kg NPK ha⁻¹ can be recommended as the most rewarding management practice for polyhouse tomato cultivation under similar mid-hill agro-climatic conditions.

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