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Response of tomato to fertilizer nutrients integration and herbicides spray: Evaluating growth, yield, fruit quality and herbicides residue

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Abstract

The interaction between fertilizer nutrients and pesticides and their impact on tomato production and quality has been insufficiently studied in tropical agricultural conditions. This research investigated four fertilizer nutrient management (FNM) approaches: major nutrients (NPK), micronutrients, farmyard manure (FYM), and traditional farmer practices (FP), alongside three herbicides—glyphosate, pendimethalin, and metribuzin applied using seven methods. Results highlighted the substantial influence of FNM strategies and herbicide applications on tomato growth and yield parameters such as plant height, cluster count, fruits per plant, fruit number, and yield per plant. Notably, the NPK+FYM strategy consistently yielded superior results across herbicides and application methods. Individually applied herbicides, particularly glyphosate, exhibited detrimental effects on growth and yield parameters, and the negative impact was conspicuously higher with glyphosate > metribuzin > pendimethalin than with their sequential or combined application. While herbicides decreased tomato yield across FNM practices, the reduction ranged from 1.90–10.95%, 1.79–6.75%, 1.62–6.49%, and 1.40–9.10% in NPK, NPK+MN, NPK+FYM, and FP treatments, respectively. Fruit quality remained unaffected by FNM practices and herbicides, except for elevated ascorbic acid content and shelf life under NPK+FYM. Herbicide residues in tomato fruits were within permissible limits (below 0.1 mg/kg for glyphosate and 0.05 mg/kg for pendimethalin and metribuzin) across treatments. This study showed that the NPK+FYM practice is the best strategy for increasing the tomato yield and quality parameters besides reducing the herbicide's toxicity effect on tomato growth at an early stage.

Keywords

Tomato; herbicides; nutrients management; micronutrients; farm yard manure; interaction

Introduction

Tomato (*Solanum lycopersicum*) is a culinary favorite that rivals even the prestigious potato (1, 2). With global production of 189.1 million metric tonnes (1) during 2021, these versatile crops gift us health-enhancing treasures: lycopene, ascorbic acid, and ß-carotene celebrated for both their vibrant colors and delectable flavors (3). Lycopene is hailed as an antioxidant powerhouse, and carotenoid, a non-provitamin A (4–6), commands the spotlight for its anticancer properties. As our world's appetite grows and arable lands stagnate, tomatoes beckon us to find ingenious solutions. Enter the realm of chemical fertilizers and herbicides, promising amplified nutrient uptake and diminished weed rivalry (7). However, the recurrent and excessive application of these agrochemicals not only deteriorates soil health but poses a huge threat to sustainable agriculture (8). Also, the simultaneous application of two major agro-inputs might have antagonistic or synergistic interactions in soil (9); accordingly, the soil's biological health, tomato fruit production, and quality will be affected (10).

The diverse fertilizer nutrition techniques begin to take form like expert conductors, offering hope. Soil test-based major nutrients application through inorganic and organic sources, blanket recommendations, the inclusion of micronutrients, etc., is recommended in India to increase tomato productivity and maintain soil health (9, 10). Research findings from various studies have consistently highlighted the advantageous outcomes of integrating organic and inorganic fertilizers for tomato cultivation. Significant improvements in the total number of tomatoes and weight were reported (11), when a combination of organic and inorganic fertilizers was utilized. The observed increase was statistically significant ($p \leq 0.05$), underscoring the efficacy of this approach in enhancing tomato yield. Similarly, the highest number of flower clusters (31.2), fruit clusters (24.9), fruit yield (15.3 t/ha), and plant height (71.6 cm) with mixed fertilizers (organic + inorganic) compared to no fertilizer application was observed in tomato (12). Improvements in both yield and quality parameters of tomato fruit by the combined use of compost and inorganic fertilizers were attributed to the synergistic benefits of integrating organic and inorganic fertilizers are responsible for the increased yield (13) and observed positive effects (14) in tomato productivity due to inorganic and organic fertilizers. In addition to macronutrients, micronutrients are essential components for optimal plant growth and development and are underscored by their holistic nutritional requirements (15). The balanced fertilization strategy demonstrated the potential for increased agricultural production (16, 17), and about 42.7% increase in tomato yield was reported due to the combination of organic and inorganic fertilizers compared to the control (18). Height was positively linked to yield, highlighting the role of organic matter in enhancing soil fertility, structure, and nutrient availability for improved plant growth and higher yields (18, 19).

In addition to various nutrient fertilizer management practices, the farmers are using herbicides frequently in tomato cultivation (20). Mostly, herbicides like glyphosate, pendimethalin, and metribuzin are applied as pre-plant, pre or early post-emergence to manage weed menace and reduce the input cost frequently (21). However, their interactive influence on nutrient uptake, tomato growth and yield parameters, and fruit quality was little investigated in Indian tropical conditions. Hence, the present study investigated the effect of fertilizer nutrient integration through different strategies and herbicide spray on tomato growth, yield, and fruit quality, including herbicide residue levels in fruits.

Materials and Methods

Experiment details

A pot experiment was conducted under a controlled, transparent glass house at the Dept. of Soil Science and Agricultural Chemistry, TNAU, Coimbatore, India, by cultivating tomato hybrid Darsh Gold as a test crop. The soil samples collected from the continuous tomato growing farmer's field from 0–15 cm depth were processed and used to conduct the experiment. The soil was mixed black in nature and belongs to the *alfisol* order, had a sandy loam texture, neutral in reaction (7.5), and low in soluble salts (EC of 0.21 dS/m). Also contains medium organic carbon (0.51%), medium available N (262.8 kg/ha) and high P (29.7 kg/ha) and K (420 kg/ha) besides deficient in micronutrients *viz*., Fe, Cu, Zn, Mn and B (3.05, 1.19, 1.22, 4.51and 0.62 mg/kg, respectively) and sufficient in secondary nutrients (Ca-261 mg, Mg-135 mg, and S-12.5 mg/kg soil) status.

The experiment was laid out during the winter season (2022-2023) in a pot having a capacity of 7 kg. Processed soil was filled in each pot by maintaining 1.35 Mg/m^3 bulk density and then irrigated to field capacity moisture. Thirty day's old tomato seedlings were transplanted with a population of two plants per pot. Irrigation was given at 4-6 intervals depending on the weather conditions. Pest and disease control were done as per the recommendation of the crop production guide of Tamil Nadu, India.

Imposing fertilizer nutrients and herbicide treatments

An experiment was laid out in Factorial Completely Randomized Block Design (FCRD) with four fertilizer nutrients management (FNM) strategies and seven herbicide treatments and replicated thrice. The fertilizer nutrients were applied in four ways, as in Table 1. The major nutrients *viz*., nitrogen (N), phosphorus (P), and potassium (K) were applied based on soil test values. The NPK nutrients were supplied to the crop through urea, superphosphate, and potassium chloride, respectively. The N and K fertilizer nutrients were applied in three and two equal splits, respectively, during 0, 30, and 60 days for N and 0 and 45 days for K after transplanting the tomato. Seven herbicide treatments were imposed, as given in Table 1 as factor 2. The glyphosate 41% SL was applied @ 7.5 L/ha 10 days prior to transplanting. The pendimethalin 50% EC @ 1000 mL/ha and metribuzin 70% WP @ 500 g/ha were applied as pre-emergence on 3rd day after transplanting. Herbicides were sprayed on the soil surface, adopting the recommended spray volume of 500 L/ha in India.

Plant growth, fruit yield, and quality analysis

Growth of tomato plants was assessed on 15, 30, 45, and 60 DAT by measuring the plant height and number of clusters. Fruit yield was recorded by harvesting well-ripened tomatoes from each pot. A total of five pickings were done,

Table 1. Treatment details of fertilizer nutrient management practices and herbicide treatments.

Factors	Acronym used	Details
Factor 1: Fertilizer nutrients management (FNM) practices	NPK	203 kg N, 238 kg P_2O_5, 150 kg K_2O per ha only through inorganic fertilizers *viz.*, urea, superphosphate, and muriate of potash
	NPK+MN	Major nutrients - 203 kg N, 238 kg P_2O_5, 150 kg K_2O per ha and micro nutrients *viz.*, $ZnSO_4$ 50 kg, $FeSO_4$ 50 kg, sodium tetraborate salt 10 kg and $CuSO_4$ 3.75 kg per ha
	ST-NPK+FYM	203 kg N, 238 kg P_2O_5, 150 kg K_2O per ha was supplied through farm yard manure (25 t/ha) and inorganic fertilizers
	Farmers practice	200 kg N, 250 kg P_2O_5 and 208 kg K_2O, $ZnSO_4$ 50 kg, Borax 10 kg, $CuSO_4$ 3.75 kg per ha as per the general recommendation to tomato
Factor 2: Herbicides treatments	PP G	Pre-plant glyphosate spray @ 7.5 L/ha
	PE P	Pre-emergence pendimethalin spray @ 1000 g ai/ha
	PE M	Pre-emergence metribuzin spray @ 500 g ai/ha
	PP G fb PE P	Pre-plant glyphosate followed by pre-emergence pendimethalin
	PP G fb PE M	PP glyphosate followed by pre-emergence metribuzin
	PE G fb PP P + M	PP Glyphosate followed by pre-emergence pendimethalin and metribuzin as tank mix
	Control	No herbicide

and weight was pooled to calculate the fruit yield from each treatment. The morphological quality parameters like fruit color and shelf life were randomly assessed by selecting five fruits/pots. Representative tomato fruits were sampled from each treatment replication after sub-sampling from the smashed pieces using a pestle and mortar. The sub-samples were subjected to the analysis of quality attributes like ascorbic acid content, lycopene content, beta-carotenoid content, and titrable acidity, which were analyzed and determined by adopting the standard methods (19, 22, 23).

Statistical analysis

Data collected were analyzed by two-way analysis of variance (ANOVA) using R statistical software (version 4.2.2. package doe bioresearch). Graphical visualization was performed by R statistical software and MS Excel. Correlations among the variables were assessed by performing Pearson correlation coefficients and probability analysis.

Results and discussion

Effect of fertilizer nutrients and herbicides on growth parameters

The growth parameters of tomato, *viz.*, plant height and cluster number, were recorded at various time intervals to assess the effect of fertilizer nutrient management strategies and herbicide application. Results showed that the plant height was significantly influenced by the NPK+FYM strategy irrespective of applied herbicides and stage of the crop (Table 2). At 15 and 30 days, NPK (25 cm) and NPK+MN (46 cm) recorded significantly higher plant height, followed by the NPK+FYM practice. However, on the 45th and 60th days, the NPK+FYM produced significantly taller plants of 63 and 95 cm, respectively, followed by NPK and NPK+MN strategies. Lower plant height under NPK+MN and FP strategies could be attributed to the reduced availability of nutrients, particularly micronutrients, due to their complexation by glyphosate. Being a chelating

Table 2. Effect of fertilizer nutrients integration and herbicides on growth parameters at different days after transplanting (DAT) of tomato.

Treatments	Plant height (cm)				No clusters/plant	
	15 DAT	30 DAT	45 DAT	60 DAT	45 DAT	60 DAT
NPK						
PP Glyphosate (G)	25	42	56	82	2.0	5.0
PE Pendimethalin (P)	25	45	57	80	1.0	5.2
PE Metribzuin (M)	23	45	55	83	2.0	5.1
PP G fb* PE P	26	47	56	83	0.0	5.3
PP G fb PE M	26	45	58	82	1.0	5.1
PP G fb PE P & M	22	41	57	82	2.0	5.2
Control	27	35	56	82	0.0	5.3
Mean	**25**	**43**	**56**	**82**	**1.1**	**5.2**
NPK+MN						
PP Glyphosate (G)	25	47	57	83	1.0	5.1

PE Pendimethalin (P)	23	47	56	81	2.0	5.2
PE Metribzuin (M)	23	45	56	81	0.0	5.0
PP G fb* PE P	25	47	57	82	0.0	5.1
PP G fb PE M	20	45	55	82	1.0	5.2
PP G fb PE P & M	21	47	58	82	1.0	5.1
Control	18	45	58	83	0.0	5.0
Mean	**22**	**46**	**57**	**82**	**0.7**	**5.1**
NPK+FYM						
PP Glyphosate (G)	22	40	63	96	2.0	5.5
PE Pendimethalin (P)	21	42	62	95	2.0	5.4
PE Metribuzin (M)	24	43	63	95	1.0	5.1
PP G fb* PE P	20	40	64	94	2.0	5.3
PP G fb PE M	25	42	64	95	2.0	5.3
PP G fb PE P & M	23	41	64	95	2.0	5.4
Control	25	45	64	95	2.0	5.4
Mean	**23**	**42**	**63**	**95**	**1.9**	**5.3**
Farmers practice						
PP Glyphosate (G)	18	39	57	82	1.0	5.1
PE Pendimethalin (P)	15	40	57	81	1.0	4.6
PE Metribuzin (M)	19	40	57	81	0.0	4.8
PP G fb PE P	22	44	55	82	1.0	5.1
PP G fb PE M	23	43	56	82	0.0	5.1
PP G fb PE P & M	21	43	57	83	1.0	5.1
Control	18	43	57	83	1.0	5.0
Mean	**19**	**42**	**57**	**82**	**0.7**	**5.0**

	SED	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**
FNM strategies (N)	0.18	0.36	0.38	0.76	0.439	0.88	0.651	1.30	0.011	0.02	0.043	0.08
Herbicides (H)	0.238	0.48	0.50	1.01	0.581	1.16	0.861	1.73	0.015	0.03	0.057	0.11
Interaction (N × H)	0.475	0.95	1.01	2.02	1.161	2.33	1.723	3.46	0.029	0.05	0.114	0.23

G- Glyphosate; P-Pendimethalin; M-Metribuzin; PE-Pre emergence; PP-Pre plant; fb-followed by

agent, glyphosate might interact with the cationic micronutrients, specifically the Fe and Cu, besides competing with the phosphate molecule released to soil solution and reducing its availability. Glyphosate, being a chelating agent, might change the availability of essential as well as toxic metals that are bound to soil particles besides impacting the soil life depending on soil characteristics, e.g., on micronutrient supply, on amounts of glyphosate applied and climatic conditions (24). Also, the application of pendimethalin and metribuzin might inhibit tomato growth during the early period and could be ascribed to their persistent residue in the soil (25, 26). Increased plant height in NPK+FYM on the 45th and 60th days after transplanting could be attributed to the continued mineralization of nutrients and their supply, including micronutrients to the crop, besides providing conducive soil physical and biological properties. A similar positive effect of the combined application of inorganic and organic fertilizers on tomato growth was reported by (27). It was found that all the other three FNM strategies performed equally and significantly lower than NPK+FYM on influencing the plant height. Significant variation was not achieved with respect to the number of clusters per plant among the FNM practices except NPK+FYM, which increased the clusters 2-3 times higher than other practices on the 45th day, though almost equal on the 60th day. This showed that the FYM application increased the availability and supply of all nutrients in the soil, and their uptake by the plant is reducing the herbicide's toxicity effect on crops by increasing their sorption and degradation in soil. It also indicates the earliness of cluster and flower formation in tomatoes due to enhanced source-sink in the plants by the integrated nutrients supply through inorganic and organic combinations. Application of herbicides reduced the number of clusters on the 45th day visibly compared to control and on the 60th day (28), and all treatments were on par except metribuzin. This could be ascribed to the positive effect of combinations of organic and inorganic nutrient sources on the growth parameters of tomatoes (18).

The effect of herbicides on tomato plant height and cluster density was studied irrespective of FNM practices (Fig. 1). It was seen that the individual application of each herbicide had reduced the plant height significantly when compared to the control and their sequential and or combined application. This demonstrated glyphosate's ability to inhibit root elongation, lateral root formation, and root biomass production in soybeans (29) and upto 29% height reduction in tomato plants due to glyphosate application, depending on the dose reported (30). Less effect of pendimethalin on reducing the growth of tomato when compared to trifluralin and S-metolachlor and only at higher applied concentrations was observed by (20). Reduction in tomato growth due to metribuzin was noticed and showed its indirect toxicity during the early growth period. Metribuzin did not have a specific site of uptake in tomatoes, and plants were more susceptible to metribuzin when grown under high humidity and high temperature and maintained under low light intensities (31).

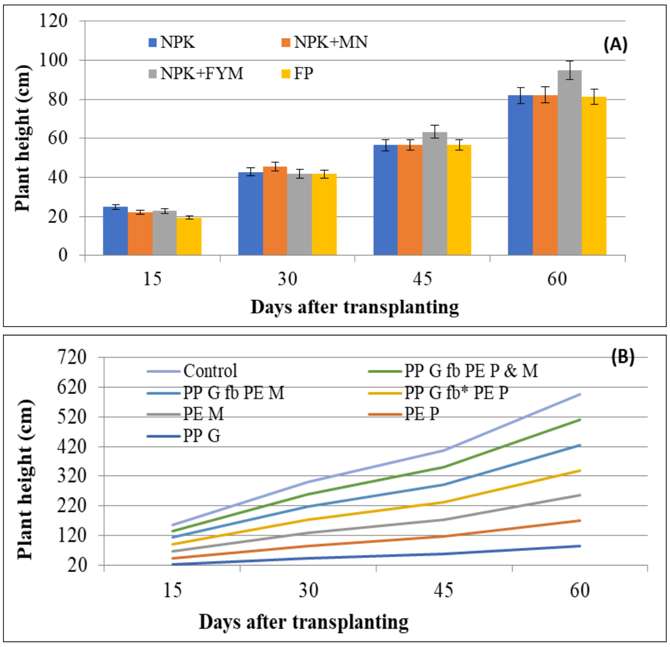

Fig. 1. Effect of fertilizer nutrients management strategies (**A**) and herbicides (**B**) on changing the tomato plant height at different growth period.

Less impact in sequentialor combined herbicides applied soil could be ascribed to the enhanced mineralization/degradation due to the application of herbicides with different modes of action and behavior in soil (25). When pendimethalin and or metribuzin were applied after glyphosate, they might reduce the release of sorbed glyphosate to soil colloids and clay minerals. Hence, the growth of tomatoes under these soils is higher than in the glyphosate-applied soil. A similar effect of metribuzin followed by pendimethalin on increasing the tomato fruit yield was reported in Egypt (21).

Effect of fertilizer nutrients and herbicides on fruits number and yield

The data recorded revealed a significant interaction and influence between FNM strategies and herbicides on fruit weight, number, and yield per plant (Tables 3 & 4). Among the FNM practices, the NPK+FYM produced significantly more fruit weight and tomato yield when compared to others, and their interaction also showed strong influence. Though the change in fruit number and weight per fruit was insignificant among the herbicide's treatment, fruit yield was influenced significantly. This could be attributed to the increased plant height, number of clusters per plant, and efficient source-sink utilization. This has been confirmed by the positive correlation of fruit yield with yield parameters *viz.*, number of fruits (R^2= 0.734*) and fruit weight (R^2= 0.664*).

The decrease in tomato yield due to herbicides across the FNM practices was observed over control and was found to range from 1.90-10.95, 1.79-6.75, 1.62-6.49, and 1.40-9.10 %, respectively in NPK, NPK+MN, NPK+FYM and FP pots (Fig. 2). The highest decrease was under glyphosate-treated soil and was followed by the PE pendimethalin and or PE metribuzin-treated soils. Being a divalent metal chelator, glyphosate might reduce the uptake and translocation of nutrients in the crop, as reported by Kanissery *et al.* (32), and hence reduce the tomato yield significantly over other herbicides in the present study. The decrease was found to be low with PP glyphosate fb PE pendimethalin and was followed by PP glyphosate fb PE metribuzin treated soils. These showed that the

Table 3. Effect of fertilizer nutrients integration and herbicides on number of tomato fruits per plant.

Treatments	NPK	NPK+MN	NPK+FYM	Farmers practice	Mean
PP Glyphosate (G)	50	52	52	50	**51**
PE Pendimethalin (P)	52	52	53	51	**52**
PE Metribuzin (M)	52	51	52	51	**52**
PP G fb* PE P	53	52	54	52	**53**
PP G fb PE M	52	53	54	53	**53**
PP G fb PE P & M	53	53	54	53	**53**
Control	53	53	54	53	**53**
Mean	**52**	**52**	**53**	**52**	

	FNM (N)	Herbicides (H)	Interaction (N ×H)
SEd	0.41	0.55	1.09
CD (P=0.05)	0.82	1.09	2.19

G- Glyphosate; P-Pendimethalin; M-Metribuzin; PE-Pre emergence; PP-Pre plant; fb- followed by

Table 4. Effect of fertilizer nutrients integration and herbicides on tomato yield (g/plant).

Treatments	NPK	NPK+MN	NPK+FYM	Farmers practice	Mean
PP Glyphosate (G)	2000	2080	2106	2000	**2047**
PE Pendimethalin (P)	2080	2080	2120	2040	**2080**
PE Metribuzin (M)	2080	2075	2095	2040	**2073**
PP G fb* PE P	2183	2184	2214	2184	**2191**
PP G fb PE M	2132	2173	2214	2173	**2173**
PP G fb PE P & M	2120	2120	2197	2120	**2139**
Control	2226	2226	2241	2215	**2227**
Mean	**2117**	**2134**	**2170**	**2110**	
	FNM (N)	**Herbicides (H)**	**Interaction (N × H)**		
SEd	17	23	46		
CD (P=0.05)	35	46	92		

G- Glyphosate; P-Pendimethalin; M-Metribuzin; PE-Pre emergence; PP-Pre plant; fb- followed by

sequential herbicide spray reduced the toxicity of the herbicide and increased the fruit yield when compared to their single spray. Results are in line with the findings of Mohamed and Hassanein (33), who documented higher tomato yield with metribuzin (sensor) and pendimethalin (Stomp). This could be attributed to the antagonistic interaction among the applied herbicides in soil and reduced residue availability of the toxic molecule for crop absorption and, hence, enhanced crop performance.

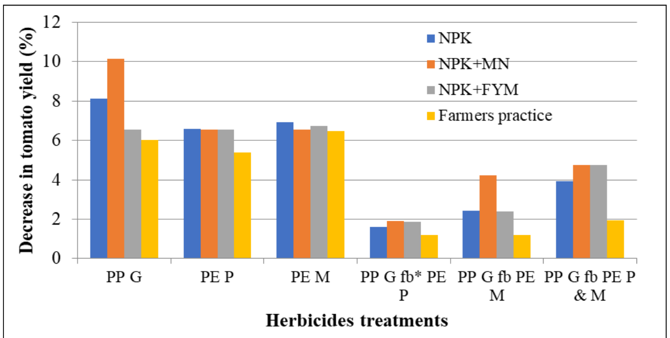

Fig. 2. Effect of fertilizer nutrients management strategies and herbicides on decreasing the tomato fruit yield [**G**-Glyphosate; **P**-Pendimethalin; **M**-Metribuzin; **PE**-Pre emergence; **PP**-Pre plant; **fb**-followed by].

Effect of fertilizer nutrients and herbicides on fruit quality and herbicides residue

Analyzed fruit quality parameters, such as titrable acidity, beta carotene, and lycopene, were not influenced significantly. However, the ascorbic acid, TSS, and shelf life of tomatoes were influenced significantly by the FNM strategies, irrespective of herbicides (Table 5). The treatment combinations *viz*., NPK alone and FP showed a significantly less effect than the NPK+MN and NPK+FYM practices. The ascorbic acid, TSS, and shelf life were found to be higher in NPK+FYM-treated fruits and were followed by the NPK+MN. This could be attributed to the increased and balanced supply and acquisition of micronutrients along with the major nutrients until the harvest of the crop. A similar result was reported by (27), who observed that these parameters were high in NPK+FYM and or NPK+ vermicompost-treated tomatoes. Significant and enhanced shelf life was observed with NPK+FYM>NPK+MN>FP>NPK. This could be ascribed to the continued iron and zinc supply to the tomato, which might have reduced the rate of respiration and transpiration, resulting in reduced ethylene production during the storage of tomato fruits, which results in increasing the shelf life of the fruits (34, 35). The spraying of herbicides singly or sequentially and combinations did not show a significant effect on tomato fruit quality except shelf life, and all parameters were on par with those of control (21). In some cases, the application of both metribuzin and tiburon-methyl as embedded forms increases the vitamin C concentrations in tomato fruits by 1.7-fold compared to free metribuzin alone, as reported by (21). Multiple correlation analysis was carried out to understand the dependency of the fruit quality parameters (Fig. 3) and found that all parameters were correlated significantly among themselves and showed the on-par efficiency of the applied FNM practices on influencing the fruit quality and less impact of applied herbicides at recommended rates.

Table 5. Effect of fertilizer nutrients integration and herbicides on tomato fruit quality parameters.

Treatments	Titrable acidity (%)	Beta carotenoid (mg/100g)	Lycopene (mg/kg)	Ascorbic acid (mg/100g)	TSS (%)	Shelf life (days)
NPK						
PP Glyphosate (G)	0.65	2.15	5.13	44.35	4.94	14.2
PE Pendimethalin (P)	0.64	2.16	5.14	43.95	4.95	14.0
PE Metribuzin (M)	0.65	2.17	5.14	43.82	4.92	14.1
PP G fb PE P	0.64	2.16	5.17	44.32	4.94	14.0
PP G fb PE M	0.65	2.18	5.15	44.95	4.92	13.9
PP G fb PE P & M	0.66	2.19	5.19	44.98	4.96	13.9
Control	0.64	2.16	5.13	44.36	4.91	14.2
Mean	**0.65**	**2.17**	**5.15**	**44.39**	**4.93**	**14.0**

NPK+MN						
PP Glyphosate (G)	0.65	2.21	5.16	44.42	4.96	14.7
PE Pendimethalin (P)	0.64	2.19	5.14	44.65	4.98	15.0
PE Metribuzin (M)	0.66	2.21	5.15	44.45	4.96	15.2
PP G fb PE P	0.65	2.23	5.17	44.43	4.95	14.9
PP G fb PE M	0.66	2.21	5.16	44.45	4.95	15.0
PP G fb PE P & M	0.66	2.24	5.20	44.48	4.98	15.1
Control	0.63	2.18	5.13	44.75	4.95	15.2
Mean	**0.65**	**2.21**	**5.16**	**44.52**	**4.96**	**15.0**
NPK+FYM						
PP Glyphosate (G)	0.71	2.25	5.23	46.08	5.04	16.3
PE Pendimethalin (P)	0.73	2.28	5.25	46.12	5.06	16.3
PE Metribuzin (M)	0.72	2.29	5.22	46.15	5.04	16.4
PP G fb PE P	0.71	2.31	5.22	46.15	5.03	16.2
PP G fb PE M	0.72	2.28	5.23	46.16	5.06	16.3
PP G fb PE P & M	0.73	2.34	5.29	46.18	5.08	16.4
Control	0.74	2.15	5.18	46.05	5.05	16.2
Mean	**0.72**	**2.27**	**5.23**	**46.13**	**5.05**	**16.3**
Farmers practice						
PP Glyphosate (G)	0.65	2.17	5.13	44.38	4.95	14.8
PE Pendimethalin (P)	0.64	2.18	5.15	43.29	4.97	14.8
PE Metribuzin (M)	0.66	2.20	5.16	43.38	4.95	14.8
PP G fb PE P	0.65	2.22	5.14	44.29	4.94	14.7
PP G fb PE M	0.66	2.20	5.14	44.32	4.93	14.7
PP G fb PE P & M	0.66	2.23	5.19	44.42	4.97	14.9
Control	0.64	2.15	5.12	44.23	4.92	14.4
Mean	**0.65**	**2.19**	**5.15**	**44.04**	**4.95**	**14.73**

	SED	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**	**SED**	**CD (P=0.05)**
FNM strategies (N)	0.005	NS	0.016	0.03	0.038	NS	0.37	0.75	0.035	NS	0.118	0.23
Herbicides (H)	0.007	NS	0.021	NS	0.051	NS	0.49	0.99	0.046	NS	0.157	0.31
Interaction (N x H)	0.014	NS	0.042	NS	0.102	NS	0.99	NS	0.092	NS	0.313	0.63

G- Glyphosate; **P**-Pendimethalin; **M**-Metribuzin; **PE**-Pre emergence; **PP**-Pre plant; **fb**-followed by

Tomato fruits harvested during 1st picking (75 DAT) were subjected to applied herbicide residue analysis by liquid chromatography. It was found that the residue of all three herbicides was below the instrument detection limit of 0.1 mg/L for glyphosate and 0.05 mg/L for pendimethalin and metribuzin, irrespective of FNM strategies and herbicides combination or sequential application. Since the residues of herbicides were below the instrument detection limits that correspond to below MRL fixed by the quality control organizations like CODEX, FSSAI, and FAO (36–38), these herbicides were safely applied to tomato fields.

Conclusion

The present study reveals that the supply of major plant nutrients (NPK) following soil test recommendation through farm yard manure @ 25 t/ha and inorganic fertilizers to the tomato hybrid with sequential application of herbicides *viz*., pre-plant glyphosate and PE tank mix of pendimethalin and metribuzin at recommended rate is a significant option for producing higher fruit yield. Though the farmer's practice produced on par yield, the quantity of major nutrients applied is high and might increase the production cost besides causing environmental issues. Also, the residues of the applied herbicides in tomato fruits were recorded below the MRL of 0.1 mg/kg for glyphosate and 0.05 mg/kg for pendimethalin and metribuzin, irrespective of nutrient management strategies. This showed that the application of herbicides at the recommended rate did not cause toxic accumulation in fruits. However, the impact of their continuous application on tomato performance, residue bioaugmentation, and soil environmental health under field conditions needs to be evaluated to understand the influence of climate and on-site field conditions.

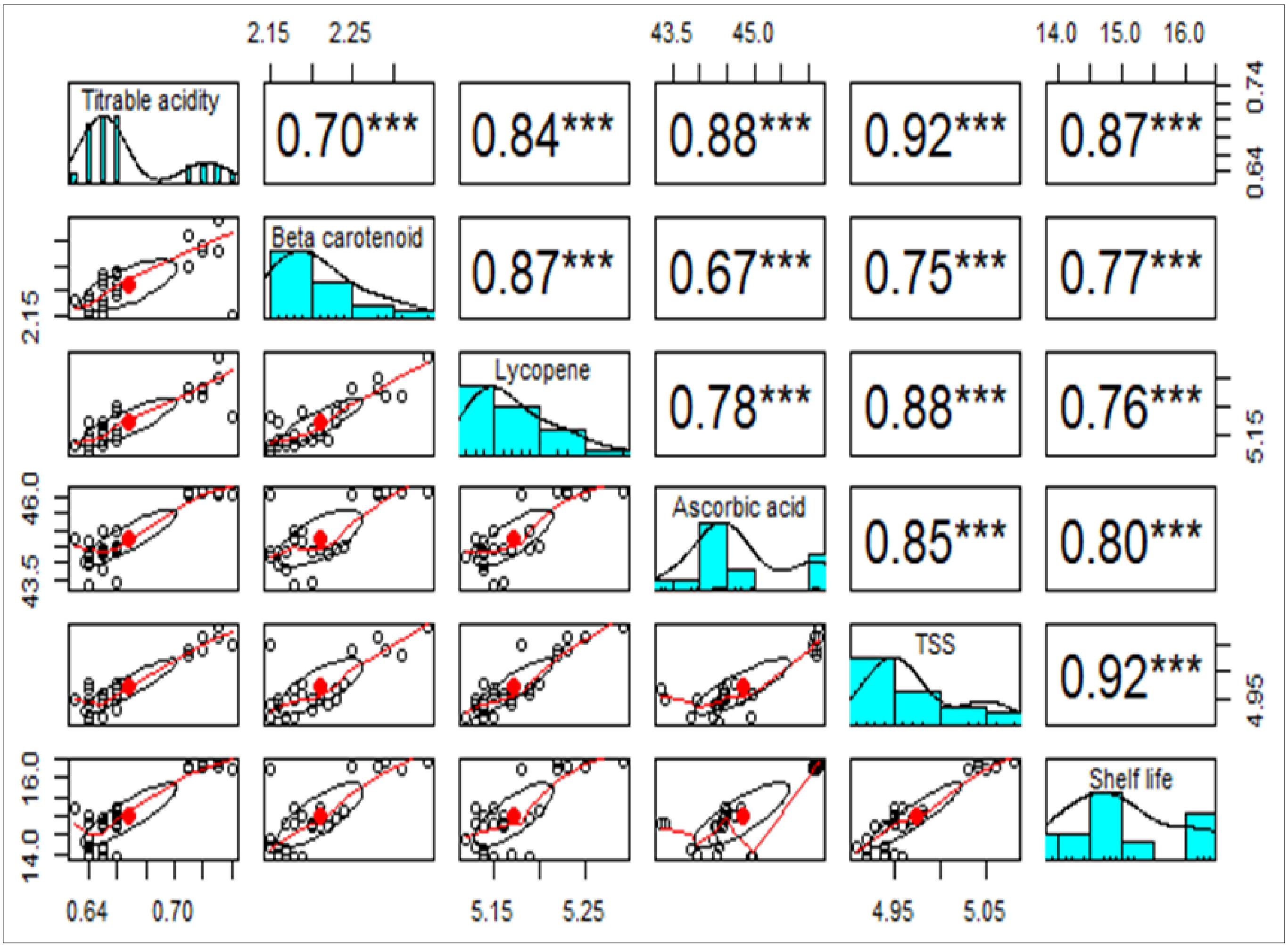

Fig. 3. Multiple correlations among tomato fruit quality characters.

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Authors contributions

PJ, RS, PM, AS, and AR conceived, designed, coordinated the experiments, and corrected the manuscript. YP carried out the experiment, analyzed the data, and wrote the draft manuscript. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors have no conflict of interest to declare.

Ethical issues: None.

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