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Integration of Mineral Fertilizer with Organic Fertilizer for Improved Tomato Fruit Yield and Quality

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Abstract

This study aimed to evaluate the effects of chemical and organic fertilizers in different fertilization regimes on vegetative growth, fruit yield, and fruit quality of tomatoes. The experiment was arranged in a randomized complete block design with three replications in the winter season of 2021. The treatments were: no fertilizers, application of NPK fertilizer (15-15-15) at a rate of 1000 kg ha^{-1}, application of chicken manure at a rate of 12 tons ha^{-1}, and three treatments of the combination of NPK fertilizer and chicken manure at the ratios of 70:30, 50:50, and 30:70, respectively. The results indicated that the combination of chemical and organic fertilizers led to improved vegetative plant growth. Combining 70% of NPK fertilizer with 30% of chicken manure gave the maximum fruit yield component values and fruit yield of tomatoes. Adding chicken manure to the fertilization regimes also led to better fruit quality. The integrated fertilization increased the TSS and vitamin C values, and when 50-70% of the chemical fertilizers were substituted with chicken manure, the sugar content and total acid increased in the fruits. The color at the red stage was more intense in tomato fruits treated with the NPK fertilizer and integrated fertilization regimes compared to those from organic fertilization.

Keywords

Tomato, integrated nutrient management, organic fertilizer, tomato fruit quality, tomato fruit color

Introduction

Nutrient and fertilizer management has played an important role in providing sufficient and nutritious food for the continually growing human population as well as sustaining environmental quality (Ishfaq *et al.*, 2023). Nutrient management means managing all possible nutrient sources, including chemical fertilizers, organic

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manures and waste materials suitable for recycling nutrients, and biofertilizers, in such a way that crop yield is maintained sustainably to meet human demands, and to enhance the quality of land and water resources (Singh & Singh, 2001). Inorganic fertilizers improve crop yield and productivity, but their long-term use poses negative effects on soil health and the environment (Sarwar *et al.*, 2021). On the other hand, Islam *et al.* (2017) reported that the continuous application of organic sources improves crop performance as well as soil organic matter and soil quality. However, organic fertilizers act as slow-release fertilizers with lower contents of nutrients, which can cause to insufficient crop nutrient requirements during the growing period (Shaji *et al.*, 2021). Therefore, organic farming cannot increase crop yield within short time periods as compared to chemical fertilizers (Islam *et al.*, 2017; Sarwar *et al.*, 2021). Nowadays, integrated nutrient management is considered to be a sustainable option to improve soil health and crop yields (Ishfaq *et al.*, 2023).

An integrated nutrient management system is characterized by a combination of synthetic and organic fertilizers, and has been revealed to be responsible for higher crop yields and reduced fertilizer pollution (Mamia *et al.*, 2018). Many studies have shown that mixing fertilizer applications leads to an enhanced efficiency of chemical fertilizers by reducing nutrient losses and, maintaining soil nutrient balance, which results in an increase of crop growth, yield attributes, and yield as compared with using inorganic or organic fertilizer alone (Mamia *et al.*, 2018; Ghosh *et al.*, 2022). Besides, combining organic with inorganic fertilizers often leads to soil improvement through increased soil organic matter content, improved soil structure, water holding capacity, and nutrient cycling, and helps maintain the soil nutrients status, cation exchange capacity, and soil biological activity (Islam *et al.*, 2017; Liu *et al.*, 2021). Ghosh *et al.* (2022) showed that combining organic manures with chemical fertilizer effectively inhibited nutrient removal, which significantly enhanced rice yield by 10% along with a 3-7% higher nutrient uptake. Khan *et al.* (2017) concluded that maximum yield components and fruit yield, and the best NPK uptake by tomato plants were obtained under a full dose of chemical fertilizers alongside the application of compost. Ndengu *et al.* (2022) showed that bush bean yields could be enhanced by the combined application of organic and inorganic fertilizers in intercropped maize and beans. According to Mahmood *et al.* (2017), the growth and yield of maize were substantially improved by chemical fertilizer application alongside organic manures whereas soil total organic C and total NPK contents increased when inorganic fertilizers were applied alone or in combination with organic manures.

Tomato (*Lycopersicon esculentum* Mill.) constitutes one of the most valuable horticultural crops, not only because of its economic importance, but also for its sensory qualities and nutritional value. Tomato fruits are rich in vitamins, minerals, and protein, and contain many organic acids and major antioxidants such as lycopene, phenolics, and vitamin C (Ali *et al.*, 2021). The worldwide tomato production and planting area reached 189.28 million tons and 5.05 million hectares, respectively in 2021 (FAOSTAT, 2021). In Vietnam, in 2019, the planting area of tomatoes was 23.791 thousand ha, with a productivity of 673,194.5 tons, and the average fresh fruit yield was 28.3 tons ha^{-1} (Doan *et al.*, 2021), which was still low as compared to the world average (36.42 tons ha^{-1}, according to FAOSTAT (2019)). Soil fertility degradation in Vietnam caused by overuse and low use efficiency of chemical fertilizers has been considered as one of the most probable reasons associated with decreased crop yields and quality. According to Cassou *et al.* (2017), annually, Vietnam uses approximately 11 million tons of fertilizers, of which inorganic fertilizers account for 90%. However, fertilizer use efficiency is very low, around 30-45% for nitrogen, 15-25% for phosphorus, and 40-50% for potassium (Tran *et al.*, 2012). Therefore, poor soil fertility with low organic matter needs much attention for sustainable crop production, and integrated nutrient management is essential for the existing and prospective cropping systems in Vietnam.

Keeping all these aspects in consideration, the present study was therefore conducted to evaluate the effects of organic and inorganic fertilizers alone and their integration on tomato vegetative growth, fruit yield, and quality.

Materials and Methods

Treatments and experimental design

The field experiment with tomato variety F1 Pear was conducted in the winter-spring season, from October 2021 to February 2022, at the experimental site of the Faculty of Agronomy, Vietnam National University of Agriculture (Hanoi, Vietnam). The soil before the experiment was found to be neutral soil (pH = 6.63, TCVN 5979:2007) containing 2.31% of organic matter (OM) (TCVN 8941:2011), 0.13% of total N (TCVN 6498:1999), 3.86mg/100g of soil of available nitrogen (TCVN 5255:2009), 16.84 mg/100 g of soil of exchangeable P_2O_5 (TCVN 8942:2011), and 8.62 mg/100 g of soil of exchangeable K_2O (TCVN 8662:2011). The fertilizers used in the experiment were a compound chemical fertilizer with an N-P-K ratio of 15-15-15, and chicken manure (CM) with the nutrient characteristics of OM = 33.95% (TCVN 9294:2012), 1.25% of total N (TCVN 8557:2012), 0.52% of total P_2O_5 (TCVN 8562:2010), and 0.63% of total K_2O (TCVN 8562:2010).

The field experiment was laid out in a randomized complete block design (RBCD) with three replications. The treatments were as follows: C – control (without fertilization); NPK_{100} – application of NPK fertilizer at the rate of 1000 kg ha^{-1}; CM_{100} – application of chicken manure at the rate of 12 tons ha^{-1}; $NPK_{70}CM_{30}$ – combination of 70% NPK fertilizer with 30% CM; $NPK_{50}CM_{50}$ – combination of 50% NPK fertilizer with 50% CM; and $NPK_{30}CM_{70}$ - combination of 30% NPK fertilizer with 70% CM. The rates of application of the chemical fertilizer and CM in the fertilized treatments were determined based on the principle that the total applied N to the soil was equal to 150 kg N ha^{-1}.

The chemical fertilizer was applied four times: 50% before transplanting, 20% at the first top dressing (7 days after transplanting - DAT), 15% at the first flowering stage, and 15% at the first harvest. The CM was fully applied to the soil surface one week before transplanting.

The dimensions of the individual treatment plots were 5m x 1.2m. Twenty-five-day-old seedlings of tomato (Cv. Pear F1) were transplanted at a 60 x 45 cm spacing. Recommended cultural practices such as irrigation, removal of weeds, and plant protection were adopted uniformly according to standard crop management procedures. Weeds were manually controlled.

Growth and development characteristics

Five randomly selected plants in each plot were used to measure the growth indicators (plant height and number of leaves) at two-week intervals after planting until the last harvest.

The yield components (the number of fruits per plant, average fruit weight, and fruit weight per plant) were observed on five randomly selected plants in each plot, and fruit yield was measured by weighing the total number of harvested fruits of all the plants in each plot.

Thirty marketable fruits were sampled randomly from the harvest of each plot to determine the fruit size (fruit height and fruit diameter). Then, these fruit samples were dried in an oven at 105°C to a constant weight to determine the fruit dry weight. Another group of 20 ripe tomatoes was harvested in each plot and analyzed for the following parameters: the total soluble solids (TSS) (using hand refractometer), sugar content (the Anthrone method), vitamin C (the Iodine Titration method), and acidity (the titration method).

Fruit surface color measurements (L*, a*, b*) were performed with a Colorimeter KONICA MINOLTA model CR – 400 (Japan). Therein, L*, a*, and b* represent the three axes of the CIELAB color space, with L* representing lightness from black to white, a* showing the fruit redness from green (negative value) to red (positive value), and b* showing the yellowness of fruits from blue (negative value) to yellow (positive value) (Camelo & Gómez, 2004).

Color indices were computed by the following formulas according to Bilalis *et al.* (2018):

The color index (CI) shows a high correlation with the external visual color of the fruits and was calculated with the following equation: $CI = 1000a^*L^{*-1}b^{*-1}$

The hue angle (h^o), the qualitative attribute of color, is used to define the difference between a certain color and a grey color with the same lightness and was calculated with the following equation: $h^o = \tan^{-1}(b^*/a^*)$

Chrome (C*) represents the color saturation and was determined using the equation:

$C^* = (a^{*2} + b^{*2})^{0,5}$

Color difference with true red (DE) relates to the true red color and was determined using the following equation:

$DE = ((L^*-50)^2 + (a^*-60)^2 + b^{*2})^{0.5}$

The a*/b* ratio can be used to report the brightness of the red color of the tomato fruit and its products.

Statistical analysis

Data were compared among treatments using a one-way analysis of variance. Then, the treatment means were subjected to pairwise comparisons with Duncan's multiple range test using SPSS software version 20. Differences were considered statistically significant at $P < 0.05$.

Results

The effect of different fertilizer regimes on the plant growth characteristics

From the results observed, the growth indicators of the tomato plants were significantly affected by the different fertilization treatments at all measured times (**Figure 1**). The lowest plant height and number of leaves were observed under the no-fertilization treatment during the growth period of tomato plants. The combined application of organic and inorganic fertilizers produced taller plants than that of the sole application of inorganic fertilizer (NPK_{100}). From 63 DAP onwards, the plant height in plots treated with CM_{100} was statistically lower than those in plots treated with NPK_{100} or combined fertilization. For the number of leaves, there were no significant differences between the integrated fertilization with NPK_{100}, or between the integrated fertilization with CM_{100}. At the final harvest, the highest numbers of leaves were found in plants treated with NPK_{100} and $NPK_{70}CM_{30}$, which were significantly higher than those treated with CM_{100}.

The better plant growth under the combination of organic and inorganic fertilizers was probably due to the fact that in the plots treated with NPK combined with CM, tomato plants initially could use the available nutrients from the chemical fertilizer and then the available nutrients from the CM were released through the mineralization process and combined with the soil nutrients to support plant growth. Ma *et al.* (2022) revealed that the application of CM to the soil led to the increase of microbiota and their activities in the soil, which consequently improved the availability and uptake of N and P, and released plant-promoting substances, resulting in better plant vegetative growth. Mengistu *et al.* (2017) reported dramatically higher plant height and number of leaves of tomato in plots treated with combined fertilization compared to the sole addition of chemical or organic fertilizers. In addition, Laxmi *et al.* (2015) revealed the highest plant height of tomato was under a combination of 50% organic and 50% inorganic fertilizers, which was related to the improved soil fertility and adequate nutrient supply to the plants. The shortest tomato plant height was recorded in the control plots, which was due to the non-availability of nutrients (Laxmi *et al.*, 2015; Mengistu *et al.*, 2017).

The effects of different fertilizer regimes on the yield attributes and fruit yield of tomato

The effect of different fertilization regimes on the number of fruits and fruit characteristics is shown in **Table 1**. Fertilizer application resulted in dramatically higher numbers of fruits as compared to the control treatment. Higher applications of NPK led to increased numbers of fruits on tomato plants, therein the best value was achieved under $NPK_{50}CM_{50}$, which was not significantly different from NPK_{100} and $NPK_{70}CM_{30}$. On the other hand, high-rate applications of organic fertilizer (CM_{100} or $NPK_{30}CM_{70}$) drastically decreased the number of

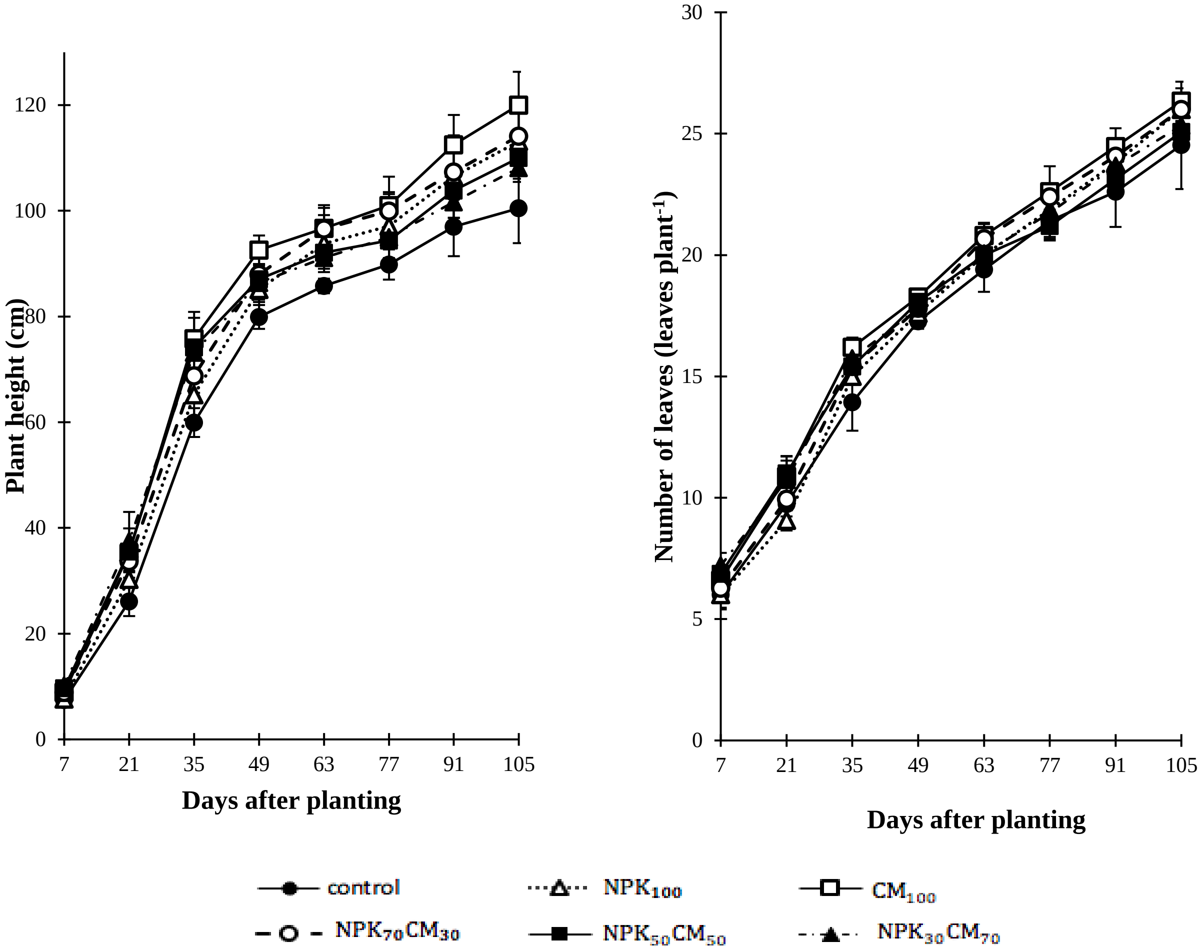


Figure 1. Influence of different fertilizer regimes on the growth indicators of tomato

Table 1. Effect of different fertilizer regimes on tomato fruit characteristics and yield attributes

Treatments	Number of fruits (fruits plant^{-1})	Fruit weight (g fruit^{-1})	Fruit characteristics			
			Fruit height (cm)	Fruit diameter (cm)	Fruit dry weight (g fruit^{-1})	Fruit dry matter (%)
Control	14.80^{d}	68.58^{b}	6.04	4.83^{b}	2.30^{c}	3.12
NPK_{100}	23.67^{ab}	75.13^{ab}	6.24	5.17^{a}	2.94^{ab}	3.24
$NPK_{70}CM_{30}$	22.53^{abc}	77.36^{a}	6.18	5.10^{a}	2.63^{bc}	3.55
$NPK_{50}CM_{50}$	25.33^{a}	76.39^{ab}	6.14	4.94^{ab}	3.11^{a}	3.65
$NPK_{30}CM_{70}$	19.67^{c}	76.62^{ab}	6.07	4.96^{ab}	2.98^{ab}	3.76
CM_{100}	19.13^{c}	73.98^{ab}	6.14	4.96^{ab}	2.64^{bc}	3.37
Sig.	*	*	ns	*	*	-
CV(%)	18.17	4.31	1.09	2.22	7.89	-

Note: *Significant at the 5% level. ^{ns} non-significant; In a column, figures with same letter or without a letter did not differ significantly whereas figures with dissimilar letters differed significantly.

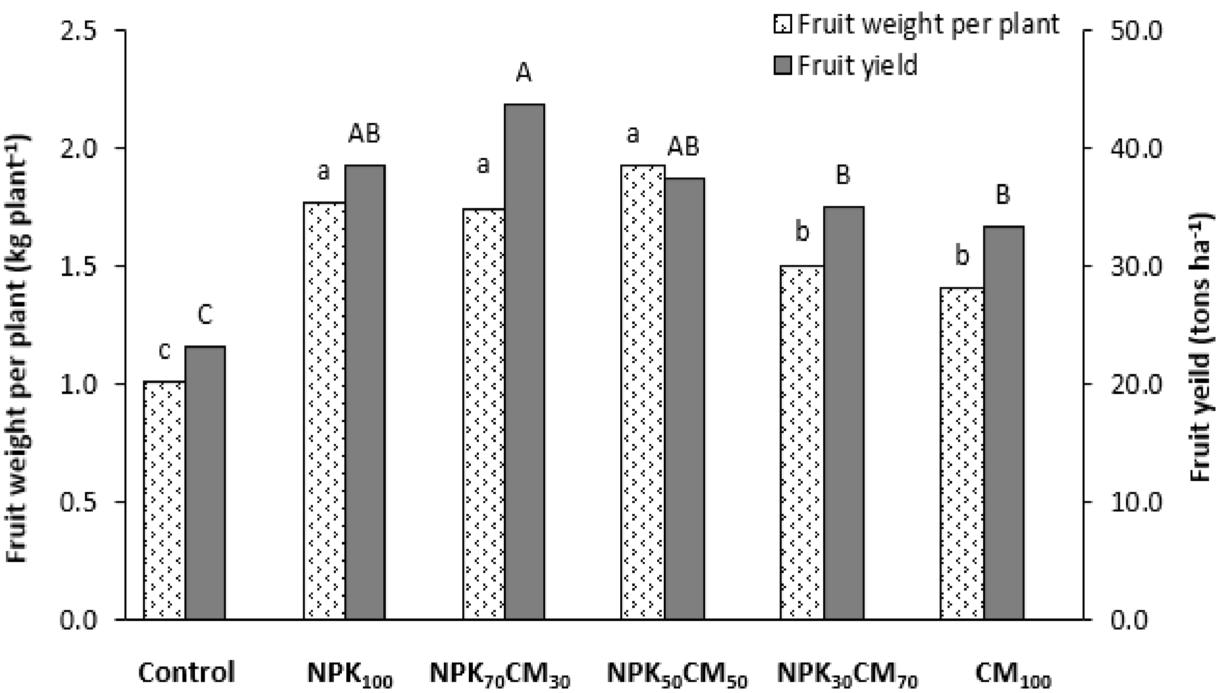
fruits compared with the combined fertilization treatments and the NPK_{100} treatment. There were no statistical differences of fruit weights among the fertilized treatments, but the fruits treated with $NPK_{70}CM_{30}$ had a significantly higher weight than those in the control treatment.

The different fertilizer regimes statistically influenced the fruit characteristics, except fruit height. The NPK_{100} and $NPK_{70}CM_{30}$ treatments gave the widest fruits, which were significantly wider compared to the control. Fruit dry weights were higher under $NPK_{50}CM_{50}$ and $NPK_{30}CM_{70}$, which were comparable with NPK_{100}. Fruit dry matter increased in plots treated with fertilizers, and was higher under integrated fertilization.

Fruit weight per plant and total fruit yield of tomato under the different fertilization methods are shown in **Figure 2**. The results reported that these indicators were statistically lower in the control plots. The treatments $NPK_{70}CM_{30}$ and $NPK_{50}CM_{50}$ gave comparable fruit weights per plant with NPK_{100}, and were statistically higher than the other treatments. The best fruit yield was reached under the $NPK_{70}CM_{30}$ application, which was slightly higher than NPK_{100} and $NPK_{50}CM_{50}$, and significantly higher than the other treatments. The applications of $NPK_{30}CM_{70}$ and CM_{100} decreased the yield components and fruit yield of tomato, and no differences were found between them.

The lowest tomato yield under control treatment was due to the insufficient available nutrients in the untreated plots, especially at the flowering and fruit setting stages. In addition, the results showed that the high-rate substitution of CM in the fertilized treatments led to lower fruit yield and yield components. This was probably related to the slow mineralization rate of organic matter in CM that led to limited available nutrients, mainly N, to meet the plants' needs, so crop yield could not be increased in a short period as compared to NPK. Islam *et al.* (2017) and Mengistu *et al.* (2017) revealed statistically higher tomato fruit yields under fertilized treatments compared to the no-fertilizer treatment, despite the fact that nutrients from organic fertilizer were not sufficient to support a high yield compared to chemical fertilizer or integrated fertilization. These were in agreement with Wu *et al.* (2022), who showed that soil treated with cow manure without the addition of NPK did not achieve good tomato quality or yield.

On the other hand, in this study, integrated fertilization was recorded as an effective way to enhance yield components and fruit yield.



Note: Means of each bar followed by the same lowercase letters (fruit weight per plant) or uppercase letters (fruit yield) are not significantly different at the 5% probability level by Duncan's multiple range test.

Figure 2. Effect of different fertilizer regimes on fruit weight per plant and fruit yield of tomato

Previous studies observed better fruit size and fruit weight (Mengistu *et al.*, 2017), fruit dry matter (Khan *et al.*, 2017; Mengistu *et al.*, 2017), and number of fruits and fruit yield (Mengistu *et al.*, 2017) in tomato grown under the integrated use of organic and NPK fertilizers than those treated with a sole application of NPK or compost. Islam *et al.* (2017) reported the highest fruit size and fruit yield in plots treated with the combined application of two-thirds organic fertilizer and one-third inorganic fertilizer. Howlader *et al.* (2019) concluded that only 75% of the recommended fertilizer could be used in combination with organic fertilizers for tomato production. Wu *et al.* (2022) found that the optimal organic-inorganic fertilizer treatment was 25% cow manure and 75% inorganic fertilizer, which significantly increased tomato yield by 245%.

Integrated use of NPK fertilizers with organic fertilizers, apart from providing balanced nutrients for plants, also increased the soil organic matter content and the quantity and diversity of soil microbes (Yang *et al.*, 2020), inhibited nutrient removal (Ghosh *et al.*, 2022), and improved nutrient use efficiency and nutrient absorption capacity (Mengistu *et al.*, 2017; Ghosh *et al.*, 2022). These resulted in vigorous vegetative plant growth and a higher photosynthetically active area (**Figure 1**), consequently leading to better fruit sizes and higher dry matter accumulation in fruits (**Table 2**), and subsequently contributing to higher fruit yield and quality indicators. According to Wu *et al.* (2022), the addition of chemical fertilizer could not maintain a high crop yield over time because of remarkable soil degradation. Therefore, integrated nutrient management has been adopted because of its ability to conserve and improve soil fertility and enhance crop performance over individual nutrient sources (Mengistu *et al.*, 2017).

The effect of different fertilizer regimes on the fruit characteristics and quality of tomato

The fruit quality indicators of the F1 Pear tomato variety under different fertilization regimes of chemical and organic fertilizer are presented in **Table 2**.

The results showed that the effects of the treatments on the fruit quality indicators were statistically significant at the 5% level of probability, except for the TSS values. Therein, the lowest fruit quality indicators were recorded under the control treatment. The total acid in fruits was highest (0.32 mg $100g^{-1}$) under $NPK_{30}CM_{70}$, which was comparable with NPK_{100}, and statistically higher than the rest of the treatments. The sugar content was higher when the rates of CM were increased in the fertilization treatments; therein the best was achieved in fruits treated with $NPK_{30}CM_{70}$ (0.39%), which was comparable with $NPK_{50}CM_{50}$ (0.33%) and statistically higher than the rest of the treatments. Integrated use of NPK and CM increased vitamin C content in fruits, and $NPK_{70}CM_{30}$ gave fruits with the best vitamin C (37.15 mg%), which was significantly higher than those treated with NPK_{100} or CM_{100}.

Table 2. Effect of different fertilizer regimes on tomato fruit quality

Treatments	TSS (°Brix)	Total acid (mg $100g^{-1}$)	Sugar content (%)	Vitamin C content (mg %)
Control	4.79	0.23^{c}	0.24^{d}	30.74^{c}
NPK_{100}	4.77	0.28^{ab}	0.26^{d}	31.58^{bc}
$NPK_{70}CM_{30}$	4.70	0.25^{bc}	0.29^{cd}	37.15^{a}
$NPK_{50}CM_{50}$	4.82	0.25^{bc}	0.33^{ab}	34.49^{ab}
$NPK_{30}CM_{70}$	4.94	0.32^{a}	0.39^{a}	34.04^{ab}
CK_{100}	4.84	0.24^{bc}	0.32^{bc}	33.00^{bc}
Sig.	ns	*	*	*
CV (%)	2.98	13.08	17.69	6.82

*Note: *Significant at the 5% level. ^{ns} non-significant; In a column, figures with the same letter or without a letter did not differ significantly whereas figures with dissimilar letters differed significantly.*

Although there were no differences among the treatments, the TSS values slightly increased according to the increase of CM rates in the combination fertilizer treatments, and the highest value (4.94%) was achieved under $NPK_{30}CM_{70}$ followed by CM_{100}.

The lowest quality parameters under the control were probably due to a lack of available nutrients (Khan *et al.*, 2017). In this study, tomatoes grown under fertilizer integration achieved higher quality results than chemically or organically fertilized crops. According to Wu *et al.* (2022), the application of 25% cow manure and 75% inorganic fertilizer enhanced vitamin C, TSS, and the total soluble sugar by 11.6%, 9.2%, and 9.4%, respectively, compared to the no-fertilization treatments. Chatterjee *et al.* (2013) reported better TSS, total sugars, and vitamin C in plants treated with higher amounts of organic manure combined with 75% of the recommended chemical fertilizer dose than those treated solely with chemical fertilizer. Hernández *et al.* (2014) reported that fruits grown under combined fertilization treatments showed slightly higher TSS than fruits from inorganic fertilization treatments, although a statistical difference was not found. According to Mengistu *et al.* (2017), despite both vermicompost and chemical fertilizer applications being liable to the increased TSS, vermicompost seemed to be more important than the inorganic fertilizer. Bilalis *et al.* (2018) and Petropoulos *et al.* (2020) found significantly higher TSS values in organically grown fruits than those in chemical production systems. The increase in quality indicators by applying CM to NPK was possibly related to the improvement of the availability of NPK and other micronutrients in the soil, which play a vital role in photosynthesis and the accumulation of assimilates in fruits (Laxmi *et al.*, 2015). Our results also found higher dry matter in fruits grown under integrated fertilization treatments (**Table 2**).

In terms of the acidity of tomato fruits, Murmu *et al.* (2013) indicated that this indicator was lower in the control and increased with the addition of both organic and chemical fertilizers. Petropoulos *et al.* (2020) found higher citric acid levels in the fruits of plants treated with chemical fertilizers than that of organically grown tomatoes, which was related to better nitrogen availability. Murmu *et al.* (2013) and Laxmi *et al.* (2015) showed higher acidity in tomato fruits under treatment of combining 50% chemical and 50% organic fertilizers. By contrast, Heeb *et al.* (2006) and Bilalis *et al.* (2018) reported significantly higher acidity in tomato fruits treated with compost compared to those treated with inorganic fertilizer. Chatterjee *et al.* (2013), Hernández *et al.* (2014), and Mengistu *et al.* (2017) did not find any significant differences in terms of titratable acidity in tomato juice. The variation of these results could be due to the environmental conditions and harvesting dates, which may have an impact on the organic content (Heeb *et al.*, 2006).

The effect of different fertilizer regimes on the fruit surface color of tomato fruits

Tomato fruit color is the most important external characteristic to assess ripeness and postharvest life and is a major factor in a consumer's purchase decision (Camelo & Gómez, 2004). The amount of the carotenoid lycopene, which causes the red coloration of fruits, is characterized by the a* value. ß-carotene is an orange colorant of fruits, which is measurable by b* in the CIELAB color system. The results from **Table 3** show that the CIELAB values in the tomato fruits were significantly different by fertilization treatment.

The results showed that there were no statistical differences in terms of the a* values among the experimental treatments, but the highest value was observed in $NPK_{50}CM_{50}$, followed by NPK_{100}. The highest L* and b* values were observed in fruits given the CM_{100} addition. Polat *et al.* (2010) also reported that L* and b* values in fruits treated with organic fertilizers were significantly higher compared to treatments combining organic and chemical fertilizers. Carricondo-Martínez *et al.* (2022) reported that statistically greater L* values were obtained in tomato fruits treated with organic fertilization treatments, whereas a* was the best under inorganic fertilizer additions. On the other hand, Bilalis *et al.* (2018) observed the highest L* and a* values in fruits given organic

Table 3. Effect of different fertilizer regimes on CIELAB values of tomato fruits

Treatments	CIELAB values		
	L*	a*	b*
Control	47.68^{ab}	23.96	34.02^{b}
NPK_{100}	47.54^{ab}	25.66	33.73^{b}
$NPK_{70}CM_{30}$	47.39^{ab}	23.52	31.58^{c}
$NPK_{50}CM_{50}$	47.24^{b}	26.49	33.31^{b}
$NPK_{30}CM_{70}$	47.82^{ab}	24.64	32.73^{bc}
CM_{100}	48.65^{a}	24.59	36.41^{a}
Sig.	*	ns	*
CV (%)	1.58	2.91	6.03

Note: *Significant at the 5% level. ^{ns} non-significant; In a column, figures with the same letter or without a letter did not differ significantly whereas figures with dissimilar letters differed significantly.

fertilizers, while the b* value was not significantly influenced by combining fertilizers or by chemical or organic fertilizers alone.

Regarding the color indices shown in **Table 4**, hue (h^{o}), color index (CI), color difference (DE), and the a*/b* relationships could be used as objective ripening indexes giving a realistic estimation of consumer perception. These indicators significantly differed among the fertilization regimes. There were similar trends in terms of the CI, h^{o}, and a*/b* values, and as such, the fruits treated with $NPK_{50}CM_{50}$ gave the highest values, which were statistically higher compared to the CM_{100} treatment and were on par with the other treatments. The results of the CIELAB values and color indices showed that the color at the red stage was more intense in tomato fruits treated with chemical fertilizer and the integrated fertilization regimes compared to those given just organic fertilizer. This was agreed upon in the study of Camelo & Gómez (2004), who showed that CI and a*/b* increased with higher percentages of red color. Carricondo-Martínez *et al.* (2022) observed dramatically higher CI and a*/b* in fruits treated with inorganic fertilizers compared to organic fertilizer applications. In contrast, Bilalis *et al.* (2018) observed the highest a*/b* and h^{o} in fruits treated with compost despite the absence of a significant influence between compost and conventional treatments. According to Polat *et al.* (2010), when h^{o} increased, the color changed from red to orange, and h^{o} values were found to be higher following various organic fertilizer treatments as compared with conventional treatments, but no differences were observed. In terms of DE and C*, the best values were reached in the organic production regime. Bilalis *et al.* (2018) also reported the highest C* in fruit harvested from organic plots, but there were no differences of DE among the no-fertilization, compost, and inorganic fertilizer treatments. The variations of fruit color indices in the different studies could have been due to the presence of diverse carotenoid pigment systems subject to both genetic and environmental conditions, and could also be attributed to the applied agricultural practices.

Conclusions

The yield and quality characteristics of tomato crops were affected by different fertilization regimes. Adding higher rates of chemical fertilizer with an additional application of chicken manure led to increased vegetative plant growth and fruit yield of tomatoes, with a higher fruit yield reached under the application of 700kg of NPK fertilizer (15-15-15) and 3.6 tons of chicken manure per ha. The integrated addition of fertilizers with higher rates of chicken manure led to increased sugar content, vitamin C, and TSS in tomato fruits. The red color was more intense in tomato-ripened fruits treated with the chemical fertilizer and integrated fertilization regimes. Therefore, the combination of 70%

Table 4. Effect of different fertilizer regimes on the color indices of tomato fruits

Treatments	Color indices				
	CI	h°	C*	a*/b*	DE
Control	14.77[ab]	0.15[ab]	41.6[abc]	0.70[ab]	49.65[ab]
NPK_{100}	16.00[ab]	0.26[ab]	42.38[ab]	0.76[ab]	48.21[ab]
$NPK_{70}CM_{30}$	15.73[ab]	0.23[ab]	39.39[c]	0.74[ab]	48.33[ab]
$NPK_{50}CM_{50}$	16.88[a]	0.32[a]	42.57[ab]	0.80[a]	47.34[b]
$NPK_{30}CM_{70}$	15.79[ab]	0.24[ab]	41.01[bc]	0.75[ab]	48.25[ab]
CM_{100}	13.89[b]	0.09[b]	43.94[a]	0.68[b]	50.82[a]
Sig.	*	*	*	*	*
CV (%)	6.29	10.66	2.66	7.08	3.79

*Note: *Significant at the 5% level. ns non -significant; In a column, figures with the same letter or without a letter did not differ significantly whereas figures with dissimilar letters differed significantly.*

of the recommended chemical fertilizer rate with 30% of organic fertilizer should be recommended for tomato cultivation for higher crop yield and quality.

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