Chittagong Univ. J. B. Sci. Vol. 13 (1&2): 60-67, 2025

Effects of Poultry Manure Biogas Residues and Inorganic Fertilizers on Biochemical Constituents and Nutritional Quality of Tomato (*Lycopersicon esculentum* (L.) Mill)

Md. Saiful Islam, Md. Golam Kibria and Mazharul Islam*

Department of Soil Science, University of Chittagong, Chattogram-4331, Bangladesh
*Corresponding author's email: rasenviro@cu.ac.bd

DOI: https://doi.org/10.3329/cujbs.v13i1.86245
Received: 18 September, 2025; Accepted: 29 October, 2025; Published: 15 December, 2025

Abstract

Tomato (*Lycopersicon esculentum* (L.) Mill) is globally valued for its nutritional and health-promoting properties, particularly its protein and lycopene content. However, soil fertility declines and excessive dependence on inorganic fertilizers threaten both yield and fruit quality. Poultry manure biogas residue (PMBR), a stabilized organic amendment, offers a sustainable alternative, though its biochemical effects on tomatoes are not well understood. A field experiment was conducted at the University of Chittagong, Bangladesh, using a randomized complete block design with six treatments and three replicates, assessed the impact of PMBR, NPK, and their combinations on biochemical constituents (protein and lycopene) and nutritional quality of tomato. Sole PMBR (20 t ha^{-1}) markedly improved fruit quality, increasing protein by 57% (11.92 vs. 7.58%) and lycopene by 118% (52.03 vs. 23.82 mg kg^{-1}) over the control. Integrated treatments produced intermediate values, with decreasing PMBR and increasing NPK ratios, reducing protein and lycopene relative to sole PMBR. PMBR enhanced N, P, and Fe concentrations, indicating its potential for sustainable fertility management, improved tomato nutrition, and reduced chemical fertilizer dependence.

***Keywords**:* Tomato, poultry manure biogas residue, inorganic fertilizer, biochemical constituents, nutritional quality.

Introduction

Tomato (*Lycopersicon esculentum* (L.) Mill) is one of the most widely consumed vegetables worldwide, valued for its economic importance and nutritional and health-promoting qualities[1]. In addition to being a dietary staple, tomatoes are a major source of bioactive compounds, such as lycopene, proteins, vitamins, and minerals, which collectively contribute to human health by reducing oxidative stress and lowering the risk of chronic diseases, including cardiovascular disorders and certain cancers[2]. Thus, enhancing the nutritional quality of tomatoes has become a priority in both agricultural production and food security frameworks, particularly in regions where micronutrient deficiencies remain prevalent[3].

However, agricultural soils face mounting challenges owing to declining fertility, nutrient depletion, and unsustainable fertilizer practices[4, 5]. Inorganic fertilizers (NPK) have long been the cornerstone of intensive tomato production systems[6]. Although they effectively boost yields, their overuse has been associated with soil degradation, reduced microbial activity, and declining nutrient-use efficiency over time[6, 7]. In parallel, concerns about environmental sustainability and escalating fertilizer costs have stimulated interest in alternative nutrient sources that can sustain crop productivity while enhancing nutritional quality[4].

Poultry manure biogas residues (PMBR) are a by-product of anaerobic digestion and have emerged as a promising organic amendment[8]. Rich in organic matter, residual nutrients, and microbial metabolites, PMBR not only improves soil physicochemical properties but also contributes to carbon sequestration and long-term soil fertility[9]. Compared with raw poultry manure, which often poses environmental risks due to rapid nutrient release and greenhouse gas emissions, PMBR provides a more stabilized form of nutrients, with slower release patterns and potential synergy with chemical fertilizers[10]. This makes PMBR an attractive option for sustainable crop production and circular bioeconomic models.

Despite these potential advantages, the effects of PMBR alone or in combination with NPK fertilizers on the biochemical constituents of tomato fruits, particularly protein and lycopene content, remain insufficiently explored. While several studies have documented the role of organic and inorganic fertilizers in enhancing tomato yield and fruit size, fewer have systematically investigated their impact on nutritional quality parameters[11]. Protein content reflects the nutritional value of tomatoes and the efficiency of nitrogen assimilation, which may be strongly influenced by the balance of organic and inorganic nutrient inputs[11, 12]. Similarly, lycopene, a carotenoid pigment with strong antioxidant properties, is affected by both soil nutrient dynamics and plant metabolic pathways, yet the specific contributions of PMBR and NPK interactions remain poorly understood[11, 13].

The knowledge gap lies in understanding how integrated fertilization strategies influence not only the yield but also the nutrient density and bioactive profile of tomatoes. While research on soil fertility management has largely focused on crop productivity, there is an urgent need to extend this focus toward nutritional quality, aligning agricultural practices with the dual goals of food security and improved human health.

This study was designed to address this gap by systematically examining the effects of poultry manure biogas residues, NPK fertilizers, and their combinations on the biochemical constituents and nutritional quality of tomato fruits.

Materials and Methods

Experimental Site and Design

The experiment was conducted at the Department of Soil Science Research Field at the University of Chittagong, Bangladesh. The study followed a randomized complete block design (RCBD) with three replicates for six treatments. Treatments included poultry manure biogas residues (PMBR), inorganic NPK fertilizer, their integrated application, and an untreated control.

Soil sampling and PMBR Preparation and Characterization

The experimental soil was collected from the surface at 0–15 cm depths from the experimental field, where poultry manure biogas residue was collected from a local anaerobic digestion plant. The soil and residues were air-dried, homogenized, and sieved (2 mm mesh). Baseline soil and poultry manure biogas residue properties were determined using standard protocols[14, 15]. The physical and chemical properties of the soil and PMBR on a dry weight basis are presented in Table 1.

Table 1. Physical and chemical properties of the experimental soil and the collected PMBR.

Properties	Soil	PMBR
Sand (%)	52.42	-
Silt (%)	31.67	-
Clay (%)	15.92	-
Texture	Sandy loam	-
Organic carbon (%)	0.23	10.08
pH	4.85	7.13
EC (µs cm^{-1})	35.2	828
Total N (%)	0.1	1.22
Total P (%)	0.05	3.09
Total K (%)	0.43	0.08
Total Ca (%)	0.27	4.13
Total Mg (%)	0.07	0.29
Total Na (%)	0.18	0.45
Total Fe (%)	0.410	0.32
Total Zn (%)	0.021	0.12

Fertilizer and Treatments

Six treatments were established, consisting of poultry manure biogas residue (PMBR) in combination with inorganic fertilizers (Table 2). Inorganic fertilizer treatments were based on the recommended NPK fertilizer dose for tomatoes (135:45:75 kg ha^{-1})[16]. Treatments are:

Table 2. Treatments conducted in the field experiment

Treatments	Nature of Treatments
T_1	Control
T_2	100% RDF@ 135kg N ha^{-1}, 45 kg P ha^{-1} and 75 kg K ha^{-1}
T_3	20 ton ha^{-1} Poultry manure biogas residues (PMBR)
T_4	15 ton ha^{-1} PMBR + 25% RDF
T_5	10 ton ha^{-1} PMBR + 50% RDF
T_6	5 ton ha^{-1} PMBR + 75% RDF

where,

100% RDF= Recommended dose of NPK fertilizer (135kg N ha^{-1}+45kg P ha^{-1}+75kg K ha^{-1}) for tomato

25% RDF = 33.75 kg N ha^{-1}+ 11.25 kg P ha^{-1}+ 18.75 kg K ha^{-1}

50% RDF = 67.5 kg N ha^{-1}+ 22.5 kg P ha^{-1} + 37.5 kg K ha^{-1}

75% RDF = 101.25 kg N ha^{-1}+ 33.75 kg P ha^{-1} + 56.25 kg K ha^{-1}

Nitrogen and potassium fertilizers, supplied as urea and muriate of potash (MP), were applied in two equal splits at 15 and 35 days after transplantation.

Both applications were considered as basal doses. In contrast, the entire amount of phosphorus, provided as triple superphosphate (TSP), was incorporated into the soil during the first split at the time of final land preparation.

Tomato Cultivation

Tomato (*Lycopersicon esculentum* L. Mill [BARI-14]) seedlings were raised in nursery trays and transplanted at the four-leaf stage (30 days old). Each unit plot was 1m × 1m (1 m^2) in size and separated by 0.5 m wide furrows. Four healthy seedlings were established at the four corners of each unit plot, maintaining an equal distance (75 cm) between the seedlings[17]. The soil moisture was maintained at 70% field capacity through regular irrigation. Cultural practices, including weeding and pest management, were performed as needed.

Growth Duration and Sampling

Plants were maintained until physiological maturity, approximately 120 days. Fully ripe fruits (red stage) were harvested at different intervals time at days after transplanting (DAT) for biochemical and nutritional analyses. At each sampling, five fruits per plant per replicate were collected, homogenized, and stored for subsequent analysis.

Biochemical Constituents and Nutritional Quality Analyses

Lycopene Content

The lycopene content was determined using spectrophotometer as described by Alda *et al.* [18] Lycopene in the fresh and dried tomato samples was extracted by adding 8.0 ml of a mixture of hexane–acetone–ethanol (2:1:1, v/v/v) wrapped in aluminum foil to exclude light. The tubes were capped, mixed in a vortex mixture immediately, and then incubated in the absence of bright light. The mixture was extracted at room temperature for 30 min. The extract was reconstituted in 10 ml distilled water using a vortex mixer for 1 min. The samples were allowed to stand for 10 min to allow the phases to separate and all air bubbles to disappear. The cuvette was rinsed with the upper layer from one of the blank samples, and hexane was used as a blank to zero at 503 nm to determine the A_{503} of the upper layers of the lycopene samples. Lycopene levels in the hexane extracts were calculated as follows[18]:

$$\text{Lycopene (mg kg}^{-1}\text{ fresh wt.)} = (A_{503} \times 537 \times 8 \times 0.55)/(0.10 \times 172)$$

where the molecular weight of lycopene = 537 g/mole, the volume of mixed solvent = 8 ml, the volume ratio of the upper layer to the mixed solvent = 0.55, the weight of added tomato = 1.0 g, the extinction coefficient for lycopene in hexane = 172 mM^{-1}, and the absorbance of the spectrophotometer at 503 nm = A_{503}.

Protein Content and Nutritional Quality

Oven-dried (65° C constant weights) and ground ripe fruit samples were digested with sulfuric-peroxide mixture[19]. The digestion mixture was prepared by mixing 0.42 g selenium (Se) powder and 14 g lithium sulfate ($LiSO_4.H_2O$), 350 ml of H_2O_2, and finally 420 ml of conc. H_2SO_4. Dried fruit samples were digested with a digestion mixture in a 1:11 ratio until a transparent solution was obtained to determine the total nitrogen (N), phosphorous (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn) content in the fruit tissues. The micro-Kjeldahl method, as described by Jackson[15], was used to determine nitrogen content. The total nitrogen content was expressed as a percentage of the dry weight.

$$\%\text{ of Total Nitrogen (TN)} = \frac{(T-B) \times f \times 0.014 \times 100ml\ volume \times 100}{w \times volume\ of\ extract\ used}$$

where T = Sample titration value (mL) of standard H_2SO_4; B = Blank titration value (mL)of standard H_2SO_4; f = is the strength of H_2SO_4; W = Weight of the tomato in grams.

The protein content was estimated by multiplying the total nitrogen values by a conventional factor of 6.25, assuming that nitrogen constitutes approximately 16% of plant protein. The percentage of protein content was calculated using the following formula on a dry weight basis[20].

Protein % = % of Nitrogen × 6.25 (conversion factor)

Phosphorus was determined by vanadomloybdate yellow color method[15], and potassium, sodium, calcium, magnesium, iron and zinc were determined with an atomic absorption spectrophotometer (Agilent Technologies 200 Series AA)[15].

Statistical Analysis

The significance of differences among the means of the treatments were evaluated by one-way Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at the significance level of 5%. Statistical analyses were performed using Excel and

SPSS version 20. All data were carefully examined for accuracy and consistency prior to statistical analysis.

Results and Discussion

Biochemical constituents

The protein content of tomatoes significantly ranged between 7.58% and 11.92% (Table 3) among the treatments. The highest protein content of tomato was found in treatment T_3 (20 t ha^{-1} PMBR), and the lowest protein content was observed in control treatment T_1. The protein content of tomatoes was not significantly affected by the application of 100% RDF (T2) compared to the control treatment (T_1). The protein content of tomato in treatments T_3 (11.92 %), T_4 (11.60 %), T_5 (10.54 %), and T_6 (10.21 %) were significantly higher than that in the control (T_1). The combination of decreasing PMBR with increasing amount of RDF showed relatively lower protein content in T_4 (15 t ha^{-1} PMBR+ 25% RDF), T_5 (10 t ha^{-1} PMBR+ 50% RDF), and T_6 (5 t ha^{-1} PMBR+ 75% RDF) treatments compared to treatment T_3. However, treatments T_3, T_4, T_5, and T_6 were statistically similar to each other in terms of protein production in tomatoes.

Table 3. Protein and Lycopene content of tomato as affected by different treatments.

Treatments	Protein (%)	Lycopene (mg kg^{-1})
T_1	7.58 c	23.82 d
T_2	8.11 bc	26.08 cd
T_3	11.92 a	52.03 a
T_4	11.60 a	43.33 ab
T_5	10.54 a	34.85 bc
T_6	10.21 ab	30.23 cd

Mean values within a column followed by the same letter(s) are not significantly different by DMRT ($P \leq 0.05$).

The lycopene content in tomatoes grown in this experiment ranged from 23.82 to 52.03 mg kg^{-1} (Table 3). The highest lycopene content in tomatoes was found in treatment T_3, where poultry manure biogas residues were applied at 20 t ha^{-1}, and the lowest level of lycopene was observed in the control treatment T_1. The application of 100% RDF did not affect the lycopene content in tomatoes compared to that in the control. A similar result was found with the addition of poultry manure biogas residues @ 5 t h^{-1} mixed with 75% RDF (30.23 mg kg^{-1}; T_6). The lycopene content in tomatoes with the addition of 20 t ha^{-1} PMBR (52.03 mg kg^{-1}; T_3), 15 t ha^{-1} PMBR+25% RDF (43.33 mg kg^{-1}; T_4), and 10 t ha^{-1} PMBR+50% RDF (34.85 mg kg^{-1}; T_5) were significantly higher than that in the control (T_1). The combination of decreasing poultry manure biogas residues (PMBR) with increasing amounts of RDF showed relatively lower lycopene content in the T_4, T_5, and T_6 treatments compared to treatment T_3.

Nutritional quality

Nitrogen concentration

The nitrogen concentration in tomato fruit varied significantly from 1.21% to 1.91% among the treatments in this study (Table 4). The highest concentration of nitrogen was found in treatment T_3, where poultry manure biogas residues (PMBR) @ 20 t ha^{-1} was applied, and the lowest concentration of nitrogen was observed in treatment T_1 (control). The application of 100% RDF showed results similar to of those control treatment. The N concentrations in treatment T_3 (1.91 %), T_4 (1.86 %), T_5 (1.69 %), T_6 (1.63 %) were significantly higher compared with control treatment T1. The combination of decreasing poultry manure biogas with increasing amount of RDF showed relatively lower concentration of N in T_4 (15 t ha^{-1} PMBR+ 25% RDF), T_5 (10 t ha^{-1} PMBR+ 50% RDF) and T_6 (5 t ha^{-1} PMBR+ 75% RDF) treatments compared to treatment T_3. However, the nitrogen concentration in treatments T_3, T_4, T_5 and T_6 were statistically similar with each other.

Phosphorus concentration

The phosphorus concentration in tomato fruit under this study ranged from 0.12 % in the treatment T_1 (control) to 0.28% in the treatment T_5 (Table 4). Application of 100% RDF (0.19 %, T_2) and 5 t ha^{-1} PMBR+75% RDF (0.22; T_6) did not show any significant difference compared with control (T_1) treatment. Phosphorus concentration in treatment T_3 (0.23 %, 20 t ha^{-1} PMBR), T_4 (0.24 %; 15 t ha^{-1} PMBR+ 25% RDF) and T_5 (0.28 %, 10 t ha^{-1} PMBR+ 50% RDF) were statistically similar and these treatments showed significant differences compared with control treatment T1. There was no definite trend of variation in phosphorus concentration with decreasing amounts of PMBR with increasing RDF.

Potassium concentration

Potassium concentration in tomato fruit varied from 0.97 % to 1.23% (Table 4). Potassium concentration in tomato fruit was not significantly affected by application of inorganic fertilizer and poultry manure biogas residues. However, the highest concentration of K was found in treatment T_4 (15 t ha^{-1} PMBR+25%RDF) and the lowest K concentration was found in treatment T_5 (10 t ha^{-1} PMBR+50%RDF).

Sodium concentration

Data on sodium concentration in tomato fruit under different treatments showed that it varied from 0.06% in treatment T_1 to 0.11% in treatment T_3 (Table 4). Addition of 100% RDF (0.08%; T_2), 20 t ha^{-1} poultry manure biogas residues (0.11%; T_3), 15 t ha^{-1} PMBR+25% RDF (0.09%; T_4), 10 t ha^{-1} PMBR+50% RDF (0.08%; T_5) and 5 t ha^{-1} PMBR+75% RDF (0.10%; T_6) showed similar concentration of Na and no significant difference was found compared with control.

Table 4. Nitrogen, Phosphorus, Potassium and Sodium content of tomato as affected by different treatments.

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Sodium (%)
T_1	1.21 c	0.12 b	1.10 a	0.06 a
T_2	1.30 bc	0.19 ab	1.07 a	0.08 a
T_3	1.91 a	0.23 a	1.10 a	0.11 a
T_4	1.86 a	0.24 a	1.23 a	0.09 a
T_5	1.69 a	0.28 a	0.97 a	0.08 a
T_6	1.63 a	0.22 ab	1.00 a	0.10 a

Mean values within a column followed by the same letter(s) are not significantly different by DMRT ($P \leq 0.05$).

Calcium concentration

Calcium concentration in tomato fruit ranged from 0.0.38% in the treatment T_3 (20 t ha^{-1} PMBR) to 0.47% in the treatment T_4 (15 t ha^{-1} PMBR+25%RDF) which is shown in Table 5. Potassium concentration in tomato fruit was not significantly affected by different treatments of poultry manure biogas residues and inorganic fertilizer.

Magnesium concentration

Magnesium concentration in tomato fruit under this study varied from 0.13 % in the treatment T_2 to 0.15% in the treatments T_1 and T_5 (Table 5). Treatments with inorganic fertilizers, poultry manure biogas residues and their combinations showed no significant differences in relation to control in treatments T_2 (0.13%; 100% RDF), T_3 (0.14%; 20t ha^{-1}PMBR), T_4(0.13%; 15t ha^{-1} PMBR+25%RDF), T_5 (0.15%; 10t ha^{-1} PMBR+50% RDF), T_6 (0.14%; 5 t ha^{-1} PMBR +75% RDF), respectively.

Iron concentration

Iron concentration in tomato fruit varied significantly from 0.043% to 0.113% among the treatments under this investigation (Table 5). The highest concentration of Fe was found in treatment T_3 where poultry manure biogas residues (PMBR) @ 20 t ha^{-1} was applied and the lowest concentration of Fe was found in treatment T_1 (control) and T_2 (100% RDF). Application of 100% RDF showed same results with control treatment. The concentrations of Fe in treatment T_3 (0.113 %; 20 t ha^{-1} PMBR), T_4 (0.097 %; 15 t ha^{-1} PMBR+25% RDF), T_5 (0.063%; 10 t ha^{-1} PMBR+50% RDF) and T_6 (0.063%; 5 t ha^{-1} PMBR+75% RDF) were significantly higher compared with control treatment T_1. However, there was no significant difference in between T_3 and T_4 and between T_5 and T_6.

Zinc concentration

Zinc concentration in tomato fruit under this study varied from 0.037 % in the treatment T_6 (5t ha^{-1} PMBR +75% RDF) to 0.077% in treatment T_1 (Control) (Table 5). Application of 10t ha^{-1} PMBR+50% RDF (T_5) and 5 t ha^{-1}PMBR +75% RDF (T_6) significantly decreased Zn concentration in tomato compared to control. Treatment T_2 (0.073%; 100% RDF), T_3 (0.073%; 20t ha^{-1} PMBR), T_4 (0.067%; 15t ha^{-1} PMBR+25% RDF) showed similar concentration of Zn in tomato and no significant difference was found compared with control.

Table 5. Calcium, Magnesium, Iron and Zinc content of tomato as affected by different treatments.

Treatments	Calcium (%)	Magnesium (%)	Iron (%)	Zinc (%)
T_1	0.45 a	0.15 a	0.043 c	0.077 a
T_2	0.45 a	0.13 a	0.043 c	0.073 a
T_3	0.38 a	0.14 a	0.113 a	0.073 a
T_4	0.47 a	0.13 a	0.097 a	0.067 a
T_5	0.39 a	0.15 a	0.063 b	0.040 b
T_6	0.42 a	0.14 a	0.063 b	0.037 b

Mean values within a column followed by the same letter(s) are not significantly different by DMRT ($P \leq 0.05$).

The findings of this study demonstrate that poultry manure biogas residues (PMBR), whether applied alone or in combination with inorganic fertilizers, enhanced the nutritional quality of tomato by increasing N, P, Fe, protein, and lycopene contents compared to the untreated control. However, when PMBR was applied at 10 t ha^{-1} and 5 t ha^{-1} in combination with 50% and 75% RDF, a reduction in Zn concentration was observed in tomato fruits. In contrast, the application of inorganic fertilizer, PMBR, or their combinations did not significantly alter K, Ca, Mg, and Na concentrations relative to the control. These results are consistent with Kibria *et al*.[21] who reported that tomato nutrient composition was largely unaffected by biogas residues or chemical fertilizers, except for nitrogen. This observation aligns with the broader understanding that while crops often respond positively to N and P in certain soils (termed "responsive soils"), they may exhibit negligible response to fertilizer inputs in "non-responsive soils"[22].

Moreover, Banik and Nandi[23] found that application of biogas residual slurry manure increased mushroom protein content by 38.3–57.0%. Similarly, Makádi *et al*.[24] reported that soybean protein levels rose significantly, from 30.65±1.42% in control plants to 34.83±1.50% and 35.67±1.81% under 5 and 10 L m^{-2} biogas slurry treatments, respectively. Wu *et al*.[25] documented that biogas slurry improved protein, Fe, Mn, Cu, and Zn content in oilseed rape, alongside enhanced yields. Further, TongGuo *et al*.[26] noted that biogas slurry applications improved both yield and quality of vegetables such as green pepper, tomato, and cucumber. Likewise, Yu *et al*.[27] highlighted biogas slurry as an affordable nutrient source that enhanced soil fertility and tomato quality, reporting notable increases in amino acids, protein, β-carotene, soluble sugars, vitamin C, and tannins under concentrated biogas slurry (CBS) treatments. However, they also observed that mean fruit weights under CT (control), BS (biogas slurry), and CBS were lower compared to CM (compound fertilizer, NPK), suggesting that while chemical fertilizers improve tomato yield, they may not confer comparable quality benefits.

Tomato is recognized as an important dietary source of nutrients and carotenoids, particularly lycopene, which is associated with antioxidant and potential anticancer properties[28]. Epidemiological studies link tomato and lycopene intake with reduced risks of several cancers, notably of the lung, stomach, and prostate, and suggest protective effects against cancers of the cervix, breast, oral cavity, pancreas, colorectal tract, and esophagus[29]. In the present study, application of 100% RDF did not significantly alter lycopene levels compared to the control, whereas lycopene content was maximized at 20 t ha^{-1} PMBR. A decreasing trend in lycopene concentration was observed when PMBR levels were reduced alongside increasing RDF. These findings support earlier studies showing greater influence of organic fertilizers than inorganic inputs on lycopene accumulation. Adeniyi and Ademoyegun[30] similarly reported maximum lycopene content at 20 t ha^{-1} poultry manure, with organic sources outperforming inorganic ones. Lumpkin[31] also observed elevated lycopene concentrations in organically grown tomato compared to those cultivated under inorganic fertilization. In line with these reports, Kibria *et al*.,[21] demonstrated that cow dung biogas residues applied at 30, 40, and 50 t ha^{-1} significantly increased tomato lycopene content relative to both the control and 100% RDF treatments.

Conclusion

This research demonstrated that poultry manure biogas residue (PMBR), alone or in combination with inorganic fertilizers, has a significant influence on the biochemical constituents and nutritional quality of tomato fruits. The findings highlight the potential of PMBR as a sustainable organic amendment capable of improving tomato nutritional value while reducing reliance on synthetic fertilizers. By contributing to soil fertility restoration and enhancing the density of health-promoting compounds such as protein and lycopene, PMBR represents a promising strategy to align agricultural productivity with human nutrition and environmental sustainability.

Acknowledgements

The authors would like to thanks Masud Krishi Complex at Patya, Chattogram for providing poultry manure biogas residues. The authors express their sincere gratitude to the Department of Soil Science, University of Chittagong for providing field and laboratory facilities for carrying out this research work.

References

1. Samaila, A., Amans, E. B., Abubakar, I. U., and Babaji, B. A. 2011. Nutritional Quality of Tomato (Lycopersicon esculentum Mill) as Influenced by Mulching, Nitrogen and Irrigation Interval. *The Journal of Agricultural Science*, **3(1**), 266. https://doi.org/10.5539/JAS.V3N1P266
2. Rasheed, H., Javed, A., Haroon, A., and Ameen, S. 2022. Bioactive Compounds in Tomatoes and Their Effects on Human Health-A Comprehensive Review. *International Journal of Cell Science and Biotechnology*, **11**(01), 27-31.
3. Ikram, N. A., Abdalla, M. A., and Mühling, K. H. 2024. Developing Iron and Iodine Enrichment in Tomato Fruits to Meet Human Nutritional Needs. *Plants*, ***13***(23), 3438. https://doi.org/10.3390/plants13233438
4. Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farooq, M., Bhatt, R., Fahad, S., and Hasanuzzaman, M. 2020. Agricultural land degradation: processes and problems undermining future food security. In *Environment, climate, plant and vegetation growth* (pp. 17-61). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-49732-3_2
5. Telo da Gama, J. 2023. The role of soils in sustainability, climate change, and ecosystem services: Challenges and opportunities. *Ecologies*, **4(3),**552-567. https://doi.org/10.3390/ecologies4030036
6. Sande, T. J., Tindwa, H. J., Alovisi, A. M. T., Shitindi, M. J., and Semoka, J. M. 2024. Enhancing sustainable crop production through integrated nutrient management: a focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilisers–a systematic review. *Frontiers in Agronomy*, **6,** 1422876. https://doi.org/10.3389/fagro.2024.1422876
7. Ireri, D. F. 2020. *Effects of inorganic fertilizer on tomato–bacterial wilt interactions in high tunnel tomato varieties* (Doctoral dissertation, JKUAT-AGRICULTURE). http://localhost/xmlui/handle/123456789/5402
8. Mozhiarasi, V., & Natarajan, T. S. 2025. Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added conversion and biorefinery, **15(2)**, 1705-1728. products. Biomass https://doi.org/10.1007/s13399-022-02352-0
9. Kumari, M., Sheoran, S., Prakash, D., Yadav, D. B., Yadav, P. K., and Jat, M. K. 2024. Long-term application of organic manures and chemical fertilizers improve the organic carbon and microbiological properties of soil under pearl millet-wheat cropping system in North-Western India. *Heliyon*, **10(3)**. https://doi.org/10.1016/j.heliyon.2024.e25333
10. Kacprzak, M., Malińska, K., Grosser, A., Sobik-Szołtysek, J., Wystalska, K., Dróżdż, D., Jasińska, A., and Meers, E. 2023. Cycles of carbon, nitrogen and phosphorus in poultry manure management technologies–environmental aspects. *Critical Reviews in Environmental Science and Technology*, **53(8)**, 914-938. https://doi.org/10.1080/10643389.2022.2096983
11. Gao, F., Li, H., Mu, X., Gao, H., Zhang, Y., Li, R., Cao, K., and Ye, L. 2023. Effects of Organic Fertilizer Application on Tomato Yield and Quality: A Meta-Analysis. *Applied Sciences*, 13(4), 2184. https://doi.org/10.3390/app13042184
12. Tao, Y., Liu, T., Wu, J., Wu, Z., Liao, D., Shah, F., and Wu, W. 2022. Effect of Combined Application of Chicken Manure and Inorganic Nitrogen Fertilizer on Yield and Quality of Cherry Tomato. *Agronomy*, **12(7),**1574. https://doi.org/10.3390/agronomy12071574
13. Haraira, A. A., Ahmad, A., Khalid, M. N., Tariq, M., Nazir, S., and Habib, I. 2022. Enhancing health benefits of tomato by increasing its antioxidant contents through different techniques: A review. *Advancements in Life Sciences*, **9(2),** 131-142.
14. Day, P. R. 1965. Particle fractionation and particle size analysis. In: Methods of soil analysis. Editor. Black CA. Part I. Agronomy Monograph, Academic Press, New York. 545-567.
15. Jackson, M. L. 1973. Soil Chemical Analysis (New Delhi, Prentice Hall of India Private Limited).
16. BARC (Bangladesh Agricultural Research Council). 2005. Fertilizer Recommendation Guide. BARC Publication No. 45. Farmgate, Dhaka-1215, Bangladesh.
17. Papadopoulos, A. P. 1991. *Growing Greenhouse Tomatoes in Soil and in Soilless Media*. Agriculture Canada Publication 186/E, Communications Branch, Agriculture Canada, Ottawa, Canada.
18. Alda, L. M., Gogoasa, I., Bordean, D. M., Gergen, I., Alda, S., Moldovan, C., and Nita, L. 2009. Lycopene content of tomatoes and tomato products. *Journal of Agroalimentary Processes and technologies*, ***15*(4)**, 540-542.

19. Allen, S. E., Grimshaw, H. M., and Rowland, P. A. 1986. Chemical analysis. In: Methods in Plant Ecology. 2nd (Eds.): P.D. Moore and S.B. Chapman. *Blackwell Scientific Publications, Oxford*. pp. 285-344.
20. Gupta, S., Lakshmi, A. J., Manjunath, M. N., and Prakash, J. 2005. Analysis of nutrient and antinutrient content of underutilized green leafy vegetables. *LWT-Food Science and Technology*, *38*(4), 339-345. https://doi.org/10.1016/j.lwt.2004.06.012
21. Kibria, M. G., Islam, M., and Alamgir, M. 2016. Yield and nutritional quality of tomato as affected by chemical fertilizer and biogas plant residues. *International Journal of Plant & Soil Science*, **13**(2), 1-10. https://doi.org/10.9734/IJPSS/2016/29434
22. Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., and Six, J. 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. *Plant and soil*, **339**(1), 35-50. https://doi.org/10.1007/s11104-010-0462-7
23. Banik, S., and Nandi, R. 2004. Effect of supplementation of rice straw with biogas residual slurry manure on the yield, protein and mineral contents of oyster mushroom. *Industrial crops and products*, **20**(3),311-319. https://doi.org/10.1016/j.indcrop.2003.11.003
24. Makadi, M., Tomocsik, A., Eichler-Loebermann, B., and Schiemenz, K. 2008. Nutrient cycling by using residues of bioenergy production-effects of biogas-digestate on plant and soil parameters. *Cereal Research Communications*, **36**, 1807-1810. https://www.jstor.org/stable/90003077
25. Wu, J., Yang, Q., Yang, G., Shen, F., Zhang, X. H., and Zhang, Y. Z. 2013. Effects of biogas slurry on yield and quality of oil-seed rape. *Journal of plant nutrition*, **36(13)**, 2084-2098. https://doi.org/10.1080/01904167.2013.822511
26. Gao TongGuo, G. T., Chen Nan, C. N., Li WeiQun, L. W., Li BaoZhen, L. B., and Yuan HongLi, Y. H. 2011. Effect of highly efficient nutrient solution of biogas slurry on yield and quality of vegetables. *Journal of Agricultural Science & Technology-Hunan*. **12(4)**, 567-570.
27. Yu, F. B., Luo, X. P., Song, C. F., Zhang, M. X., and Shan, S. D. 2010. Concentrated biogas slurry enhanced soil fertility and tomato quality. *Acta Agriculturae Scandinavica Section B–Soil and Plant Science*, **60(3)**, 262-268. https://doi.org/10.1080/09064710902893385
28. Di Mascio, P., Kaiser, S., and Sies, H. 1989. Lycopene as the most efficient biological carotenoid singlet oxygen quencher. *Archives of biochemistry and biophysics*, **274(2**), 532-538. https://doi.org/10.1016/0003-9861(89)90467-0
29. Giovannucci, E. 1999. Tomatoes, tomato-based products, lycopene, and cancer: review of the epidemiologic literature. *Journal of the national cancer institute*, **91(4)**, 317-331. https://doi.org/10.1093/jnci/91.4.317
30. Adeniyi, H., and Ademoyegun, O. 2012. Effect of different rates and sources of fertilizer on yield and antioxidant components of tomato (*Lycopersicon lycopersicum*). *Agri. J.* **7(2)**, 135-138.
31. Lumpkin, H. M. 2005. A comparison of lycopene and other phytochemicals in tomatoes grown under conventional and organic management systems. *Tech. Bullet*. **34**, 4-48.