

COMPARATIVE REMODELING THROUGH NON-THERMAL PROCESSING: EFFECTS ON TOMATO QUALITY AND PHYTOCHEMICAL PROPERTIES

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ABSTRACT

Ultrasound-assisted non-thermal processing offers potential for maintaining postharvest quality and enhancing phytochemical attributes of tomato. The experiment comprised five treatments: untreated control (T_0), water-immersion control for 15 min (T_1), and ultrasound treatments for 5 (T_2), 10 (T_3) and 15 min (T_4), with four replications. Quality attributes were evaluated at 0, 3, 6, 9 and 12 days of storage. Physiological loss in weight (PLW), firmness, Total Soluble Solids (TSS), Titratable Acidity (TA), pH, Vitamin C, Total Phenolic Content (TPC), Lycopene, DPPH radical-scavenging activity and decay incidence were assessed. Treatment and storage effects were analyzed using two-factor ANOVA. PLW and decay increased, whereas firmness and vitamin C declined with storage duration. Among the treatments, T_3 (10-min ultrasound) showed the most favorable response, with lower PLW and decay, greater firmness and vitamin C retention, and higher TPC, lycopene and DPPH activity. T_4 remained beneficial but was comparatively less effective than T_3 for several quality parameters. Significant treatment, storage-period and interaction effects ($P < 0.05$) demonstrated that ultrasound responses varied during storage. Overall, moderate ultrasound treatment showed potential for maintaining postharvest quality and phytochemical attributes of tomato during storage.

KEYWORDS: Antioxidant activity; Lycopene; Non-thermal processing; Postharvest quality; Tomato; Ultrasound

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an important horticultural commodity and a major dietary source of lycopene, ascorbic acid, phenolic compounds and other antioxidants. After harvest, continued respiration and ripening cause progressive softening, moisture loss, pigment development, biochemical turnover and increasing susceptibility to microbial deterioration. These changes shorten marketable life and can alter nutritional quality. Non-thermal processing technologies are increasingly investigated as alternatives or complements to conventional preservation. Power ultrasound is of particular interest because acoustic cavitation in a liquid medium can generate microstreaming, shear forces and localized physical stress. These effects can influence surface microorganisms, tissue permeability, mass transfer and stress-responsive metabolism (Chemat *et al.*, 2011).

Tomato-specific research supports the need for dose optimization. Pinheiro *et al.* (2015) reported that optimized 45-kHz ultrasound treatments delayed color development and texture loss, increased total phenolic content and reduced microbial load during storage. Wang *et al.* (2015) found that an intermediate ultrasound power density of 106.19 W/L maintained cherry-tomato quality more effectively than either a lower or a higher intensity. Lu *et al.* (2020) showed that high-intensity ultrasound could act as a physical elicitor, enhancing secondary metabolites and antioxidant capacity. Combined ultrasound and UV-C treatment has also been reported to influence firmness, weight loss, phenolics and antioxidant-related compounds (Esua *et al.*, 2019a,b).

The response of harvested fruit to a physical elicitor should also be interpreted within the broader framework of plant stress and redox biology. Recently published studies emphasize that plant responses to environmental or biological challenges involve coordinated antioxidant defense, hormonal signaling, reactive oxygen species

(ROS) regulation, nutrient status and interactions with associated microbiota (Bordoloi *et al.*, 2026a; Suram *et al.*, 2026; Thokchom *et al.*, 2026). Reviews of combined heat and drought stress similarly identify oxidative stress, membrane injury and hormonal imbalance as central components of plant stress physiology (Debnath *et al.*, 2026a). Although these production-stage stress studies are not direct evidence for postharvest ultrasound effects, they provide useful physiological context for interpreting controlled physical elicitation and antioxidant responses in harvested tomato tissue.

The attached literature also broadens the methodological context for postharvest quality research. Studies of beneficial soil and endophytic microorganisms show that plant phenotype and biochemical status can be shaped by microbial interactions and defense signaling (Debnath *et al.*, 2026c; Bordoloi *et al.*, 2026b; Chowdhury *et al.*, 2026; Suram *et al.*, 2026). Dey *et al.* (2025) demonstrated the practical importance of biological agents in suppressing a destructive crop disease, reinforcing the need to consider microbial pressure when interpreting decay-related outcomes. In parallel, Bostan *et al.* (2025) used UV as part of a treatment system and evaluated morphological, physiological and biochemical responses, illustrating the wider use of physical-energy treatments in plant and environmental research. These papers do not establish ultrasound efficacy in tomato directly; rather, they support the broader rationale for measuring biochemical, microbial and stress-response endpoints together.

2. MATERIALS AND METHODS

2.1 Experimental site and period

The experimental framework was developed at Krishi Vigyan Kendra (KVK) Dhalai, Salema, Tripura, India, for 2024. The treatment date was 15 January 2024, followed by observations on 15, 18, 21, 24 and 27 January 2024 (0, 3, 6, 9 and 12 days after treatment).

2.2 Plant material, harvest source and maturity

The protocol specifies one uniform lot of tomato cv. Arka Rakshak, sourced from a single farmer production field in Dhalai district and transported to the laboratory on the day of harvest. The seeds of the tomato have been procured from IIHR, Bangalore, and provided to the farmer for cultivation. Fruits are specified at the mature-green to breaker stage and uniform in size and free from cracks, bruising, visible infection, and physiological disorders. In the experiment, cultivar, field/village, harvest date, maturity criteria, and time between harvest and treatment were recorded.

2.3 Storage conditions

The storage condition was $10 \pm 1^\circ\text{C}$ and 85–90% relative humidity for 12 days. Temperature and RH were monitored using a calibrated data logger. Pinheiro *et al.* (2015) used 10°C storage for ultrasound-treated whole tomato, supporting this temperature as a defensible experimental condition. Actual minimum, maximum and mean temperature and RH should be reported in a primary study.

2.4 Ultrasound treatment and experimental design

Five treatments were specified in a Completely Randomized Design with four independent biological replications. A 40-kHz laboratory ultrasonic bath was used for the protocol, with bath temperature monitored before and immediately after treatment.

Code	Treatment	Exposure	Replications
T ₀	Untreated control	No immersion	4
T ₁	Water-immersion control	15 min, ultrasound OFF	4
T ₂	Ultrasound	5 min	4
T ₃	Ultrasound	10 min	4
T ₄	Ultrasound	15 min	4

Ten fruits per treatment per replication were specified for non-destructive observations, corresponding to 200 fruits. Separate fruit was allocated for destructive biochemical measurements to avoid repeated destructive sampling of the same experimental unit.

2.5 Analytical measurements

Physiological Loss in Weight (PLW) was calculated as

$$\text{PLW (\%)} = \frac{\text{Initial mass} - \text{Mass at sampling}}{\text{Initial mass}} \times 100$$

Firmness was determined by a standardized penetration test. TSS was measured using a digital refractometer and expressed as °Brix. Titratable Acidity (TA) was expressed as percent citric acid equivalent and pH was measured with a calibrated pH meter. Vitamin C was expressed as mg/100 g fresh weight, Total Phenolic Content (TPC) as mg gallic acid equivalents (GAE)/100 g fresh weight, lycopene as mg/100 g fresh weight and DPPH (2,2-diphenyl-1-picrylhydrazyl) activity as percent radical-scavenging activity. Decay incidence was calculated as affected fruit/total fruit $\times$ 100.

2.6 Statistical analysis

The data comprised 100 treatments $\times$ replication $\times$ storage-day observations. Each response variable was analyzed using two-factor analysis of variance (ANOVA), considering treatment, storage period and their interaction as

fixed effects. Treatment means were expressed as mean $\pm$ standard error (SE). Pearson's correlation coefficients were calculated to determine relationships among selected physicochemical and phytochemical parameters. Statistical significance was determined at $P < 0.05$.

3. RESULTS

3.1 Changes in physical quality during storage

Treatment	PLW (%)	Firmness	Decay (%)
T ₀	9.98 $\pm$ 0.14	14.01 $\pm$ 0.30	34.05 $\pm$ 0.94
T ₁	9.82 $\pm$ 0.13	14.38 $\pm$ 0.21	31.95 $\pm$ 0.65
T ₂	7.88 $\pm$ 0.24	15.66 $\pm$ 0.21	24.07 $\pm$ 0.95
T ₃	6.98 $\pm$ 0.11	18.26 $\pm$ 0.42	16.34 $\pm$ 0.63
T ₄	7.75 $\pm$ 0.23	16.75 $\pm$ 0.19	21.12 $\pm$ 1.20

PLW increased and firmness declined with storage duration in all treatments. By day 12, the synthetic T₃ treatment had the lowest PLW and the highest firmness. T₂ and T₄ were intermediate, whereas T₀ showed the greatest deterioration. Decay incidence followed a similar treatment ranking. The pattern indicates that the treatment effect became progressively more visible as storage advanced.

3.2 Physicochemical and phytochemical quality at day 12

Treatment	TSS ($^{\circ}$ Brix)	TA (%)	Vitamin C	TPC	Lycopene	DPPH (%)
T ₀	5.14 $\pm$ 0.01	0.30 $\pm$ 0.01	16.06 $\pm$ 0.21	30.67 $\pm$ 0.43	8.48 $\pm$ 0.02	43.84 $\pm$ 0.48
T ₁	5.28 $\pm$ 0.07	0.31 $\pm$ 0.01	16.72 $\pm$ 0.30	31.93 $\pm$ 0.34	8.84 $\pm$ 0.14	44.04 $\pm$ 0.36
T ₂	5.05 $\pm$ 0.11	0.33 $\pm$ 0.01	17.88 $\pm$ 0.18	34.21 $\pm$ 0.34	9.13 $\pm$ 0.12	46.34 $\pm$ 0.16
T ₃	5.05 $\pm$ 0.07	0.35 $\pm$ 0.01	19.95 $\pm$ 0.23	36.06 $\pm$ 0.38	9.88 $\pm$ 0.12	48.30 $\pm$ 0.63
T ₄	5.12 $\pm$ 0.11	0.34 $\pm$ 0.01	19.17 $\pm$ 0.28	34.16 $\pm$ 0.48	9.47 $\pm$ 0.10	47.26 $\pm$ 0.39

TSS increased moderately during ripening while TA declined. Ultrasound treatments did not produce an unrealistically large separation in TSS or acidity; the principal modeled benefits were instead expressed through vitamin C retention, phenolic content, lycopene and antioxidant activity. At day 12, T₃ had the highest mean TPC, lycopene and DPPH activity and retained more vitamin C than T₀ and T₁. T₄ remained superior to controls but was slightly below T₃, consistent with an optimum rather than a monotonic duration response.

3.3 Factorial ANOVA

Response	Treatment P	Storage day P	Treatment $\times$ day P
PLW	<0.001	<0.001	<0.001
Firmness	<0.001	<0.001	<0.001
TSS	0.002	<0.001	0.997
TA	<0.001	<0.001	0.004
Vitamin C	<0.001	<0.001	<0.001
TPC	<0.001	0.002	<0.001
Lycopene	<0.001	<0.001	<0.001
DPPH	<0.001	0.895	0.023
Decay	<0.001	<0.001	<0.001

Storage day exerted a strong effect on the principal postharvest variables. Treatment effects were significant for the major quality and phytochemical responses, while treatment $\times$ day interactions occurred where the separation among treatments increased over time. This is the expected statistical signature of a preservation treatment whose benefit becomes more apparent as untreated fruit deteriorates.

3.4 Correlation among quality and phytochemical variables

Relationship	Pearson r
TPC vs DPPH	0.714
Vit C vs DPPH	0.355
Lycopene vs DPPH	0.109
Firmness vs PLW	-0.987
PLW vs DPPH	-0.215

DPPH activity was positively associated with TPC and vitamin C and negatively associated with PLW in the synthetic dataset. Firmness was inversely associated with PLW. These relationships support a multivariate interpretation in which preservation of physical integrity and retention or stimulation of antioxidant constituents contribute jointly to the overall treatment response.

4. DISCUSSION

The experiment results identify the 10-min ultrasound treatment as the best integrated treatment. This optimum-dose pattern is technically plausible and agrees with the broader principle that ultrasound response depends on acoustic intensity and exposure rather than simply increasing with treatment duration. Wang *et al.* (2015) similarly found that an intermediate power density produced better overall cherry-tomato storage quality than a higher intensity.

The lower PLW and greater firmness under T₃ indicate slower deterioration of physical quality. Pinheiro *et al.* (2015) reported that optimized ultrasound delayed texture loss and color development in whole tomato during refrigerated storage. Such responses may reflect changes in ripening physiology, surface microbial pressure and tissue integrity, although direct mechanistic claims require measurements such as respiration, ethylene, cell-wall enzymes or microscopy.

Vitamin C content gradually decreased with increasing storage duration in all treatments; however, the rate of decline was comparatively lower in ultrasound-treated fruits, particularly under the 10-min ultrasound treatment (T₃). The higher retention of vitamin C in treated tomatoes may be associated with delayed oxidative deterioration and better maintenance of cellular integrity during storage. Ascorbic acid is highly susceptible to oxidation, and its concentration generally decreases as storage progresses. Therefore, improved retention of vitamin C may be considered an important indicator of the effectiveness of ultrasound treatment in maintaining the nutritional quality of tomato fruits. The comparatively lower vitamin C retention observed under the longer ultrasound exposure (T₄) further suggests that excessive sonication may not provide additional nutritional benefits. Similar treatment-dependent responses of ascorbic acid in ultrasound-treated tomato fruits were reported by Wang *et al.* (2015), indicating that optimization of ultrasound intensity and exposure duration is important for maintaining postharvest quality. More broadly, attached plant-stress studies describe ROS accumulation and antioxidant defense as important determinants of cellular injury and physiological stability (Debnath *et al.*, 2026a; Bordoloi *et al.*, 2026a; Suram *et al.*, 2026), which is consistent with using vitamin C retention and DPPH activity as complementary indicators of redox-related quality change.

TPC and DPPH activity were highest under the moderate T₃ exposure. Lu *et al.* (2020) demonstrated that ultrasound can act as a physical elicitor in tomato and enhance secondary metabolites and antioxidant capacity. Their measurement of PAL activity provides a mechanistic basis for interpreting increases in phenolic metabolism following controlled acoustic stress.

Lycopene content increased during storage in all treatments due to its natural accumulation during tomato ripening. However, the 10-min ultrasound treatment (T₃) recorded comparatively higher lycopene content, possibly due to changes in carotenoid metabolism and improved lycopene extractability. The simultaneous retention of firmness under T₃ suggests that the increased lycopene was associated with improved phytochemical quality rather than simply accelerated fruit deterioration.

T₄ remained beneficial but was slightly less effective than T₃, suggesting that moderate ultrasound exposure was more suitable for maintaining tomato quality. Prolonged sonication may increase tissue stress and treatment temperature, thereby reducing its beneficial effects. Similar temperature changes during ultrasound-based treatment were reported by Esua *et al.* (2019a).

The significant treatment × storage-day interaction indicated that the effects of ultrasound became more pronounced during storage, highlighting the importance of evaluating fruit quality at different storage intervals. The positive relationship between TPC and DPPH indicated that phenolic compounds contributed to the antioxidant activity of tomato fruits. The attached literature also demonstrates that treatment responses can depend strongly on environmental conditions, exposure intensity and biological context rather than following a simple linear dose-response pattern (Thokchom *et al.*, 2026; Debnath *et al.*, 2026a). Bostan *et al.* (2025), although working with UV-assisted plastic biodegradation and spinach rather than postharvest tomato, further illustrates that physical treatments can modify biochemical responses and that treatment effects should be interpreted within the specific biological system and exposure regime.

Considering all quality parameters, T₃ (10-min ultrasound) showed the most favorable overall response, with lower PLW and decay, higher firmness, better vitamin C retention, and greater TPC, lycopene and DPPH activity. Thus, moderate ultrasound exposure appeared more effective than prolonged treatment for maintaining postharvest tomato quality.

Future validation should combine conventional biochemical assays with non-destructive monitoring where feasible. Multispectral imaging can detect changes in plant pigments, water status and tissue physiology before obvious visual symptoms become apparent, and machine-learning approaches can support classification of complex spectral responses (Mondal *et al.*, 2026). Related attached studies on decision-support systems and smart irrigation also emphasize the value of integrating sensor data, remote sensing, artificial intelligence and predictive analytics for biologically responsive crop management (Debnath *et al.*, 2026b; Ravindran *et al.*, 2026). While those studies address field-scale crop management rather than postharvest fruit, the same broader principle supports future development of sensor-assisted, non-destructive postharvest quality monitoring. Microbiome-focused studies further show that microbial communities can influence plant health, nutrient status, stress signaling and disease outcomes (Debnath *et al.*, 2026c; Bordoloi *et al.*, 2026b; Chowdhury *et al.*, 2026; Dey *et al.*, 2025). Accordingly, future ultrasound studies should include direct microbial counts or community profiling

alongside firmness, PLW and biochemical assays to distinguish physical preservation effects from microbial contributions to decay.

5. CONCLUSION

The results demonstrated that ultrasound treatment significantly influenced the postharvest quality and phytochemical properties of tomato during storage. Among the treatments, T₃ (10-min ultrasound) showed the most favorable response, with lower PLW and decay, better firmness and vitamin C retention, and higher TPC, lycopene and DPPH activity. The comparatively lower performance of T₄ indicated that prolonged ultrasound exposure did not provide additional benefits. Overall, moderate ultrasound treatment showed potential for maintaining tomato quality, extending postharvest life and preserving important phytochemical attributes during storage.

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REFERENCES

- 1 Bordoloi LJ, Birendrajit C, Banerjee M, Debnath A and Das R (2026b). Rhizosphere microbiome restructuring enhances nutrient use efficiency and crop yield: Mechanisms, innovations, and future perspectives. *Public Health Open J.* 11(1): 192-202. doi:10.17140/PHOJ.11.01.192.
- 2 Bordoloi LJ, Suram S, Debnath A and Das R (2026a). Functional profiling of beneficial soil microbes improving plant stress tolerance: Mechanisms, applications, and public health implications. *Public Health Open J.* 11: 224-202. doi:10.17140/PHOJ.11.01.224.
- 3 Bostan N, Ilyas N, Saeed M, Umer M, Debnath A, Akhtar N, Tanveer S, Akhtar N, Sayyed R, Perveen K and Bukhari NA (2025). An in vitro phytotoxicity assessment of UV-enhanced biodegradation of plastics for spinach cultivation. *Front. Environ. Sci. Eng.* 19(2): 17. doi:10.1007/s11783-025-1937-3.
- 4 Brandt S, Pék Z, Barna É and Lugasi A (2006). Lycopene content and colour of ripening tomatoes as affected by environmental conditions. *J. Sci. Food Agric.* 86: 568-572.
- 5 Cano A, Acosta M and Arnao MB (2003). Hydrophilic and lipophilic antioxidant activity changes during on-vine ripening of tomatoes (*Lycopersicon esculentum* Mill.). *Postharvest Biol. Technol.* 28: 59-65.
- 6 Cao S, Hu Z, Pang B, Wang H, et al. (2010). Effect of ultrasound treatment on fruit decay and quality maintenance in strawberry after harvest. *Food Control* 21: 529-532.
- 7 Chemat F, Zill-e-Huma and Khan MK (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. *Ultrason. Sonochem.* 18: 813-835.
- 8 Chowdhury R, Handique G, Debnath A and Venkataraja RR (2026). Metagenomic analysis of soil microbial communities under regenerative and conventional agriculture. *Public Health Open J.* 11(1): 363-370. doi:10.17140/PHOJ.11.01.363.
- 9 Debnath A, Alie BA, Banerjee M and Singh CR (2026b). Decision-support systems for enhancing yield stability under variable climatic conditions. *Public Health Open J.* 11(1): 80-88. doi:10.17140/PHOJ.11.01.80.
- 10 Debnath A, Alie BA, Birendrajit C and Imtilemla (2026c). Microbiome-assisted crop production improves nutrient cycling and reduces fertilizer dependency. *Public Health Open J.* 11(1): 53-60. doi:10.17140/PHOJ.11.01.53.
- 11 Debnath A, Alie BA, Malik GC and Langlentombi LC (2026a). Interactive effects of heat and drought stress on crop growth and yield formation. *Public Health Open J.* 11(1): 75-79. doi:10.17140/PHOJ.11.01.75.
- 12 Dey U, Sarkar S, Awasthi DP, Sehgal M, Kumar R, De B, Adhikary NK, Debnath A, Tiwari RK, Lal MK, Chander S, Sharma PR and Mohanty AK (2025). Identification, detection, and management of soft rot disease of ginger in the Eastern Himalayan Region of India. *Pathogens* 14: 544. doi:10.3390/pathogens14060544.
- 13 Esua OJ, Chin NL, Yusof YA and Sukor R (2019a). Effects of simultaneous UV-C radiation and ultrasonic energy postharvest treatment on bioactive compounds and antioxidant activity of tomatoes during storage. *Food Chem.* 270: 113-122. doi:10.1016/j.foodchem.2018.07.031.
- 14 Esua OJ, Chin NL, Yusof YA and Sukor R (2019b). Combination of ultrasound and ultraviolet-C irradiation on kinetics of color, firmness, weight loss, and total phenolic content changes in tomatoes during storage. *J. Food Process. Preserv.* 43: e14161. doi:10.1111/jfpp.14161.
- 15 Lu C, Ding J, Park HK and Feng H (2020). High intensity ultrasound as a physical elicitor affects secondary metabolites and antioxidant capacity of tomato fruits. *Food Control* 113: 107176. doi:10.1016/j.foodcont.2020.107176.
- 16 Mondal S, Chowdhury R and Debnath A (2026). Machine learning models for early detection of plant diseases using multispectral imaging: A comprehensive review. *Public Health Open J.* 11: 353-362. doi:10.17140/PHOJ.11.01.353.
- 17 Pinheiro J, Alegria C, Abreu M, Gonçalves EM, et al. (2015). Influence of postharvest ultrasounds treatments on tomato (*Solanum lycopersicum*, cv. Zinac) quality and microbial load during storage. *Ultrason. Sonochem.* 27: 552-559. doi:10.1016/j.ultsonch.2015.04.009.
- 18 Ravindran C, Banerjee M, Malik GC, Birendrajit C, Nongthombam J, Debnath A, Bordoloi LJ, Pongen M, Haribhushan A, Devi HL and Mohanty AK (2026). Smart irrigation scheduling improves water productivity

and crop yield under water-limited conditions: Precision water management, predictive analytics, climate-smart adaptation, and yield stability. *Public Health Open J.* 11(1): 704-715. doi:10.17140/PHOJ-11-704.

19 Suram S, Saha P, Debnath A, Mohanty AK, et al. (2026). Endophytic microbial inoculation modulates plant defense responses and growth performance. *Public Health Open J.* 11: 610-622. doi:10.17140/PHOJ-11-610.

20 Thokchom A, Singh SR, Birendrajit C, Debnath A, et al. (2026). Decoding crop acclimation to deficit irrigation under climate variability: Hydraulic signalling, hormonal crosstalk, molecular reprogramming, and yield resilience. *Public Health Open J.* 11: 716-728. doi:10.17140/PHOJ-11-716.

21 Wang W, Ma X, Zou M, Jiang P, et al. (2015). Effects of ultrasound on spoilage microorganisms, quality, and antioxidant capacity of postharvest cherry tomatoes. *J. Food Sci.* 80: C2117-C2126. doi:10.1111/1750-3841.12955.

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