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**Original Research**

# Influence of Partially Burnt Rice Hull (PBRH) Soil Amendment on Physical Damage Tolerance and Postharvest Loss Reduction in Tomato (*Solanum lycopersicum* var. Platinum L.)

HLJ Imali[1*], HLD Weerahewa[1], RPSS Rajapakse[2] and WLSMIDM Thilakaratne[1]

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## ABSTRACT

***Purpose:*** *Tomato (Solanum lycopersicum L.) is a major vegetable crop grown in Sri Lanka. However, their extreme perishability during harvesting, handling, transportation, and storage leads to significant postharvest loss and quality deterioration. This study evaluated the effects of soil amendment with partially burned rice hull (PBRH) on tomato firmness, quality, and tolerance to physical damage.*

***Research Method:*** *Three ratios of PBRH were applied: R0 (control), R1 (0.3 kg $m^{-2}$), and R2 (0.6 kg $m^{-2}$) in tomato grown in Suriyawewa, Hambantota district, Sri Lanka. The fruits were harvested at the colour-breaker and pink maturity stages. Fruit quality parameters and storage quality were evaluated at room temperature under refrigerated conditions.*

***Findings and Values:*** *The R2 treatment significantly improved tomato quality, resulting in the highest fruit weight (colour breaker: 47.49±0.01 g, pink: 46.73±0.01 g), overall firmness (colour breaker: 6.42±0.01 N, pink: 5.94±0.01 N), longest shelf-life (14.0±0.2 days) and lower weight loss (0.88% at room temperature and 0.30% in cold storage) and reduced firmness loss (17.52% at room temperature and 13.88% in cold storage) after 14 days. Additionally, R2 tomatoes showed delayed ripening, improved drop resistance for up to 10 days, and enhanced quality retention with a lower weight loss percentage (0.41%) and the highest overall firmness (5.77±0.01 N) with an ethylene adsorbent. This study highlighted the use of an optimum dosage of rice hull as a soil amendment to enhance the quality of tomatoes and reduce postharvest losses.*

**Keywords:** *Ethylene absorption, Firmness, Postharvest losses, Quality parameters, Shelf-life*

## INTRODUCTION

Global postharvest losses of fruits and vegetables have become a significant challenge by representing 30 - 40% (210,000 metric tons) of the harvest, equating to approximately US$ 90 million (FAO *et al.* 2020). Among these, tomato (*Solanum lycopersicum* L.) is a highly perishable fruit that suffers from mechanical injuries during harvesting, handling, and transportation, leading to rapid deterioration (Sarma 2018). In Sri Lanka, postharvest losses account for 30–40% of the total production (Rajapaksha *et al.* 2021), which has remained unchanged for decades. Tomato is a climacteric fruit that ripened during the postharvest value chain, causing loss of firmness and quality. When tomatoes turn colour from green to red, firmness declines and their

[1]Department of Botany, Faculty of Natural Sciences, Open University of Sri Lanka, Nawala, Sri Lanka.
[2]United Graduate School of Agricultural Sciences, Kagoshima University, Japan.
*liyanagejinesha@gmail.com
https://orcid.org/0009-0008-1669-8569

susceptibility to mechanical and physical injuries during the supply chain increases by reducing the quantity and quality of the tomatoes. As a result, higher postharvest losses are experienced in the postharvest value chain of tomatoes (Najjar & Abu-Khalaf 2021). Various pre and postharvest practices have been explored to mitigate postharvest losses. These include careful handling, proper sorting, and packaging in ventilated containers (Kiaya 2014, Rajapaksha *et al.* 2021) and the use of cushioned containers and wrapping to prevent injuries. In addition, reducing ethylene synthesis by low-temperature or controlled atmosphere (CA) storage and/or by the application of the competitive ethylene antagonist 1-MCP, which blocks the response of plants to ethylene, can greatly delay the ripening of climacteric fruits and alleviate physiological disorders (Kumar *et al.* 2023). Additionally, the use of plant hormones (gibberellin) significantly slows the ripening of green vegetables and tomatoes, while modified atmosphere packaging and edible coatings have also extended shelf life by reducing respiration and delaying ripening (Aysel *et al.* 2019, Yadav *et al.* 2022). Pre-harvest factors, such as the use of chemicals; fungicides, balanced nutrition, and proper irrigation, also contribute to improved postharvest quality (Zewdie *et al.* 2021). However, these practices often incur high input costs and have negative implications for human and environmental health to enhance fruit quality (Kumar *et al.* 2023).

It is important to implement technologies to improve product quality and reduce postharvest losses of tomatoes. One promising approach is the use of silicon sources as a pre-harvest soil amendment to improve product quality and reduce diseases (Somapala *et al.* 2016). Silicon (Si) is a quasi-essential element which enhances plant resilience to biotic and abiotic stresses, increases plant growth, and improves fruit firmness, cuticle thickness, and shelf-life (Pathare & Al-Dairi 2021). Silicon enhances the postharvest quality and action of photosynthesis in various crops, including tomatoes, where it reduces susceptibility to mechanical damage and spoilage (Weerahewa & David 2015). It has been reported that uptake and deposition of Si in the tissue enhances the strength and rigidity of the tissue, which may have contributed to an increase in fruit firmness in cucumbers (Abd-Alkarim *et al.* 2017).

Silicon has been applied to various crops as foliar and soil applications through different sources, such as sodium/potassium/calcium silicate, silicic acid, and rice husk biochar (Thimmappa & Basavarajappa 2021). According to Ratnayake *et al.* 2018, rice hull ash contains a plant-available soluble silicon content of 56.1%. This high availability is attributed to the regulatory release of silicon from its tightly bound form, which occurs as a result of the elevated temperatures used during processing (Ratnayake *et al.* 2018). PBRH has been considered a rich organic source of silicon, containing 90% to 97% silica (Thimmappa & Basavarajappa 2021). The application of PBRH has been proven to be effective in improving tomato quality by increasing cuticle thickness, fruit firmness, and total soluble solids (Weerahewa & Somapala 2016). PBRH also enhanced the growth parameters and quality (yield, firmness, and colour) of hydroponically grown tomatoes (David & Weerahewa 2012, Weerahewa 2013) while increasing the total sugar and ascorbic acid content in tomatoes and improving postharvest qualities in other crops, such as leeks and pineapples (Hien *et al.* 2017, Jayawardana *et al.* 2016, Weerahewa & Wicramasekara 2020). The use of biochar enhances the shelf life and reduces spoilage of fruits and vegetables, including strawberries, by improving pigment development and firmness during storage (Rajapakse & Tanaka 2018). Rice hulls have also shown beneficial effects on growth and yield in crops such as carrots and capsicum, enhancing various growth parameters such as plant height, fruit diameter, length, and number of leaves/shoots (Sudeshika *et al.* 2018, Jayawardana *et al.* 2014). Therefore, PBRH is a potentially cheaper and natural source of silicon for enhancing postharvest quality and promoting environmental sustainability (Somapala *et al.* 2016).

In this study, a partially burned rice hull (PBRH) soil amendment was applied as a pre-harvest application in tomato cultivation to evaluate its effects on fruit quality, firmness, storage quality, and shelf life. The tomato cultivar "Platinum-701" was selected for this experiment due to its widespread cultivation and reputation for high yield potential under local environmental conditions. (Imali *et al.* 2025). The main objective of this study was to identify the influence of soil amendment with PBRH on the physical damage tolerance and postharvest loss reduction in tomatoes. This includes determining the optimum dosage of PBRH for tomato plants, assessing quality improvements from PBRH treatment, and comparing the postharvest quality and shelf life of treated fruits with those subjected to other handling practices. This approach focuses on providing a sustainable solution to improve the postharvest management of tomatoes and reduce economic losses.

## MATERIALS AND METHODS

### *Experimental site, PBRH application and tomato cultivation*

Tomato cultivation was carried out in 'Suriyawewa', Hambantota District, Southern Province, Sri Lanka (6°18′60.00″ N to 81°00′0.00″ E, 67 m) for a period of eight months, from May 2023 to January 2024. The average rainfall, temperature, and humidity of 'Suriyawewa' during the cultivation period were 127±1 mm, 30±1 °C, and 76±1%, respectively. Quality evaluations of harvested tomatoes were performed at the Botany Research Laboratory of the Open University of Sri Lanka, Nawala. (Avg. rainfall: 265±1 mm, Temperature: 26±1 °C, Relative humidity: 78±1%).

Three farmers participated in the experiment, each of whom cultivated tomatoes in 1×3 $m^2$ plots. Tomato seeds of the "Platinum-701" variety were sown and allowed to germinate in a nursery. After land preparation, PBRH was applied at three ratios (R0: no PBRH, R1:1 kg PBRH, and R2:2 kg PBRH per 3 $m^2$ plot). Each farmer performed three treatment replicates (blocks 1, 2, and 3). After one week of PBRH application, healthy and uniform seedlings were transplanted into the field. Management of plant nurseries, transplantation, cultivation, pest and disease control, and fertilizer application were carried out according to the recommendations of the Department of Agriculture (DOA), Sri Lanka. After two months, tomato fruits at the colour breaker stage were harvested (Tomato Grades and Standards, USDA).

### *Analysis of quality parameters*

Fifteen marketable fruits from each colour breaker and pink maturity stage per treatment (R0, R1, and R2) (five fruits per replicate from one treatment) were randomly selected and analysed for the following quality parameters. The average fruit weight was measured using a scale (OHAUS, PA413), and the average fruit size and diameter at the widest point were measured using a vernier calliper. Fruit colour was measured at two opposite sides using the mobile 'Colour Meter' app © (version 1.0.3). Colour was expressed in L* (degree of darkness to lightness from black to white 0–100), a* (green to red –100 to +100), and b* (yellow to blue –100–100) values as defined by the International Commission on Illumination (CIE) (2004).

Tomato firmness was measured using a digital penetrometer (Model AGY-15, China). Two measurements were taken for each fruit: overall firmness was assessed on one side of the equator with the peel intact, whereas flesh firmness was measured on the opposite side after carefully removing a thin layer of peel (<1 mm) using a sharp knife. Each tomato fruit was then cut into two halves along its longitudinal side, and pericarp thickness was measured from three points on each tomato using a vernier calliper. To measure the TSS content, tomato fruits were crushed, and a few drops of tomato juice were obtained separately from each sample using a hand squeezer. The TSS content was measured using a refractometer [Model, WZ-113, China (Mainland)], and the results were expressed as °Brix.

Ten tomatoes from each treatment (R0, R1, and R2) were stored under ambient conditions for shelf-life assessment. The number of days taken by each fruit to reach an unmarketable state, characterized by signs such as over ripeness, decay, shrivelling, mould/rot, bruising, and excessive softness was recorded. All experiments were performed in triplicate.

***Evaluation of storage quality***

Two sets of 20 fruits each from R0, R1, and R2 treatments were selected at the breaker and pink maturity stages for storage. One set of fruits was stored under ambient conditions (temperature, 26±1 °C; Relative Humidity, 78±1%) and the other set was stored under refrigerated conditions (temperature, 4±1 °C; Relative Humidity, 50±1%). The weight, overall firmness, and flesh firmness of the tomatoes were measured for two weeks at three-day intervals using the methods described above. Weight loss was calculated using the following equation:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \tag{1}$$

***Evaluation of drop resistance***

Two sets of tomatoes, which included 12 tomatoes in each set from the colour breaker and pink stages from the R0, R1, and R2 treatments, were selected randomly. The initial weight of the tomatoes was measured and allowed to drop from a distance of 1 m and a 0.5 m distance (three tomatoes of each maturity stage from a particular treatment were dropped from each height) onto a cardboard and concrete surface separately (Yousefi *et al.* 2016). One set of dropped tomatoes was stored for three days under ambient conditions (temperature, 26±1 °C; Relative Humidity, 76±1%). The weight, overall firmness, and flesh firmness of the dropped surface of tomatoes were measured using the above-described methods after three days. Other sets of tomatoes were stored for 14 days under ambient conditions (temperature, 26±1 °C; Relative Humidity, 76±1%) to check their shelf life. Finally, weight loss was calculated using the equation above.

***Evaluation of storage quality with the gas absorbent***

Eighteen tomatoes, each from the pink maturity stage (six tomatoes from each R0, R1, and R2 treatments) were selected. The initial weight of the tomatoes was measured. Three tomatoes from each treatment at each maturity stage were added into zip-lock bags (3×9 inch Poly Ethelene (PE) bags) with and without a gas absorbent that can absorb ethylene gas. The experiment was conducted in triplicate. Tomato zip-lock bags were stored under ambient conditions (temperature, 26±1 °C; Relative Humidity, 76±1%), and the weight and overall and flesh firmness values were measured using the above-described measures. Finally, the weight loss was calculated using the above equations.

***Experimental design and statistical analysis***

The experimental design was a two-factor factorial design with a completely randomised design (CRD). Two-way analysis of variance (ANOVA) was conducted to evaluate the statistical significance ($p<0.05$) of the quality attributes among the tomato varieties, and Tukey's HSD was used for multiple comparisons. All statistical analyses were conducted using the Minitab 19 statistical software.

## RESULTS AND DISCUSSION

***Quality parameters***

There were no significant differences in fruit weight, fruit size (diameter) or TSS content among the different PBRH treatments. However, fruits treated at R2 had the highest average fruit weight (Colour breaker 48.43±0.01 g, Pink 55.28±0.01 g) while non-PBRH treated tomatoes (Treatment R0) had the lowest fruit weight in both stages (Colour breaker 47.49±0.01 g, pink 46.73±0.01 g) (Table 1). The research conducted by Adebajo *et al.* (2020) showed similar results of higher fruit weight in tomatoes grown in rice-husk biochar-enriched soil.

The primary external feature that determines the freshness and postharvest life of tomatoes is the colour of the fruit, which also plays a significant role in consumer purchase decisions (Camelo *et al.* 2004). Tomato colour development in terms of lightness ($L^*$value) in the colour breaker and pink stage tomatoes showed significant variation among R0, R1, and R2 treatments in both colour breaker and pink maturity stages (Table 1). However, the $a^*$ value, $b^*$value, and $a/b$ ratio did not vary significantly among different PBRH treatments. The $a^*$value and $a/b$ ratio of the fruits differed among the different maturity levels of tomatoes. The experimental results revealed that the R2 treatment had significantly lower $L^*$ and $b^*$values at the colour breaker and pink stages, respectively, compared with R0. These shifts reflect biochemical changes in the fruit, including chlorophyll breakdown and carotenoid synthesis (Thimmappa & Basavarajappa 2021). The $a/b$ ratio of immature green tomatoes is lower than 0; when the tomatoes ripen and obtain a more reddish colour, it increases to 0 and above (Thole *et al.* 2020). According to Rajapakse & Tanaka (2018), 'Sachinoka' strawberries grown in rice hull biochar growing medium showed similar $L^*$, $a^*$ and $b^*$ colour values.

There was a significant difference in firmness between the maturity stage and treatment. Fruits treated at R2 showed a significantly higher overall firmness of 6.42±0.01 N and 5.94±0.01 N when harvested at the colour breaker and pink stages respectively, while treatment R0 had the lowest overall firmness values of 5.99±0.01 N and 5.01±0.01 N at colour breaker and pink stages respectively. The flesh firmness of tomatoes under the different PBRH treatments was not significantly different.

However, colour breaker stage and pink stage tomatoes of R2 treatment had a higher flesh firmness of 4.07±0.01 N, and 2.67±0.01 N respectively, while the control treatment (R0) showed the lowest flesh firmness values of 3.14±0.01 N and 2.66±0.01 N in colour breaker and pink stage tomatoes respectively. PBRH improves firmness by increasing cuticle thickness through silicone deposition (Weerahewa *et al.* 2016). According to the findings of a similar study conducted by Rajapakse and Tanaka (2018), higher firmness values were obtained for strawberries grown in rice hull medium than in cedar bark medium.

The shelf life of the tomatoes in the different treatments ranged from 13±0.2 to 14±0.2 days. Fruits treated at R1 and R2 at the colour breaker stage and pink stage tomatoes had the highest shelf-life of 14.0±0.2 days, whereas the shelf-life of the colour breaker stage tomatoes of R0 was 13.6±0.2 days. Pink-stage tomatoes in the R0 and R1 treatments showed a shelf-life of 13.2±0.2 days.

***Storage quality evaluation***

Maturity stages, ripening conditions, and their combined effects have been shown to substantially affect the overall weight loss of fruits (Moneruzzaman et al. 2008). The results of the storage study revealed that weight loss increased significantly with the progression of the storage period. However, there was a significant variation in the weight loss percentage between the colour breaker and pink stage tomatoes subjected to different treatments at room temperature (Fig. 1). The weight loss of the colour breaker stage tomatoes varied between $0.54\%$ and $1.32\%$ in R0, $0.51\%$–$1.10\%$ in R1, and $0.23\%$–$0.88\%$ in R2, whereas the weight loss percentage of the pink stage tomatoes changed from $3.07\%-5.88\%$ in R0, $2.18\%$–$4.31\%$ in R1, and $1.53\%$–$3.82\%$ in R2 (Fig. 1). It is obvious that the percentage of weight loss was higher in ripened tomatoes; however, in the R1 and R2 treatments, the increase in weight loss during the storage period was significantly lower than that in the non-PBRH-treated tomatoes (treatment R0) of both pink and colour breaker maturity stages. R0 recorded the highest percentage of overall weight loss after 14 days of storage (Fig. 1).

The overall firmness (firmness with peel) and flesh firmness (firmness without peel) of the tomatoes in different treatments in the colour breaker and pink stage tomatoes showed a decreasing trend throughout the storage period at room temperature (Fig. 2). Although there was no significant difference in the flesh firmness values of both the colour breaker and pink stage tomatoes in R0, R1, and R2 treatments, there was a remarkable variation in the overall firmness values under room temperature storage in both colour breaker and pink stage tomatoes

**Table 1. Effect of PBRH application on the quality changes of colour breaker and pink stage tomatoes.**

| Quality parameter | | Stage | R0 | R1 | R2 | Significance | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | T | S | T*S |
| Weight (g) | | Colour breaker | 47.49±0.01 | 49.69±0.01 | 48.34±0.01 | ns | ns | ns |
| | | Pink | 46.73±0.01 | 46.91±0.01 | 55.28±0.01 | | | |
| Colour | L* | Colour breaker | $52.56^{a}$±0.05 | $49.39^{ab}$±0.05 | $48.12^{b}$±0.05 | * | * | * |
| | | Pink | $45.62^{c}$±0.05 | $45.19^{cd}$±0.05 | $41.54^{d}$±0.05 | | | |
| | a* | Colour breaker | $9.42^{b}$±0.05 | $9.25^{b}$±0.05 | $11.32^{b}$±0.05 | ns | * | * |
| | | Pink | $26.44^{a}$±0.05 | $28.39^{a}$±0.05 | $26.75^{a}$±0.05 | | | |
| | b* | Colour breaker | 48.32±0.05 | 40.6±0.05 | 40.2±0.05 | ns | ns | ns |
| | | Pink | 45.31±0.05 | 46.54±0.05 | 43.77±0.05 | | | |
| | a/b | Colour breaker | $0.20^{b}$±0.05 | $0.18^{b}$±0.05 | $0.24^{b}$±0.05 | ns | * | * |
| | | Pink | $0.60^{a}$±0.05 | $0.61^{a}$±0.05 | $0.62^{a}$±0.05 | | | |
| Fruit Diameter (cm) | | Colour breaker | 6.61±0.02 | 6.84±0.02 | 6.74±0.02 | ns | ns | ns |
| | | Pink | 6.66±0.02 | 7.02±0.02 | 6.86±0.02 | | | |
| Overall Firmness (N) | | Colour breaker | $5.99^{a}$±0.01 | $6.46^{b}$±0.01 | $6.42^{b}$±0.01 | * | * | * |
| | | Pink | $5.01^{a}$±0.01 | $5.14^{a}$±0.01 | $5.94^{b}$±0.01 | | | |
| Flesh Firmness (N) | | Colour breaker | 3.14±0.01 | 3.59±0.01 | 4.07±0.01 | ns | ns | ns |
| | | Pink | 2.66±0.01 | 2.69±0.01 | 2.67±0.01 | | | |
| TSS (°Brix) | | Colour breaker | 4.44±0.16 | 5.01±0.16 | 4.8±0.16 | ns | ns | ns |
| | | Pink | 4.96±0.16 | 4.92±0.16 | 4.67±0.16 | | | |
| Shelf-life (Days) | | Colour breaker | $13.6^{a}$±0.2 | $14.0^{a}$±0.2 | $14.0^{a}$±0.2 | ns | * | * |
| | | Pink | $13.2^{a}$±0.2 | $13.2^{a}$±0.2 | $14^{b}$±0.2 | | | |

Data are mean values. Factors are; Treatment (T) either R0, R1 and R2 and Stage (S) either colour breaker or pink. The asterisk (*) represents the significant effect of the factors. Values followed by different superscript letters are significantly different within a column, according to Tukey's test ($p<0.05$). 'ns' refers not significant.

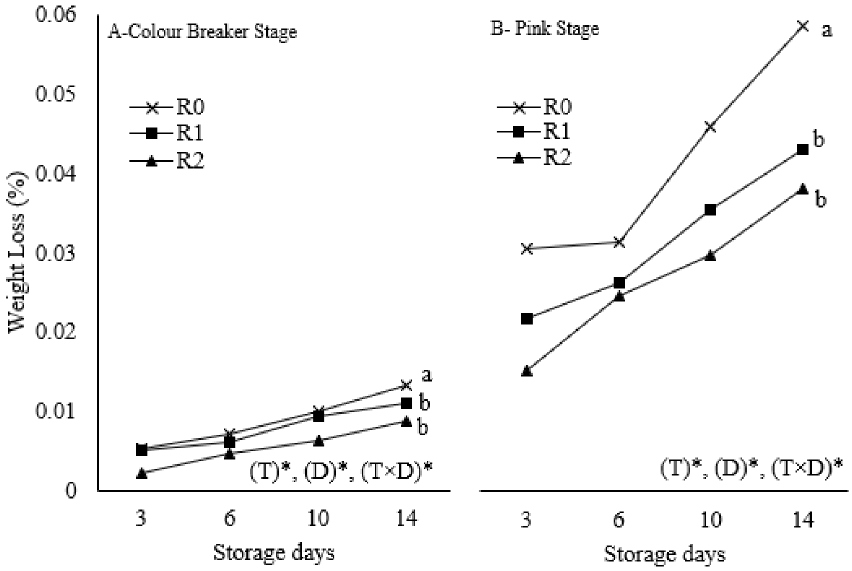


**Figure 1. Effect of PBRH application on the weight loss of (A) colour break-stage tomatoes and (B) pink-stage tomatoes stored at 26±1°C and 76±1% RH.** Data are mean values. Factors are; Treatment (T) either R0, R1 and R2 and Storage Days (D) either 3, 6, 10 or 14 days. The asterisk (*) represents the significant effect of the factors. Values followed by different letters are significantly different within each storage day, according to Tukey's test ($p < 0.05$).

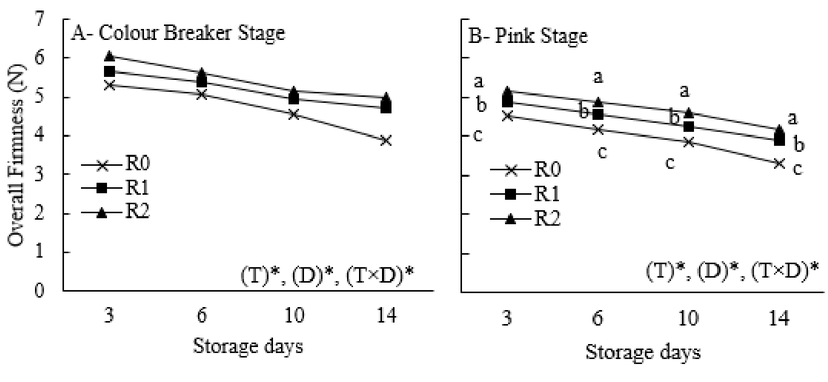


**Figure 2. Effect of PBRH application on the overall firmness of (A) colour breaker stage and (B) pink-stage tomatoes stored at 26±1 °C and 76±1% RH.** Data are mean values. Factors are; Treatment (T) either R0, R1 and R2 and Storage Days (D) either 3, 6, 10 or 14 days. The asterisk (*) represents the significant effect of the factors. Values followed by different letters are significantly different within each storage day, according to Tukey's test ($p<0.05$).

in R0, R1, and R2 treatments. According to the results, the highest reduction of firmness values with the storage period was shown by treatment R0 (colour breaker stage: firmness reduced from $5.33 \pm 0.01$N on the 3rd day of storage to $3.90 \pm 0.01$N after the 14th day of storage; pink stage: firmness reduced from $4.50 \pm 0.01$N on the 3rd day to $3.30 \pm 0.01$N on the 14th day) and the lowest reduction was obtained from R2 (colour breaker stage: firmness reduced from $6.05 \pm 0.01$N on the 3rd storage day to $4.99 \pm 0.01$N after the $14^{th}$ storage day; pink stage: overall firmness reduced from $5.13 \pm 0.01$N on the 3rd day to $4.15 \pm 0.01$N on the $14^{th}$ day) in both colour breaker and pink stage tomatoes (Fig. 2). According to the findings of Rajapakse and Tanaka (2018), fruits grown in rice hull media had greater firmness metrics during storage. Tomatoes stored in cold storage (temperature 4±1 °C, Relative Humidity 50±1%) showed the same pattern of data fluctuation as the room-temperature storage among both the colour breaker and pink stage tomato fruits in the R0, R1, and R2 treatments. Even though the data were not significant, when compared to the room temperature conditions, in cold storage, both colour breaker and pink-stage tomato fruits showed a lower weight loss percentage, lower reduction in overall and flesh firmness values and delayed ripening in all three treatments. Owing to severe water dehydration, tomatoes have been shown to lose weight more quickly under ambient storage conditions (Fagundes *et al*. 2015). Tomatoes stored in cold storage have the potential to alter vapour pressure and enhance water retention, leading to a modest weight loss at low storage temperatures (Al-Dairi*et al*. 2021). The relative humidity increased, which had the potential to halt softening and improve or maintain the firm condition of the tomatoes throughout storage. This results in a slow increase in the firmness of tomatoes maintained at low temperatures (Ayomide *et al*. 2019).

***Evaluation of drop resistance***

The results of the drop test revealed that there was no significant difference in weight loss among the maturity stage of the fruits, drop height, and drop surface (Table 2). However, the pink stage fruits of R0, which were dropped from 100 cm onto the concrete surface, had the highest weight loss (1.044±0.01 g), while the R2 treated colour breaker stage fruits that dropped onto the cardboard surface from a 50 cm drop height showed the lowest weight loss (0.560±0.01 g). Fruits from treatment R2 had significantly higher overall firmness in both the colour breaker and pink stages (5.31±0.01 N in the colour breaker stage and 4.56±0.01 N in the pink stage) than in the non-PBRH-treated fruits (4.86±0.01 N in the colour breaker stage and 4.03±0.01 N in the pink stage). Also, overall firmness was higher in R2 treated fruits when the fruits which were dropped on to a cardboard surface (4.86±0.01 N) at 0.5 m height (4.84±0.01 N) compared to the non-PBRH treated fruits dropped on cardboard surface (4.51±0.01 N) at 0.5 m height (4.43±0.01 N) (Table 2). However, there were no significant differences in flesh firmness (without peel) between the maturity stage, drop height, and drop surface.

Tomatoes treated for R2 at the colour breaker stage had a significantly longer shelf life of 10±0.2 days, whereas treatment R0 showed only 7.4±0.2 days of shelf-life at the colour breaker stage (Table 2). The fruits treated with R2 had a significantly higher shelf-life of 8.6±0.2 days when dropped at 1m height, and 8.1 days when dropped on concrete surface while non-PBRH treated fruits had 8.1±0.2 days when dropped at 1m height and 8.1±0.2 days when dropped on concrete surface. Fresh fruits are exposed to several external pressures that might result in bruising owing to their lengthier marketing chain and postharvest activities, such as handling, harvesting, and shipping (Sun *et al.* 2021).

Fruit fall can be regarded as a typical impact that occurs during harvesting, processing, and transport; hence, the drop height of tomatoes is a significant parameter in practical applications (Pathare *et al.* 2023). Thus, enhancing the knowledge of farmers and handlers about the impact levels of drop heights can minimise damage to fresh produce during postharvest handling and storage (Hussein *et al.* 2017). According to our study, PBRH-treated tomatoes showed a greater drop in resistance than non-PBRH-treated tomatoes.

**Table 2. Effect of PBRH application on drop resistance in terms of drop surface characteristics and maturity stage of tomatoes.**

| Quality Parameter | Factor | Level | R0 | R1 | R2 | Significance | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | T | S | DH | DS | T*S | T*DH | T*DS |
| Weight Loss (g) | Stage | Colour breaker | 0.89±0.01 | 0.71±0.01 | 0.56±0.01 | ns | ns | | | ns | | |
| | | Pink | 0.87±0.01 | 0.88±0.01 | 0.72±0.01 | ns | ns | | | ns | | |
| | Drop Height | 1 m | 1.04±0.01 | 0.84±0.01 | 0.80±0.01 | ns | | ns | | | ns | |
| | | 0.5 m | 0.74±0.01 | 0.63±0.01 | 0.57±0.01 | ns | | ns | | | ns | |
| | Drop Surface | Concrete | 0.92±0.01 | 0.88±0.01 | 0.83±0.01 | ns | | | ns | | | ns |
| | | Cardboard | 0.69±0.01 | 0.69±0.01 | 0.61±0.01 | ns | | | ns | | | ns |
| Overall Firmness (N) | Stage | Colour breaker | 4.86$^{a}$±0.01 | 5.00$^{ab}$±0.01 | 5.31$^{b}$±0.01 | * | * | | | * | | |
| | | Pink | 4.03$^{a}$±0.01 | 4.11$^{ab}$±0.01 | 4.56$^{b}$±0.01 | * | * | | | * | | |
| | Drop Height | 1 m | 4.61±0.01 | 4.66±0.01 | 4.71±0.01 | ns | | ns | | | ns | |
| | | 0.5 m | 4.43±0.01 | 4.72±0.01 | 4.86±0.01 | ns | | ns | | | ns | |
| | Drop Surface | Concrete | 4.59±0.01 | 4.73±0.01 | 4.81±0.01 | ns | | | ns | | | ns |
| | | Cardboard | 4.51±0.01 | 4.52±0.01 | 4.84±0.01 | ns | | | ns | | | ns |
| Flesh Firmness (N) | Stage | Colour breaker | 2.48±0.01 | 2.58±0.01 | 2.62±0.01 | ns | ns | | | ns | | |
| | | Pink | 2.18±0.01 | 2.14±0.01 | 2.18±0.01 | ns | ns | | | ns | | |
| | Drop Height | 1 m | 2.26±0.01 | 2.34±0.01 | 2.48±0.01 | ns | | ns | | | ns | |
| | | 0.5 m | 2.14±0.01 | 2.41±0.01 | 2.47±0.01 | ns | | ns | | | ns | |
| | Drop Surface | Concrete | 2.25±0.01 | 2.34±0.01 | 2.37±0.01 | ns | | | ns | | | ns |
| | | Cardboard | 2.38±0.01 | 2.36±0.01 | 2.42±0.01 | ns | | | ns | | | ns |
| Shelf-life (Days) | Stage | Colour breaker | 7.4$^{a}$±0.2 | 8.8$^{ab}$±0.2 | 10$^{b}$±0.2 | * | * | | | * | | |
| | | Pink | 7.2±0.2 | 8.4±0.2 | 8.3±0.2 | ns | ns | | | ns | | |
| | Drop Height | 1 m | 8.1$^{a}$±0.2 | 8.1$^{ab}$±0.2 | 8.6$^{b}$±0.2 | ns | | * | | | * | |
| | | 0.5 m | 8.8±0.2 | 9.0±0.2 | 8.8±0.2 | ns | | ns | | | ns | |
| | Drop Surface | Concrete | 8.1$^{a}$±0.2 | 8.4$^{ab}$±0.2 | 8.7$^{b}$±0.2 | ns | | | * | | | * |
| | | Cardboard | 8.7±0.2 | 8.8±0.2 | 9.0±0.2 | ns | | | ns | | | ns |

Data are mean values. Factors are: Treatment (T) — R0, R1, R2; Stage (S) — colour breaker or pink; Drop Height (DH) — 1 m or 0.5 m; Drop Surface (DS) — concrete or cardboard. The asterisk (*) indicates a significant effect. Values with different superscript letters differ within a column by Tukey's test ($p<0.05$). 'ns' = not significant.

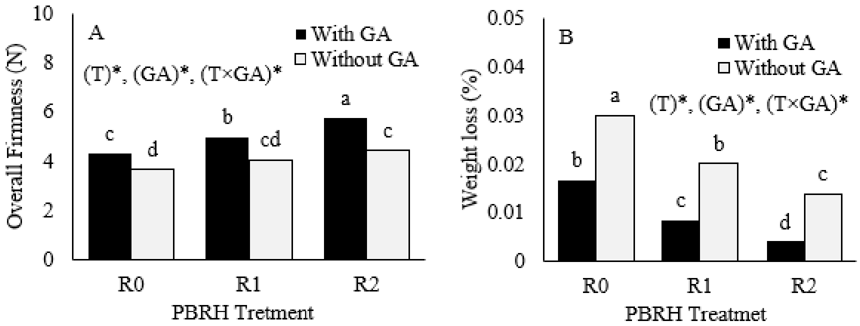


**Figure 03. Effect of PBRH application on (A) overall firmness and (B) weight loss % and (N) of pink stage tomatoes stored for three days with a gas absorbent sachet at room temperature (26 ± 1 °C) and RH (76 ± 1 %).** Data are mean values. Factors are; Treatment (T) either R0, R1 and R2 and Gas Absorbent treatment (GA) either with/ without GA. The asterisk (*) represents the significant effect of the factors. Values followed by different letters are significantly different according to Tukey's test ($p<0.05$).

***Keeping quality with gas absorbent***

The results of the experiment revealed that the gas absorbent (GA) sachet significantly decreased the weight loss percentage of tomatoes despite the PBRH treatment (Fig. 3). However, there was a significant reduction in weight loss percentage (0.41%) in the pink stage R2 treated tomatoes, which were stored for three days with a GA sachet (Fig. 3). Tomatoes become unmarketable within a few days of storage because of accelerated ripening and ethylene production (Guillén *et al.* 2007).

Studies have suggested that different gas absorbents can absorb ethylene and other gases that accelerate fruit ripening and extend the shelf life of fresh produce (Dobrucka et al. 2017, Guillén *et al.* 2007, Mansourbahmani *et al.* 2018). Mansourbahmani *et al.* (2018) showed that a palladium-based ethylene scavenger significantly reduced the weight loss percentage of tomatoes. There was no significant difference in the flesh firmness of R0, R1, and R2 tomatoes with the gas absorbent.

According to the experimental results, the overall firmness after three days of storage was significantly higher in tomatoes stored with GA than in those stored without GA. The overall firmness of R2-treated tomatoes stored with the GA sachet for three days was remarkably higher (5.77±0.01 N) than that of all other treatments (Fig. 3). The lowest overall firmness value was observed in the non-PBRH-treated tomatoes stored without the GA sachet. According to the findings of the research done by Mansourbahmani *et al.* (2018) ethylene absorbent reduces the softening process of tomatoes over the storage period. However, in our study, PBRH treatment, together with GA treatment, reduced the percentage of weight loss and delayed the firmness reduction of tomatoes upon storage. Both treatments ultimately led to an extended shelf-life, delay in ripening and improvement of the postharvest quality of tomatoes.

## CONCLUSION

In conclusion, this study revealed that incorporating PBRH as a soil amendment significantly affected various quality parameters, thereby increasing the postharvest quality of tomatoes. PBRH-treated tomatoes showed a significant improvement in fruit quality by improving colour (L*, a*, and a/b values) and overall firmness, ultimately leading to an extended shelf life. The best treatment was PBRH 0.6 kg $m^{-2}$ (R2), which showed significant improvement in overall firmness, colour and better keeping quality with a gas absorbent. Even though not significant, R2 treated fruits showed higher fruit weight, increased shelf-life, higher drop resistance, and improved storage quality than R1 and R3 treatments. These findings indicate that applying PBRH to the soil at a concentration of 2 kg per 3 $m^2$ plot effectively enhanced fruit quality, minimised postharvest losses, and may provide economic benefits for tomato farmers. Further research will be conducted to evaluate the social acceptability and economic viability of PBRH as a treatment for sustainable crop production in different agroecological regions.

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