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Effect of lactic acid bacteria and propolis extract on the control of post-harvest decay in tomato and its quality attribute changes

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Abstract
The postharvest exposure of tomato fruit, being a climacteric crop, has a limited postharvest life owing to the occurrence of postharvest diseases, rapid ripening and senescence which causes significant quantity and quality losses throughout the supply chain. This study investigated the bio-control efficacy of lactic acid bacteria (LAB) and propolis extract against the postharvest decay caused by bacterial and fungal pathogen such as *E. coli* and *Aspergillus* sp. respectively in tomatoes. Results indicated that there was a significant difference ($P < 0.05$) in the lesion diameter (mm) and disease incidence (%) of the tomatoes treated with LAB strain and propolis extract when compared to the control at the end of 6th day. LAB and propolis treated tomatoes on 6th day showed lower disease incidence of 75% and 60% for *E. coli* and 72 and 68% for *Aspergillus* sp. respectively. Thus, it indicated the efficacy of the antimicrobial agents in controlling the decay caused by *E. coli* and *Aspergillus sp*. Further, the postharvest quality changes were evaluated for the delay in the occurrence of disease when stored at 30 ºC and 95±2% relative humidity for 7 days. The results indicated that there was a significant difference between the control and treatment groups in all the (Postharvest quality) parameters such as pH, total soluble solids (TSS), titratable acidity (TA), weight loss and firmness at the end of the 6th day. These findings demonstrate that the LAB and propolis extract effectively contributed to the delay in senescence of tomato fruit, thereby extending the freshness and preserving the quality of tomatoes which are perceived as an important quality parameter by the end consumer.

Keywords: Bio-control, tomato, lab, propolis, senescence

Introduction
Tomatoes have become one of the most popular and ubiquitous fruits (labelled as vegetable) in the world. The FAO classed 15 vegetables, with tomatoes standing at sixth in terms of total annual world production (Ishtiaq *et al*., 2017). Tomatoes are ranked 4th in terms of worldwide importance as a commercially grown vegetable crop (Ahmed *et al*., 2017). They have a global output value of $50 billion, demonstrating their economic significance in comparison to another vegetable/fruit crops. In terms of global tomato output, it ranks second next to potatoes. Tomatoes originated in tropical America and were later introduced to Africa. It was then imported to Europe by Spanish immigrants in the 16th century, and its popularity extended to Asia as well. As it is more extensively eaten in affluent nations than in underdeveloped ones, tomatoes are considered the most valuable crop. Its output has risen to 163 million tonnes, with an area under cultivation of around 4.8 million hectares. China produces the most tomatoes (50 million tonnes), followed by India (17 million tonnes) (Firdous, 2021) [11].

Tomato (*Solanum lycopersicum*) is an important commercial crop and cultivated throughout India, with its application in diversified forms including a raw, ingredient in several salads, sauces, drinks, dishes etc. (Rodrigues & Kakde, 2019; Sowmya *et al*., 2022) [19, 22]. Tomato yields in India were 24.2 MT ha-1 whereas the global average was 33 MT ha-1, and the total average post-harvest losses of tomatoes were found between 4.2 and 18% (FAOSTAT, 2016). Naturally, tomatoes are rich in phytonutrients namely carbohydrates (dietary fibre), protein, vitamins and minerals. In addition to serving as food, they are also used as a dietary supplement, medication, flavouring agent, detoxifier and human system cleanser (Bello & Olawuyi, 2016) [5]. Tomatoes contain lycopene, beta-carotene, polyphenols including quercetin and kaempferol and vitamins C and E. Environmental elements such as temperature, light, and growth procedures may affect tomato fruit's technological, sensory, and antioxidant levels. Generally fresh produces take an extraneous way from harvest through sorting; packing and transportation undergo longer periods of storage before the arrival.

Over time, the fresh produce having a higher respiration rate acts as an excellent substrate for the growth of micro-organisms paving the way/leading to the spoilage/deterioration of fresh fruits/vegetables (rotting) being unfit for human consumption. The total post-harvest losses to the total production encountered were higher in tomatoes (15.16%), followed by beans (11.06), brinjal, (11.0%) and pea (10.06%) (Vegetable Statistics IIVR, 2011). The post-harvest life of tomatoes are affected by numerous primary and secondary factors along the supply chain: mechanical injury due to improper handling at the time of harvest, packing, transportation, storage, presence of insects and birds; microbial attack, environmental factors like temperature, humidity, gasses present in the atmosphere (Tilahun *et al*., 2017; SM, 2019; Kabir *et al*., 2020) [21, 13]. Hence, much of these losses are due to the invasion of several fungal pathogens on account of soft texture, high moisture content, rich nutrients, low pH and loss of intrinsic decay resistance. Appropriate microbiological information and fruit handling techniques would reduce the amount of waste. Tomato fruit is succulent with about 80% water content, low pH, and highly rich nutrients elements and sugars that served as a suitable medium for microbial growth (Bello & Olawuyi, 2016; Singh & Sharma, 2007) [5]. Being perishable, tomato is more vulnerable to damage due to its shape and structure, as well as its relatively soft texture, which is associated with a high moisture content; these factors contribute to rapid deterioration in transit and storage under the influence of high temperature and humidity; consequently, substantial losses are incurred (Erena, 2020) [9]. The two primary classes of microorganisms that cause decay in tomatoes are bacteria and fungi. However, viruses and nematodes, which may cause post-harvest illnesses and losses, do not cause tomatoes to deteriorate quickly (Etebu *et al*., 2013) [10]. These microbes render the fresh produce undesirable for human consumption as they deteriorate the texture and quality of tomatoes due to nutrient loss and off-flavour development.

Chemical fungicides have traditionally been used to reduce postharvest deterioration, but their widespread usage has raised serious concerns about human health and environmental concerns, spurring a quest for safer alternatives. Furthermore, customers prefer buying fruit with few or no pesticide residues, prompting importing nations to tighten import restrictions governing maximum residual levels in the edible part of the fruit (Vilaplana *et al*., 2018) [25]. The rate of degradation of the tomato crop is dependent on several aspects, and to reduce post-harvest losses, cost-effective and technologically appropriate procedures must be developed. To keep storage losses under control in the long haul, other alternatives, one of which is natural substances with a long-standing repute for antimicrobial and preservation qualities (Mari *et al*., 2016) [16]. Propolis, often known as "Bee-glue," is a resinous substance of bee colonies that honey bees use as an adhesive to repair and secure the hive entrance to prevent excluders from entering and to protect the beehive from germs (fungi, bacteria and viruses). It is richly nutrient composed of sugars, amino acids, several flavonoid compounds (chalcones, flavones, flavonoid), phenolic compounds, fatty acids, esters, triterpenes, minerals (Mg, I, Ca, Cu, Zn, Mn, Fe) and vitamins (C, B1, B6, B2, E) thereby providing exhibiting biological activities such as antimicrobial(anti-bacterial, anti-fungal, anti-protozoa, anti-viral), immune-modulatory, antioxidant, antidiabetic activity, anti-inflammatory, anti-cancerous and hepato-protective (Anjum *et al*., 2019; Lad Sunaina Sunil, 2021) [14]. Additionally, extensive research has been done in the recent years on the biological control of postharvest decay of fruits based on naturally occurring micro-organisms. Biological control using antagonistic bacteria is a new and appealing alternative among the several techniques to manage postharvest disease and decay caused by pathogens. It takes place with more than one mechanism of action such as through the production of anti-microbial substances, volatile organic compounds, antibiotics released by the antagonistic organism, competition for nutrients and space, siderophore production, secretion of cell wall lytic enzymes (Spadaro & Droby, 2016; Dukare *et al*., 2018) [23, 8]. Tomato's acceptability by wholesalers and customers is determined by postharvest quality characteristics such as pH, weight loss, titratable acidity (TA), total soluble solids (TSS) content, and firmness. Hence the objective of this study is to

1. Study the control effect of decay caused by *E.coli* and *Aspergillus* sp. and
2. Quality attribute changes on tomatoes during the treatment process for the post-harvest disease management in tomatoes.

Materials and Methods

Sample collection and materials

Mature, red ripened and healthy tomatoes were procured from a local market at Thanjavur, Tamilnadu, India. Fruits of uniform colour and size that were free of physical/mechanical harm or illness were chosen. Other chemicals, reagents, and microbiological mediums (AR grade) were obtained from Himedia Pvt. Ltd., Mumbai, India. For the whole research, sterile ultrapure Milli Q water was utilised.

Isolation of pathogens

Pathogenic bacteria (*E. coli*) and fungi (*Aspergillus sp.*) were isolated and partially identified from decayed/rotten tomato fruits for this experiment. Bacterial and fungal isolates were isolated from decayed tomato fruits using their respective growth medium such as nutrient agar (NA) and potato dextrose agar (PDA) respectively. One gram of the sample was suspended in 100 ml of sterile distilled water, serially diluted followed by spread plate technique (0.1 ml used) and incubated at 35 ºC for bacteria and 25 ºC for fungus. To obtain the pure culture of the isolated pathogens (bacteria and fungus), isolated colonies were picked from higher dilution and successively streaked in separate plates and stored at 4 ºC in nutrient broth and potato dextrose broth respectively for short-term maintenance. Further, the culture supernatants were extracted by centrifuging at 10,000 rpm (15 min at 4 ºC) and used for further assays (Zheng *et al*., 2011).

Isolation of Antagonist

Lactic acid bacteria (LAB) was isolated from the curd sample available at the local market at Thanjavur, Tamilnadu. One gram of the sample (wet weight) was suspended in 100 ml of sterile distilled water, serially diluted, followed by a spread plate on De Man Rogosa Sharpe (MRS) agar (Merck, Darmstadt, Germany). Further, the plates were incubated for 24 h at 35 ºC. After incubation, the milky white, pale-yellow colonies were identified and arbitrarily picked at higher dilutions, and successive streaking was carried out for purification. It was later transferred to MRS broth and stored

at 4 ºC for short-term storage. Later the culture supernatants were extracted by centrifuging at 10,000 rpm (15 min at 4 ºC) and used for further assays (Yashwant *et al*., 2021).

Preparation of propolis extract

Propolis extract was prepared by modifying the method followed by Lad Sunaina Sunil (2021) [14]. About Ten grams of the propolis were dissolved in 100 ml of 99% ethanolic solution in 1:10 (w/v) ratio and kept in a shaking incubator (SCIENTECH, Delhi) for 7 days at 200 rpm at 25 ºC. The extracted samples were filtered using Whatman No. 1 filter paper and centrifuged for 10 minutes at 4000 rpm. The collected supernatants were used as ethanolic extract of propolis (EP).

Control effect of L and PE on the post-harvest rot of tomatoes: The mature and healthy fruits were rinsed with sterile distilled water, disinfected with 70% alcohol solution, and air dried. Each of the sterile fruits was wounded (5mm wide x 5 mm depth) equally with a sterile corn borer at the equatorial zone of the fruit surface. An aliquot of 40 µL of the L suspension (24 h culture used) was inoculated into each wound, an aliquot of 40 µL of sterile distilled water was added to the wounds of the control group (C) and the fruits were stored at 30 ºC at 95±2% relative humidity in a relative humidity chamber. After 6 h, about 40 µL of an aliquot of pathogen suspension *E. coli* and *Aspergillus* sp. were inoculated into the same wound including control, air-dried and stored at 30 ºC at 95±2% relative humidity for 7 days. Lesion diameter (in mm) and disease incidence (%) were calculated after the control samples were completely rotten (spoiled). 10 tomatoes were used in each treatment for every pathogen and three replicates were taken independently for each treatment. The experiment was conducted only once (Parafati *et al*., 2015) [17] (Zhang *et al*., 2017) [27].

Effect of the bacterial strain L and propolis extract PE on the post-harvest tomato quality

To assess the effect of L and PE on the post-harvest quality parameters of tomatoes, freshly harvested fruits were treated and stored as described above. Quality parameters were measured on three replicates of every group of tomatoes each, after every 48 hrs and performed at ambient temperature (25 ºC). The testing methods are described below.

pH

The pH of the decayed tomato paste samples (10 g) were analysed for pH using the pH meter calibrated at pH 7.0 at 25 ºC.

Total soluble solids (TSS)

Three layers of cheese cloth were used to wrap the tomato paste, and the liquid was squeezed out. TSS was determined by placing 1- 2 drops of the juice samples using a hand held refractometer (SHIMADZU, Mumbai) and the results were expressed as percentage (g per 100 g fruit weight) (Kabir *et al*., 2020) [13].

Titratable acidity (TA)

The TA of the tomato samples were determined by the titration method. A 5ml sample of the juice was obtained and diluted with 95 ml of distilled water and phenolphthalein as a reference. TA was estimated by titrating against 0.1 N NaOH and expressing the results as a percentage of citric acid using the equation below (Eq. 1) (Al-Dairi *et al*., 2021) [3]:

$$\% \text{ Titratable acidity (g citric acid/ kg tomato)} = \frac{V \; X \; 0.1 \; X \; 1000 \; X \; 0.064}{m}$$

V is the volume of NaOH consumed (ml)
0.1 is the Normality of NaOH
0.064 is the citric acid conversion factor
m is the Amount of tomato juice added

Weight loss

The weight loss of the tomato fruit was measured using before the pathogen inoculation (A) and after storage with inoculation (B), and the weight loss was calculated using the following equation (Eq. 2) (Kabir *et al*., 2020) [13]:

$$\text{Weight loss\%} = \frac{A-B}{B} \text{ x } 100$$

Firmness

The firmness of tomato was measured at two equatorial areas using the Texture Analyser Stable Micro Systems TA HD plus. The firmness was measured using a 5 mm penetrometer probe. The maximum force (N) required to penetrate into the fruit sample was determined as firmness (Kabir *et al*., 2020) [13].

Statistical analysis

Minitab Statistical Software 21 was used to perform analysis of variance (ANOVA) on all experimental data that were subjected to this study. Tukey test was used to estimate the significance of differences between mean values at P <0.05. For graphical data analysis, Origin Pro 2022 Software was adopted.

Result and Discussion

Control effect of L and PE on the post-harvest rot of tomato

This study evaluated the efficacy of the strain L and PE in reducing decay development in tomatoes. The disease incidence and lesion diameter on both the treatments (L and PE) were significantly lower ($p < 0.05$) than those of the control. The results are presented in Fig. 1 (A & B) and it indicated that the disease incidence of the control was 100% at the 6th day, whereas L and PE treated groups were 75% and 60% respectively for *E. coli*. The same pattern was observed in *Aspergillus* sp. where the disease incidence of L and PE treated groups were 72% and 68% respectively. A similar pattern of control effect was obtained on the control of *Botrytis cinerea* in tomatoes by *Bacillus subtilis* (Bu *et al*., 2021) [6]. The lesion diameter of the L and PE treated groups were 15 and 13 mm respectively for *E. coli* which was significantly ($P > 0.05$) lower than the control (21 mm). A similar pattern was observed for the decay caused by *Aspergillus* sp. which was 10, 12 and 17 mm for PE, L and control groups respectively. These results were in accordance with the study on the control of grey and blue mould rot in kiwifruit, where the single and combined treatments of the yeast *Candida oleophila* and oligogalacturonide significantly ($P > 0.05$) reduced the lesion diameter in kiwifruits when compared to control (Gao *et al*., 2021) [12]. Interestingly, in this study, PE exhibited the best control effect when

compared to the *lactic acid bacteria* species L. It can be attributed to the presence of abundant anti-oxidant and anti-microbial properties of phenolic compounds present in propolis extract (Pobiega *et al*., 2019; Lad Sunaina Sunil, 2021) [14]. This result was consistent with the study conducted on the control of *Penicillium digitatum* in lemons, where the ethanolic extracts of propolis exhibited significant control ($P < 0.05$) of 60% disease incidence and lesion diameter of 1.9 cm which was lesser than control (100% and 5 cm respectively) in lemons (Abo-elyousr *et al*., 2021). However, there were no significant differences ($P > 0.05$) between propolis extract and lactic acid species for the control effect of *E.coli* and *Aspergillus* sp. in tomatoes. Hence these results demonstrated that the efficacy of PE and Lactic acid bacteria in the control of decay caused by *Aspergillus* and *E.coli.*

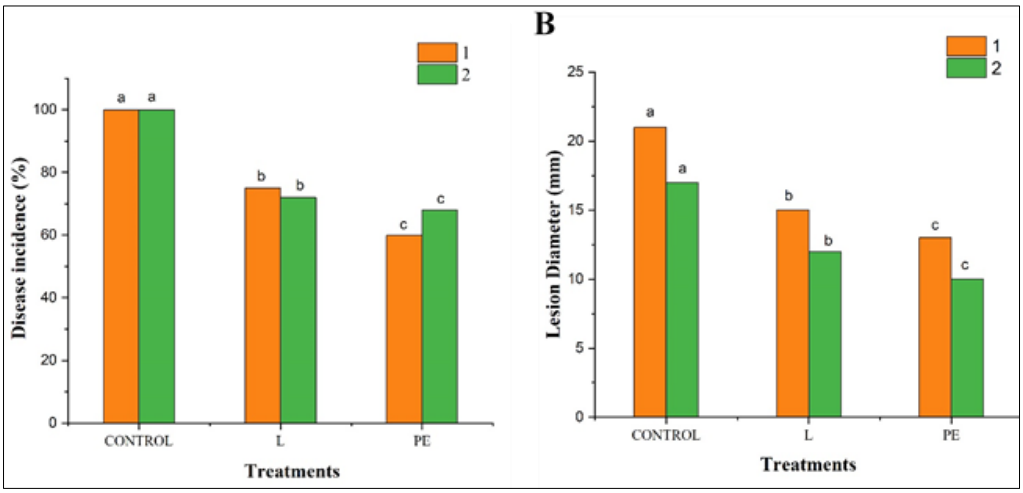


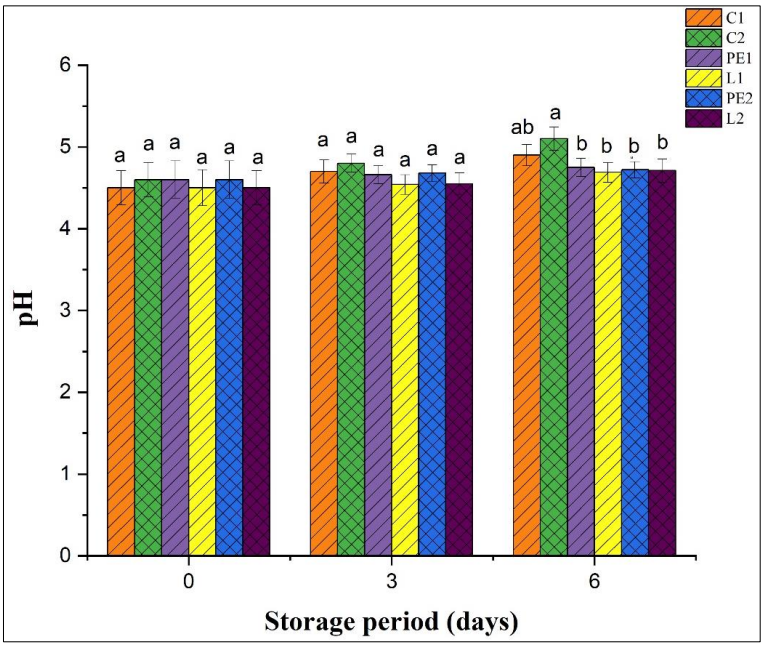
Fig 1: Effect of Propolis extract and LAB species on (A) Disease incidence (%) and (B) Lesion diameter (cm) of the control of post-harvest decay on tomatoes.

Data were analysed using one-way ANOVA and mean separations were performed using Tukey-test. Columns with different letters represent significant differences ($P < 0.05$) between treatment means. The scripts 1 and 2 corresponds to *E.coli* and *Aspergillus* sp. respectively. The same data analysis applies for Fig. 2,3,4,5 and 6.

Effect of the bacterial strain L and propolis extract PE on the post-harvest tomato quality

Changes in pH

The pH of tomato is an important quality parameter which is usually described as the fruit's acid content that contributes to the flavour of the tomato products. The change in pH of the tomato fruits for the control and treatments is represented in Fig. 2. In this study, the pH of all the groups of tomatoes generally increased during storage. This trend of increase in pH is due to the production of alkaline by-products into the tomato tissues which may be induced by the metabolic activity associated with the growth of micro-organisms (Wade & Beuchat, 2003) [26]. It could also be attributed due the ripeness level, length of the storage period, level of acids and ratio of sugars (Amadi *et al*., 2019) [4]. The PE and L treated groups showed decreased pH at every storage interval (3rd and 6th day) when compared to the control. The pH of *E.coli* control increased from 4.5 to 4.9 whereas in PE and L treated tomatoes, it increased from 4.6 to 4.75 and 5.5 to 4.69 respectively at the 6th day (no significant difference $P > 0.05$ between control and treatment). The *Aspergillus* sp. showed a significant ($P < 0.05$) increase in pH at the end of the 6th day of storage from 4.6 to 5.1, 4.6 to 4.72 to 4.68 for control, PE and L groups respectively. Even though there was no significant difference ($P > 0.05$) found between the treatments on the pH of tomatoes for the post-harvest decay control, the L treated group maintained a lower pH than propolis extract for both the pathogens (C1 & C2). This might be due to the acidic nature of the L and the alkaline nature of propolis which had contributed to maintain a lower pH in LAB treated samples than PE treated. The gradual delay in the increase of pH of all the treated groups was due to the effect of propolis extract and LAB sp., which had exhibited a control effect on the fruits treated with pathogens. Studies conducted by Wade *et al*., 2003 [26] on decayed tomatoes showed a similar trend with a wider range of pH shifts. In another study conducted on the antimycotic activity of alum on tomato deterioration where the pH of tomatoes treated with alum increased from 4.35 to 4.52 after two days of storage (Amadi *et al*., 2019) [4]. In spite of this, the higher pH (5.6) of the *Aspergillus* sp. is due to the secretion of several proteins and enzymes (cellulases, polygalacturonases) by the fungus during the deterioration process as the change in pH affects the ionic characteristics of amino and carboxyl groups on protein as well as the catalytic site and conformation of the enzyme (Ajayi & Olasehinde, 2009).



*C represents control, PE- propolis extract, L-LAB strain and the scripts 1 & 2 corresponds to *E. coli* and *Aspergillus* sp. respectively.

Fig 2: The changes in pH on the post-harvest decay of tomatoes during storage

The data are represented in mean ± SE of three replicates. Values with different letters at each day indicate significant differences ($P < 0.05$) between the treatment means.

Changes in TSS

Total soluble solids (TSS) in ºBrix is a measure of ripeness and a gauge for the number of accessible minerals and sugars in fresh food that are present. The changes in total soluble solids of tomato fruits during storage are represented in Fig. 3. Generally, the TSS of all the fruits decreased during storage; however the decrease in TSS of control groups of both the pathogens was higher when compared to treat ones. It was observed that there were no significant ($P > 0.05$) changes in the TSS of control and treated fruits till the end of 3rd day. However, there was a significant difference ($P < 0.05$) in the TSS content of control and treated tomatoes, where the TSS of PE and L treated samples were 4.5 & 4.3 for *E.coli* and 4.6 & 4.4 for *Aspergillus* sp. respectively at the 6th day. Hence it is demonstrated that the antimicrobial treatment on the fruits inoculated with pathogen had delayed the decrease in TSS during the storage period. This was in accordance with a previous study on tomatoes artificially inoculated with *Alternata* sp. and *Penicillium* sp. and treated with different concentrations of natural nanoparticles, where the soluble solids decreased from 4.87 to 2.73 and 5.53 to 4.43 respectively after 20 days of storage (Abdel-Rahman *et al*., 2020) [1]. However, the overall trend in TSS decline during storage may be related to the use of simple sugars (produced as a consequence of polysaccharide hydrolysis during the ripening process) and carbohydrates by microorganisms during fruit cellular respiration. Reduced respiration and metabolic activity resulted in a delayed conversion of carbohydrates to sugars, resulting in lesser soluble solids. (Safari & Ding, 2020) [20]. Hence, both L and PE were able to maintain the decrease in TSS content as far as posible and thereby delaying the senescence of the fruit.

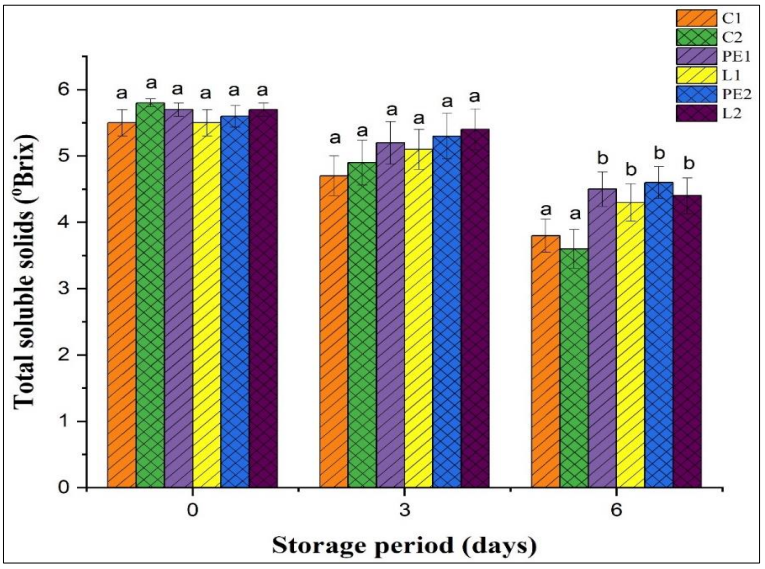


Fig 3: The changes in total soluble solids on the post-harvest decay of tomatoes during storage.

The data are represented in mean ± SE of three replicates. Significant differences (P < 0.05) between the treatment means values are indicated by different letters at each day

Changes in Titratable acidity

The changes in titratable acidity of the tomato fruits are depicted in Fig. 4. The acidity at harvest (TA) is the single most important measure that reflects the storage qualities of the tomato fruit. The changes in the titratable acidity of tomato fruits during storage are represented in Fig. 4. It is observed that there is a decrease in TA as storage time increases which is in accordance with the results obtained in pH; however the decrease in TA of control groups (*E.coli* & *Aspergillus* sp. alone) were higher on compared to the treated tomatoes. There observed a significant difference (P > 0.05) between the control and PE and LAB sp. treated groups from the end of 3rd day of storage. The TA was 0.23, 0.39, 0.43 and 0.25, 0.38, 0.4%in control, PE, L group of tomatoes for *E.coli* & *Aspergillus* sp. respectively at the 6th day. The presence of L helped maintain higher acidity than PE treated tomatoes. The overall pattern of TA decline during storage may be attributed to the continuation of the fruit ripening and senescence processes, which entail a rise in the rate of respiration, which would be responsible for the degradation of organic acids such as malic and citric acids present in tomatoes (Sugri *et al*., 2013; Amadi *et al*., 2019) [4]. These findings are in agreement with a study on coating of chitosan and vannilin for post-harvest quality deterioration of tomatoes (Safari & Ding, 2020) [20].

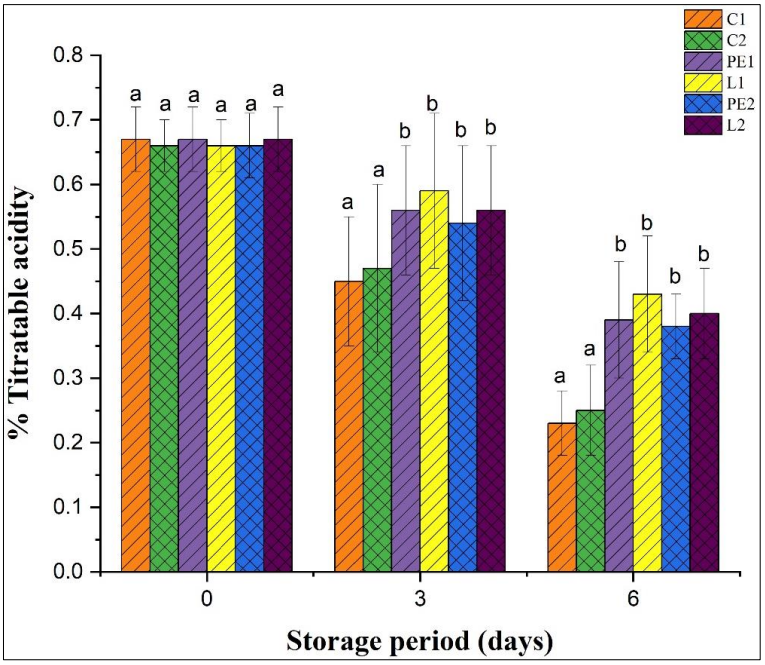


Fig 4: The changes in titratable acidity on the post-harvest decay of tomatoes during storage.

The data are represented in mean ± SE of three replicates. Significant differences (P < 0.05) between the treatment means values are indicated by different letters at each day

Changes in weight loss

The relative change in weight loss of tomatoes on storage is represented in Fig. 5. Weight loss in fruits is generally caused by respiration and diffusion through the surface of agricultural commodities, thereby resulting in a decrease in the quality. Additionally, slight variations in relative humidity at a constant temperature might result in significantly greater vapour pressure (Kabir *et al*., 2020) [13]. In this study, there prevailed a drastic increase in weight loss in the storage of tomatoes at constant relative humidity and temperature. There prevailed a significant difference in weight loss between control and treatment groups right from the 1st day, with control groups suffering an extremely higher weight loss than tomatoes treated with L and PE. The drastic percentage increase in weight loss in PE and L-treated tomatoes were 1.3 – 2.8% and 1.5 – 7.9% in tomatoes artificially inoculated with *E. coli* which was lesser when compared to control which was 10.3% at the end of the 6th day of storage. A similar trend was observed in tomatoes treated with *Aspergillus* sp., however, the lowest weight loss was exhibited by L treated tomatoes. Consequently, the slower rate of moisture loss for the treated samples from the fruit may be due to the addition of an antimicrobial agent which had created a layer of barrier against diffusion through stomata (Safari & Ding, 2020) [20]. A similar trend was observed in a study on the biocontrol efficacy of *Bacillus subtilis* on the post-harvest grey mold of the tomato where there was no significant difference in weight loss between the control and treatment groups (Bu *et al*., 2021) [6]. However, the drastic variation in the overall significant difference between the controls and between the treatments from day 1 indicated variations in physiological character as the tomatoes subjected to this may vary due to differences in size, different cultivators, the different temperature of storage and handling, different maturity stage at harvest (Pinheiro *et al*., 2013) [18].

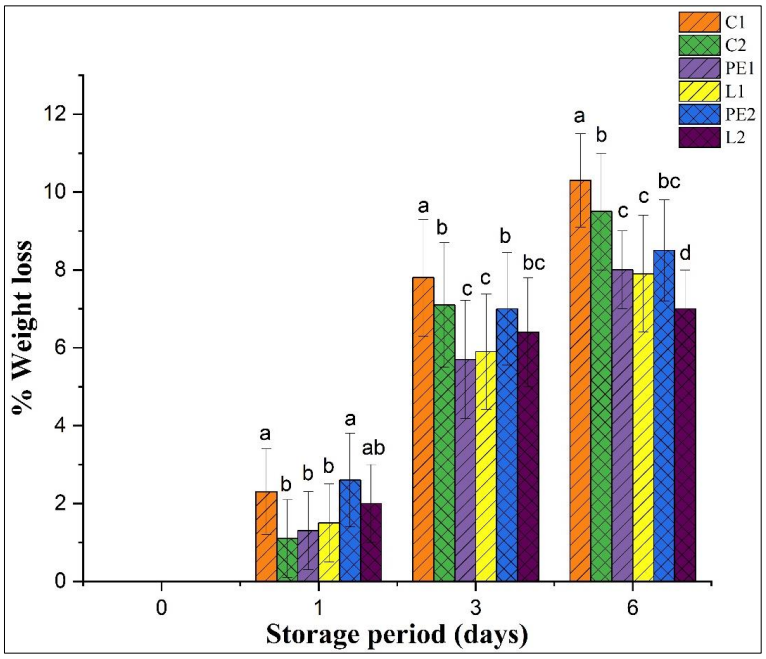


Fig 5: The changes in weight loss on the post-harvest decay of tomatoes during storage.

The data are represented in mean ± SE of three replicates. Significant differences ($P < 0.05$) between the treatment means values are indicated by different letters at each day

Changes in Firmness

Firmness is a target trait in tomatoes as it is an important aspect of quality as it facilitates storage and transportation. The changes in the firmness of tomato fruits during storage are depicted in Fig. 6. The firmness generally decreased in both control and treated groups during storage. This behaviour is a result of the softening of tissues induced by the breakdown of cell wall components and the rise in soluble pectin concentration, which reduces cohesive forces and weakens cell walls (Majidi *et al*., 2014) [15]. In this study, there was a significant difference in the firmness of control and treatment groups from 1 to 6 days. However, the L and PE treated tomatoes exhibited an increased firmness (34 and 38 N respectively) than the control (14N) for *E.coli* inoculated group. Similarly in *Aspergillus* sp. group; the L and propolis-treated tomatoes it was 37 and 30 N respectively at the end of the 6th day of storage. However, there were extreme variations in firmness as the data presented exhibited significant differences ($P > 0.05$). This behaviour can be due to the variations in physiological character as the tomatoes subjected to this may vary due to differences in size, different cultivators, the different temperatures of storage and handling, and different maturity stages at harvest. This was inconsistent with the results obtained in a study of change in the physical quality parameter of tomatoes on storage. (Pinheiro *et al*., 2013) [18].

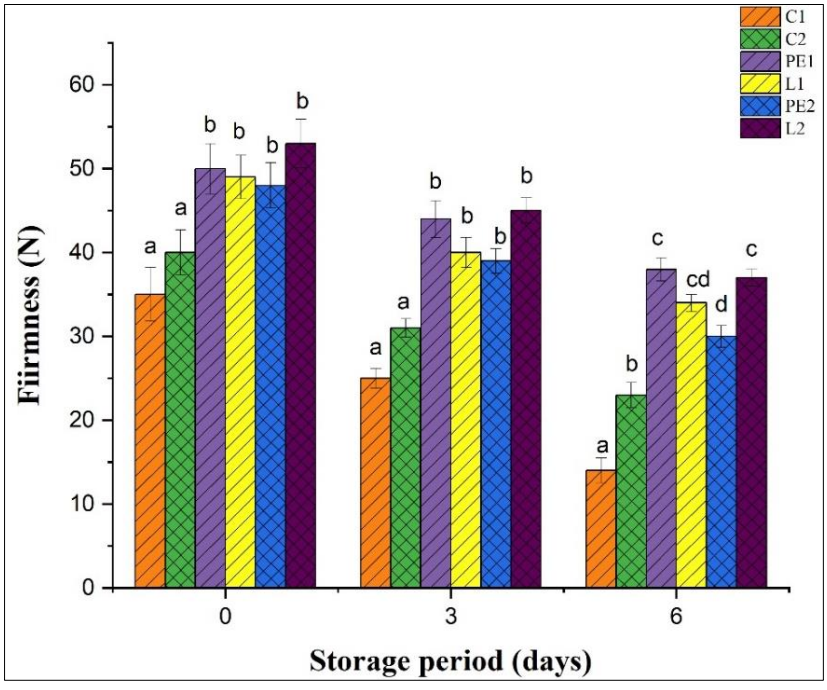


Fig 6: Changes in firmness on the post-harvest decay of tomatoes during storage.

The data are represented in mean ± SE of three replicates. Significant differences ($P < 0.05$) between the treatment means values are indicated by different letters at each day.

Conclusion

Altogether, our findings indicated that the application of PE and L constitutes a successful management approach to the postharvest degradation brought by tomatoes during fruit storage, hence preserving the postharvest quality. Therefore, we propose that L and PE may be a promising biocontrol agent against the postharvest decay of tomatoes caused by *E. coli* and *Aspergillus* sp. However, this work has just gone one step toward the use of biological agents in the postharvest preservation of fruits. Further research has to be explored on the in-vitro antimicrobial activity for the quantification of the inhibitory effect of these biological agents for the control of postharvest decay in tomatoes. Therefore, to effectively prevent postharvest diseases of perishable crops, particularly tomatoes, integrated approaches may also be used.

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