



(RESEARCH ARTICLE)



Nutritional and keeping quality of round gourd in response to exogenous application of salicylic acid during storage

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Abstract

The researchers studied the impact of salicylic acid (SA) coating treatment on the nutritional quality and shelf life of the round gourd as well as its postharvest parameters during storage. The use of SA was assessed with regard to its effects of weight loss, marketability, diseases occurrence, and its many sensory properties which include: aroma, taste and firmness, texture, and color. Moreover, the nutritional values that included protein, ash, fats, ascorbic acid, reducing sugars, non-reducing sugars, and total soluble solids (TSS) were also examined to check how the gourd nutritional value had been affected after coating with SA. An elemental and AI FTIR (Fourier-transform infrared) analysis were also conducted to learn the biochemical alterations in storage. Findings depicted that the nutritional quality of foods enhanced by SA coating with a lessened weight loss and a longer shelf life taking place, through pathogen containment and the maintenance of sensory characteristics. These results indicate that SA coating may become a viable strategy to enhance the marketability of round gourds and its postharvest life quality.

Keywords: FTIR; Bio-Chemical Analysis; Elemental Analysis; TSS; Physiological Parameters

1. Introduction

Exogenous salicylic acid (SA) is also crucial in regulating physiological processes of plants, especially developing their resistance to stressing conditions and showing defense response (Zhao et al., 2017). SA is a naturally-occurring plant chemical which is also capable of regulating the various plant functions such as disease resistance. Research has contributed to the finding that SA lowers the production of ethylene hormone in plants which plants and fruits speed up the ripening process. Also, it is possible that the SA might not allow any growths of fungi and free radicals and both of them are capable of deteriorating the quality of the fruits. The gray mold rot can be managed successfully and the storage life of kiwi fruit can be prolonged by SA (H. Fatemi et al., 2013). Round gourd contains a lot of potassium that keeps the blood pressure at normal levels and lowers the risk of cardiovascular diseases. Its fiber and antioxidants sustain heart healthy conditions in lowering cholesterol levels and prevents oxidative stress in the cardiovascular system (Raghav P and Jain M et al., 2019). Also, SA leads to the capacities of Plants that can experience various abiotic stresses including primarily drought, salinity, and extreme temperatures. This is done through the regulation of the antioxidant system, which relieves the oxidative stress and spares the plant cells against injuries (Hayat et al., 2012). Other impacts of exogenous AS besides stress responses are on plant growth and development. It needs to control seed germination, roots development and flowering even though its impacts differ based on SA concentration and environmental conditions of the plants (Sharma et al., 2013). Moreover, it has been reported that SA controls metabolic functions like photosynthesis and nutrient absorption enhancing the overall plant growth during the stress (Verma et al., 2016). Literature review has revealed the ability of SA treatment to enhance the antioxidant activity in fruits due to its effect on increasing levels of compounds such as ascorbic acid and phenolics (Mohamed et al., 2017). This addition

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of antioxidant capacity would assist in defense mechanism of the fruits with the oxidative degradation that would improve their quality and shelf life better. Also, SA can postpone the ripeness due to the prevention of an ethylene synthesis that has been called the plant hormone, a hormone that prompts the process of ripening and fades away plants (Lolaei et al., 2012). This slows down ripening which makes fruits in this way stay firm, colored and tasting longer. Moreover, one of the ways that SA can promote nutritional value of fruits is through elevation of essential nutrients, such as vitamins, minerals, or dietary fiber (Youssef et al., 2017). SA coating can enhance several biochemical factors that influence fruit quality, and thus lower post-harvest fruit wastage as well as consumer satisfaction. In spite of its importance there are obstacles which jeopardize its productivity and quality such as poor weather conditions, seed quality, and disease, insects and mite's damage. It is commendable to note that insect and mite pests negatively affect the dependent yield as well as quality of round gourd (Sita Nehra et al., 2019). One of the commonly consumed and economically valuable vegetable, round gourd, has been known to suffer postharvest losses because of the ease of its spoilage during storage. To eliminate this, there is a requirement to find ways of enhancing its shelf life and its nutritional value keeping it intact. In different crops, salicylic acid (SA) has been shown to have potential as a plant growth regulator and as a way of inducing stress tolerance. Yet little is known of how it may affect the round gourd after harvest in terms of quality and nutritive value. Hence, the aim of this study to determine the impact of the exogenous application of SA on the nutritional composition of round gourd and to extend the shelf life of round gourd by decreasing spoilage and maintaining quality of round gourd during storage was attained.

2. Materials and methods

2.1. Fruit material

Fresh round gourd fruits weighing 10 kg were obtained from a local farm in Lahore, institute of chemistry at university of engineering and technology, Pakistan. The fruits were carefully harvested at the desired stage of maturity, ensuring uniformity within the samples. Fruits were grown under irrigation during the hot summer months (March to June) and as rain-fed crops after the monsoon (August to October). Any damaged or diseased fruits were excluded from the study. Round gourd fruits were cleaned by first immersing them in a solution of sodium hypochlorite for disinfection. They were then rinsed with tap water in order to remove contaminants. Freshly harvested round gourds were subjected to a dipping treatment in salicylic acid solutions at four different concentrations: 0 mM (control, CK Water Dipping), 2 mM, 6 mM, and 10 mM Each round gourd was immersed in the respective SA solutions for a duration of 10 minutes. After treatment, the round gourd was stored for 16 days at 4°C. To track alter over time, samples were collected and analyzed on days 1, 4, 8, 12, and 16.

2.2. Fruit firmness (N)

A digital penetrometer was used to evaluate the firmness of the round gourds. A single measurement was taken from each gourd to ensure consistency in data collection. To enhance accuracy, two measurements were performed for each replication, taken from opposite sides of the fruit's equatorial region. This method provided a more comprehensive assessment of firmness by accounting for potential variability across different areas of the gourd. The average of these two measurements was calculated and considered the most representative value, ensuring a reliable and precise evaluation of the fruit's firmness (M. Javed Tareen et al., 2012).

2.3. Weight loss (%)

Weight loss was determined using a digital weighing balance (Model: SHIMADZU, ELB12K) and recorded in grams. The cumulative weight loss of the fruit was expressed as a percentage and calculated using the following formula (Sakeena Tul-Ain et al., 2019)

$$\text{Fruit weight loss} = \frac{\text{Initial weight}(g) - \text{final weight}(g)}{\text{final weight}} \times 100$$

2.4. Marketability index (%)

The marketability index was determined by calculating the number of healthy fruits observed visually was expressed as percent. Each replication was tested for marketability for all days of data recording

$$\text{Marketability index (\%)} = \frac{\text{number of healthy fruits}}{\text{Total fruits}} \times 10$$

2.5. Fruit visual quality (score)

One bunch of round gourd fruits from each replication and treatment was randomly placed at designated marked locations. A panel of five judges visually examined the fruits and recorded their evaluations using an assessment proforma. An average score was calculated for each treatment. The visual quality of the fruits was rated on a 1-9 scale, where 1 indicated poor and inedible, 3 represented fair and the usability limit, 5 indicated good and the marketability limit, 7 signified very good, and 9 represented excellent with a fresh appearance (Ibrahim et al., 2018).

2.6. Fruit decay (Score)

Fruit decay was assessed visually using a 1-9 scale, where 1 indicated no decay, 3 represented slight decay, and 4 signified moderate decay. A bunch of fruits from each replication and treatment was randomly placed at designated marked locations. A panel of five judges visually examined the fruits and recorded their evaluations using an assessment proforma. The average score for each treatment was then calculated to provide a representative measure of fruit decay (Kader et al., 1973).

2.7. Disease incidence (score)

The data on the rate of the disease was calculated during the storage period, and all illness or damaged round gourd fruits were immediately deleted. The percentage incidence of the disease was calculated using the following formula and was expressed in % (acaseena tul-ain hater et al, 2019).

$$\text{Disease incidence (\%)} = \frac{\text{number of spoiled fruits}}{\text{Total number of fruits}} \times 100$$

2.8. Organoleptic evaluation

Fruits were tested using a 1-9 scale to assess organoleptic properties such as color, taste, texture, flavor, and overall acceptance (Peryam and Piligram, et al., 1957). A panel of five judges completed the questionnaire for evaluating organoleptic properties of fruits. Average score was considered for each treatment. Organoleptic properties were rated on the basis of a 1-9 scale, viz 1=poor (inedible, 3=fair (limit of usability), 5=good (limit of marketability), 7=very good, 9=excellent and fresh.

2.9. Total soluble solids (TSS) (Brix)

A few drops of round gourd juice were placed on the digital hand refractometer to calculate the total soluble solids (TSS) at room temperature. The value of TSS was expressed in Brix.

2.10. Determination of moisture content

To determine the moisture content of a round gourd fruit, the sample was placed in a China dish and dried in an oven at 70 degrees Celsius. The first weight of the fruit was recorded, and then the weight was measured again after complete drying. The moisture content was calculated using this formula

$$\text{Moisture content \%} = \frac{w_1 - w_2}{\text{weight of sample}} \times 100$$

2.11. Determination of protein

In order to analyse the protein content of 1g sample, 30 ml of concentrated sulfate was added after first combining with a 5 g digestive mixture in the digestion balloon. Next, the mixture was heated for 3 hours to complete digestion process. After cooling, the digest was diluted to a final volume of 250ml with distilled water. A 10ml aliquot of this diluted solution was transported to a distillation apparatus, where it was mixed with 10ml of 40% NaOH. The mixture was distilled and the distillate was collected in a 250 ml Erlenmeyer flask containing 10 ml of boric acid and 2 drops of naphthalene indicator. The color of the solution changed to yellow, indicating the presence of ammonia. This solution was then titrated with sulfuric acid using a burette and the titration reading was recorded. The final protein content was calculated by multiplying the titration volume by 2.2 times.

2.12. Determination of crude fiber

The determination of crude fiber content of pumpkin samples was carried out following the standard procedure of AOAC (2003). First, a 2-gram amount from each sample was mixed with a solution containing 1.25% H₂SO₄ 40.31 N NaOH (volume 200 ml). The mixture was then boiled for 30 minutes. The residue was washed twice with ethanol and

petroleum ether and then dried overnight in a pre-weighed crucible at a temperature of 100°C. Following the aforementioned procedure, the crucibles were subjected to a controlled heating process within a muffle furnace, precisely set at a temperature of 600°C, for a duration of six hours. Subsequently, a period of cooling was granted to the crucibles, after which their weights were meticulously reevaluated. These weight differences were expressed as a percentage of the initial sample weight as reported by Nielsen in 2010.

$$\% \text{ Fiber} = \frac{w_1 - w_2}{w_3} \times 100$$

- W₁ = weight of the sample before heating
- W₂ = weight of the sample after heating

2.13. Determination of crude fats

The crude fat content in round gourd sample was measured using a standardized method from the Association of Official Analytical Chemists (AOAC) from 2003. In this process, petroleum ether was used as a solvent to extract the fat. Five grams of each sample were placed into a Soxhlet apparatus, along with 55 mL of petroleum ether. The mixture was heated for six hours, and then the solvent was removed using a vacuum rotary evaporator at 40°C. The remaining fat was dried in an oven at 70°C for 30 minutes. To measure the fat content, the weight of an empty flask was subtracted from the total weight. The percentage of crude fat was calculated using the weight of the dried fat according to the method described by Nielsen and Carpenter in 2017. The formula used to determine the crude fat percentage is:

$$\% \text{ Fat} = \frac{(W_1 - W_2)}{W_1} \times 100$$

2.14. Determination of Ash

A sample of round gourd was analyzed for ash content. The procedure began by taking a crucible and recording its weight. Then, 3 grams of the round gourd sample were added to the crucible. The crucible, with the sample, was placed into a muffle furnace for four hours. After the heating process, the sample turned to ash. The crucible with the ash was then weighed again to determine the ash content of the round gourd sample. The formula used to determine the crude fat percentage.

$$\% \text{ Ash} = (w_3 - w_1) \times \frac{100}{w_3}$$

2.15. Determination of ascorbic acid

The quantification of vitamin C in the sample of round gourd was conducted using the 2, 6-dichloroindophenol-dye method as outlined by Ruck in 1961. A total of 10 grams of the fruit sample was combined with 2.5 milliliters of metaphosphoric acid solution, which had a concentration of 20%. The resulting mixture was then diluted with distilled water to a final volume of 100 milliliters. Next, a volume of 10 ml of the suspension was subjected to titration using a recently prepared standard solution of 2, 6-dichloroindophenol. The titration process lasted for a duration of 15 seconds, during which a light pink color became visible. The concentration of vitamin C was quantified and reported as milligrams per 100 grams of the sample. The mean value was computed and subsequently subjected to statistical analysis.

$$\text{Ascorbic acid} = 1 \times R_1 \times V_R \times W \times V_1 \times 100$$

2.16. Determination of total sugar

In a 100 mL volumetric flask, 25 mL of a pre-prepared solution was combined with 5 mL of concentrated hydrochloric acid and 20 mL of distilled water. The mixture was then left for 24-48 hours to ensure complete hydrolysis, converting non-reducing sugars into reducing sugars. The final volume was adjusted with distilled water the following day. Phenolphthalein was used as an indicator, and 0.1 N NaOH was added for neutralization. For total sugar analysis, the solution in the burette was titrated with 10 mL of Fehling's solution. Using the resulting data, total sugar content was calculated with the appropriate formula

$$\text{Total sugar} = 25 \times \frac{A}{C}$$

2.17. Determination of reducing sugar contents (%)

This solution was made by 10 mL Fehling solution adding 2-3 drops of methylene blue trihydrate solution was grasped against 2mL burette and with aliquot drops on boiling the solution to that time the brick color originates. The quality of aliquot use was writing down and further plan of action to observe reducing sugars is as

$$\text{Reducing sugar (\%)} = 6.25 \times \frac{A}{B}$$

2.18. Determination of non-reducing sugar contents (%)

Non-reducing sugar was calculated as

$$\text{N-R-S (\%)} = 0.95 \times (\text{Total inverted sugar} - \text{Reducing sugars}) \text{ By (Hortwitz, 1960) formula By Hortwitz, 1960.}$$

2.19. Determination of NFE

Nitrogen-free extracts believe in non-fiber carbohydrates such as sugar and starch. The only immediate analysis estimation value based on the difference Chemical analysis with appropriate calculations is a definition without nitrogen. Equation for extract without nitrogen:

$$\% \text{ NFE} = 100 \% - (\text{humidity} + \text{raw protein} + \text{ash} + \text{fat} + \text{raw fiber})$$

Since the caricature extract is defined as a difference, the overall analysis of the nearest analysis. The error is extracted without nitrogen.

2.20. ATR-FTIR spectral analysis

Fourier transform infrared spectroscopy (FTIR) measurements were performed using an Agilent Cary 630 FTIR spectrometer equipped with a diamond attenuated total reflection (ATR) accessory. Measurements covered the spectral range of 4000-450 cm⁻¹ with a spectral resolution of 4 cm⁻¹. For each FTIR spectrum, three scans were averaged and infrared (IR) spectra were obtained based on an accumulation of 128 scans. Methanol extracts (50 µL) of each pumpkin sample were applied to the germanium crystal of a ftir and dispensed by a pipette tip. Prior to measuring the samples, background spectra were collected from the surface of an empty germanium crystal and automatically subtracted from the sample spectra. Between spectral collections, the crystal cell was washed with a methanol rinse, wiped with soft tissue, and then dehydrated (Lahcen Hssaini et al., 2021).

2.21. Determination of mineral analysis

The analysis of minerals is necessary to know the nutritional profile and bio chemical composition of the round squash, as it includes quantification of macro and micro minerals. include calcium (Ca), potassium (K), magnesium (Mg), sodium (Na) and phosphorus (P), and the trace elements include Iron (Fe) and Zinc (Zn) and manganese (Mn), copper (Cu) and selenium (Se) in smaller amounts to facilitate a number of physiological functions. Acid digestion A mixture of nitric acid (HNO₃) and perchloric acid (HClO₄) is used to break down a given sample of minerals making their mineral content available to measure by successively preparing round gourd samples. Each mineral is then measured using special methods of analysis after digestion. To give an example, calcium, magnesium, iron content can be determined through atomic absorption spectroscopy (AAS) with a Z-8230 Polarized Zeeman Atomic Absorption Spectrophotometer, potassium content through a flame colorimeter and phosphorus through a standard spectrophotometer. Comparison of the sample measurements with known standards yields accurate mineral concentrations, and this will be useful information on nutritional quality of the entire round gourd.

2.22. Stats

The statistical analysis of round gourds using the Origin and excel software centered on assessing the impacts of treatment on quality variables of the moisture content, firmness, and TSS during the process of storage. One-way ANOVA demonstrated significant differences through different treatments and the storage times (p < 0.05). Regression and correlation analysis showed how quality reduces with time and related quality attributes and attributes that are necessary to maintain good quality of round gourds, respectively.

3. Results and Discussion

3.1. Weight loss

The analysis of weight loss in round gourds treated with salicylic acid (T1, T2, T3) compared to a control group (T0) revealed statistically significant findings. The control group maintained a mean weight of 37.20 kg (\pm 3.21) and served as the baseline. The application of salicylic acid in treatments T1, T2, and T3 resulted in progressively lower mean weights, with T1 averaging 32.00 kg (\pm 2.66), T2 showing the most significant reduction at 24.00 kg (\pm 3.49), and T3 at 26.40 kg (\pm 2.24). These results suggested that salicylic acid coatings played a substantial role in promoting weight loss, with T2 demonstrating the greatest effect. This significant treatment effect aligned with past findings on salicylic acid's physiological impact on stored produce, including weight and quality preservation by slowing ripening processes and reducing water loss (Srivastava and Dwivedi, 2000). Research showed that salicylic acid's ability to enhance stress resistance and modulate metabolic responses, including inhibiting ethylene production—a hormone closely associated with fruit ripening—likely contributed to observed weight loss reductions in treated gourds (Khan et al., 2015).

3.2. Firmness

The effects of a salicylic acid coating with 10mM solution on the round gourd firmness during the storage period created a significant positive role in the preservation of the texture and the influence of softening. The results in the form of observations revealed that both control (uncoated) and salicylic acid coated gourds had initial similar firmness. As storage continued, however, the individual difference became very clear; firmness declined more in both groups but the pace was much slower in the coated fruits. The tendency reflects that the 10mM coating with salicylic acid was efficient in inhibiting the loss of firmness as compared to the control group. Several studies have revealed that salicylic acid can induce plant defences, which could be in the form of strengthening the cell walls using the accumulation of lignin, suberin, or other structural polysaccharides (Leslie and Romani, 2020). Ethylene is a ripening hormone, which has been associated with the ripening process in climacteric fruits by quickening the process resulting in their softening and other ripening related characteristics. Salicylic acid was found to curb ethylene formation therefore retarding the ripening process and the consequent softening (Asghari and Aghdam, 2010). This is because the ethylene can be reduced through the method of coating the round gourd in a layer of salicylic acid thus preventing the fruit from becoming too soft too soon. These results correspond with other studies that have shown that salicylic acid has the ability to prolong the postharvest life of fruits by preventing ethylene synthesis as well as retaining cell wall integrity (Srivastava and Dwivedi, 2000). Consequently, coatings of salicylic acid have been developing as one of the promising methods in retention of fruit quality, lowering softening rates and increasing consumer acceptability.

3.3. Visual quality

The findings identify the promise of salicylic acid as a post-harvest treatment to increase shelf life but maintain visual appeal. The control fruits (uncoated) and those that are coated with 10mM SA have equally high initial visual quality scores at the beginning of the experiment. The SA-coated fruits in the storage period continually had a better visual quality score than the control versions. Salicylic acid is a broadly recognized phytohormone that takes part in different safety procedures. It has been demonstrated to increase the tolerance of fruits to the environmental stresses and reduce activities related to senescence like the breakdown of cell walls and oxidation (Bari and Jones, 2009). The abundance of ethylene is linked to enhanced aging which is caused by a reduction in visual attractiveness (Lashbrook et al., 1998). It has been reported that salicylic acid prevents the formation of ethylene, which reduces the rate of ripening and increases the shelf life of fruit appearance (Zhang et al., 2017). Findings indicate that the potential approach would be a salicylic acid coating to ensure a longer shelf life and to keep fruits in good appearance. The ANOVA results showed that the various treatments that transpired such as the use of salicylic acid, did not have any significant difference in the visual quality of the samples.

3.4. Marketability index

The marketability index of round gourd samples that contained different concentrations of salicylic acid was carried out and the result showed that salicylic acid positively influences maintaining the market quality of the fruit in storage. The marketability index of the control group (T0) that was not subjected to any application of salicylic acid was categorized with the lowest percentage of 4% and it indicates that untreated gourds lowered in marketability level more quickly as compared to treated samples. This is congruent with the studies that reported softer fruits without any preservation treatments to be prone to rapid losses in visual attractiveness and quality since the fruits experience natural ripening effects and physiological alterations in the post-harvest process (Hassanpour et al. 2015). This corresponds to the index being slightly over 8% in this group (10 mM). These findings are in agreement with the past reports showing that salicylic acid could effectively postpone the ripening and lower post-harvest loss through various physiological

responses like regulating ethylene formation and antioxidative defense (Asghari and Aghdam, 2010; Srivastava and Dwivedi, 2000). It was observed that treatment of salicylic acid increased the marketability of round gourds in a concentration-dependent manner where this enhancement was highest at a concentration of 10 mM. The t-test was not significant; however, the results are indicative of the possibility of salicylic acid as a treatment in order to prolong the market life of round gourds as supported in other studies in which salicylic acid delayed ripening and maintained post-harvest quality.

3.5. Texture

The bar graph demonstrated how a 10 mM coating of salicylic acid on the surface of round gourd affected the texture of the fruit after a twenty-day storage period when compared to an untreated, control. The control and treated samples have equivalent texture scores by the 20th Day, which implies that salicylic acid efficacy decreases with long-term storage. The effect of the coating of salicylic acid has been shown to keep the round gourd samples with better scores in terms of texture, especially by the Day 10. Salicylic acid has been referred to play cell wall strengthening and minimization of the consequences of softening enzyme (Shafiee, Taghavi, and Babalar, 2010). This decrease of ethylene synthesis which is a ripening hormone stimulated by exposure to salicylic acid could make the fruit maintain firmness as it avoids textural degradation (Asghari and Aghdam, 2010). The results show that the use of salicylic acid is a possible coating treatment to extend the storage life, its quality of perishable fruits like the round gourd, particularly during the short-term storage. These findings were supported by the statistical analysis in which ANOVA test showed F-statistic equal to 3.37 and p-value equal to 0.045 which is less than 0.05 which is extremely significant to prove the differences between the treatment groups.

3.6. Color

The experiment that discusses the preservative activity of salicylic acid on round gourd samples that had been coated with different concentrations of the compound over a period of time used to study color retention during a storage period has important information regarding the preservative power of the said compound. The outcomes showed that salicylic acid is effective in countering the loss of color with increasing concentration achieved significantly better retention of color though still with a touch of variability. The untreated control group also diminished color significantly as the storage continued with time. Such a result concurs with the prior findings that untreated produce tends to have a worrying quality decline, such as its color loss, as a result of enzymatic browning and oxidative stress (Bai et al., 2020). Conversely, the number of bars that showed resistance in color reseason by the salicylic acid treated samples differed in levels. In a 2 mM concentration, there was increased stability of color but with some level of variability. This treatment at 6 mM turned out to be even better with regard to color retention and was found to be more consistent than the other treatments and the 10 mM concentration turned out to perform the best of all, maintaining a high level of color and having a lower variability than the other lower concentrations. These results reinforce the use of salicylic acid as an agent that regulates plant growth, as reported in literature on its capacity to minimize the effect of oxidative damage and boost quality among postharvest in round gourd samples (Zhang et al., 2016; Zhan et al., 2019). Although the results themselves still exhibit variability, the general tendency is beneficial to the possibility of using salicylic acid as a postharvest treatment to keep the produce visually appealing.

3.7. Aroma

The use of salicylic acid helped to maintain the aroma of the samples of round gourd coated with different concentrations of salicylic acid after 20 days when compared to the control. Although aroma scores decreased with time in all treatments, the least decline was seen in 10 mM treatment followed by 6 mM and 2 mM treatments with the lowest correlation being in the control. Such results are in par with the earlier investigation reports on the impact of salicylic acid on sensory qualities of fruits and vegetables. It was demonstrated that salicylic acid could be used to enhance quality preservation in produce by delaying the impact of oxidative stress, the rate of volatile substances degradation, and increased shelf life (Zhang et al., 2016; Zhang et al., 2020). The findings pointed in the direction of the hint that salicylic acid assist in aroma maintenance, it showed variation in the results, and the statistical insignificance indicate that there are lot of factors affecting the maintenance of aroma like concentration and environment.

Table 1 of between subject effect (one-way ANOVA) on round gourd at 4°C

Quality Parameters	DF	SS	MS	Mean	F	P-value	Effect of p-value
Weight loss	20	119668	17378	99.8	4.11	0.0242	p<0.05
Firmness	20	55	13.66	17.65	11.71	0.0007	p<0.05
Marketability index	20	47	7.0	23	3.23	0.06	p<0.05
Visual quality	20	43.80	3.99	23.85	3.37	0.0003	p<0.05
Texture	20	47	6.06	25.97	0.780	0.556	p<0.05
Color	20	326	11	26.45	0.77	0.318	p<0.05
Taste	20	340	11.36	26.57	1.26	0.003	p<0.05
Aroma	20	333	16.76	5.30	5.46	0.0005	p<0.05
TSS	20	537	70.14	11.13	18.9	0.0005	p<0.05
Disease incidence%	20	80.9	23.6	26.07	12.2	0.02	p<0.05
Dry matter content	20	88.4	22.2	22.05	4.3	0.001	p<0.05
Ash	20	53	9.25	34.2	8	0.03	p<0.05
Fat	20	505	122.3	78.1	10.6	0.001	p<0.05
Crude fiber	20	109	17.8	10.06	3.85	0.003	p<0.05
Crude protein	20	8811	126	9.68	3.02	0.0009	p<0.05
Reducing sugar	20	2.89	0.77	9.91	10.5	0.0001	p<0.05
Non-reducing sugar	20	1.66	0.47	12.02	16.3	0.0001	p<0.05
Total sugar	20	1.30	0.40	12.02	30	0.0004	p<0.05
NFE%	20	360	92.0	39.7	21	0.0003	p<0.05
Ascorbic acid	20	226	58	26.7	13.0	0.002	p<0.05
Elemental analysis	20	39.2	10.71	97	13.7	0.556	p<0.05

3.8. Taste

An example is the study on the effect of salicylic acid (SA) coating on fruit taste retention during 20 days of storage, which shows that SA can be a very powerful effect in slowing the decay rate of fruit taste as compared to control fruit. Such protective action demonstrates the potential of SA as a technology to enhance the shelf life of fruits without losing quality features, including taste, that are important determinants of consumer acceptance. At the beginning of the study it is observed that both the control and 10mM SA-coated fruits would start with comparable initial taste scores. The control does not differ much as taste scores along fruits treated with 10mM SA-coated fruits are always highest, which validates the notion that the SA has a positive impact on the retention of fruit flavor. This finding can be explained by the numerous studies that postulate that SA strengthens the process of fruit preservation by including the activity as a regulator of plant defense (Hao et al., 2019). Salicylic acid is well known as a plant hormone which plays a big part in multiple layers of defense. It is known to induce systemic acquired resistance that does not only assist plants in combating against the pathogens but also aiding in maintaining fruit quality too (Bari and Jones, 2009). This may seem to be the reason why SA-coated fruits have better taste retention after storage. One of the active plant hormones is ethylene which controls the process of fruit ripening and elevated concentrations of ethylene lead to a quick loss of flavor and texture (Lashbrook et al., 1998). SA has demonstrated ethylene inhibitory effect on fruits (Zhang et al., 2017), and this could be how SA prolongs the shelf life of fruits as well as the quality of fruit taste. Findings indicate that suggest that salicylic acid may be a pertinent way of increasing shelf life of fruits, especially in the retention of taste there was not much difference in the treatments when a 5 percent level of significance was taken as a cut off point in the research.

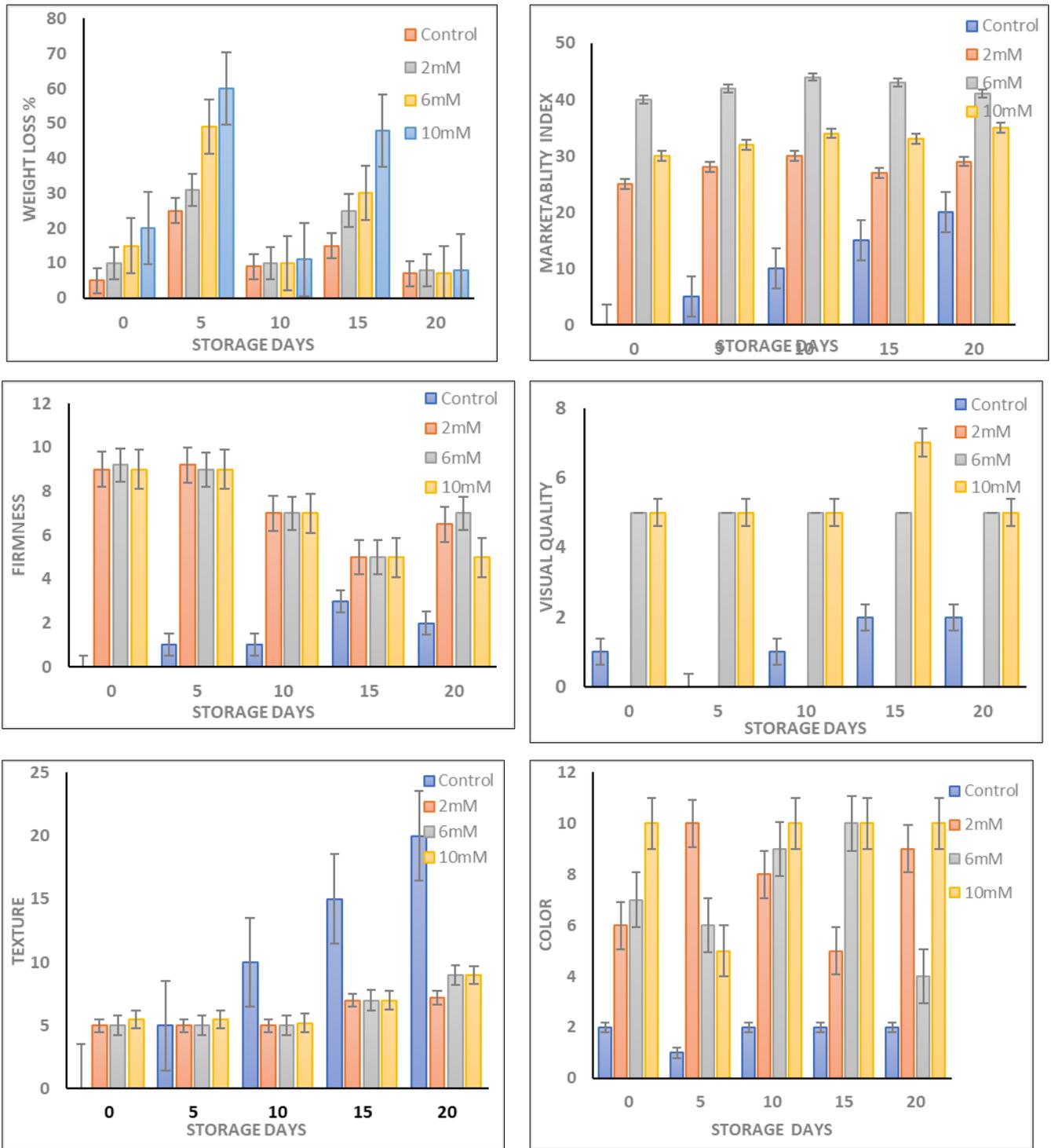


Figure 1 Effects of different concentrations of Salicylic acid on visual quality, texture, color, firmness, weight loss and marketability a of 'Round gourd during storage. Vertical bars represent the \pm SE of the means. n = 3 replicates

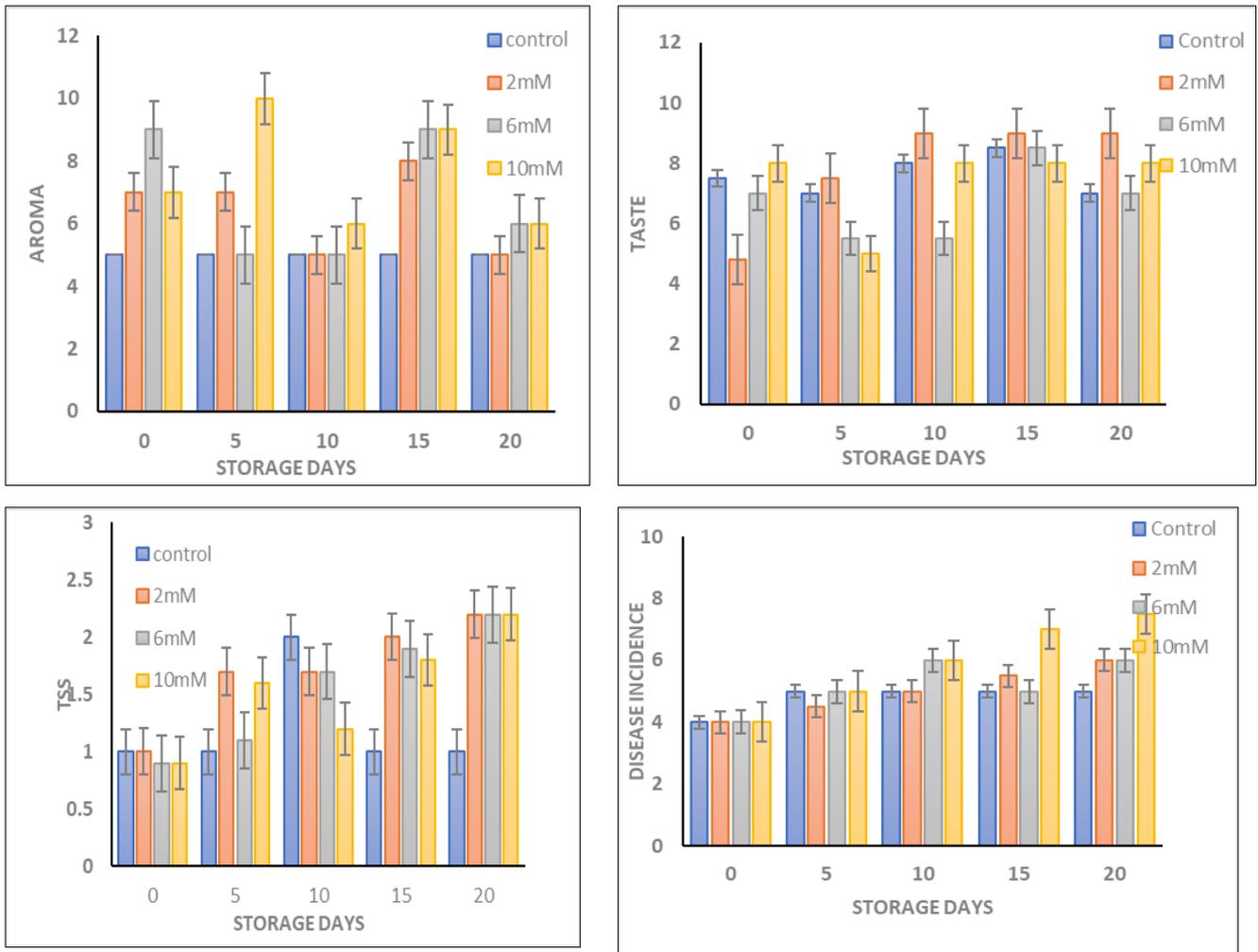


Figure 2 Effects of different concentrations of Salicylic acid on aroma, taste, TSS, disease incidence a of 'Round gourd' during storage. Vertical bars represent the \pm SE of the means. n = 3 replicates

3.9. Disease incidence

The treatment of 10mM SA significantly decreased the level of disease incidence within 20 days as compared to the control. Salicylic acid (SA) has been promising as a compound to increase the disease resistance of round gourd. Investigations have continued to reveal that treatments involving SA can be very useful in minimising the level of disease because of triggering the numerous defence mechanisms in the plant which includes induction of defence related proteins and formation of antimicrobial compounds. In the study conducted by Palamthodi et al., (2019), it was revealed that the application of SA has a great effect on boosting antioxidant activity and resistance to diseases in bottle gourd. Although more experiments are necessary to streamline the application techniques and the inner mechanisms, it is clear that SA has the potential to provide sustainable and environment-friendly management of diseases in the production process of round gourd. The ANOVA table showed the findings of a statistical analysis of the means of different groups. This p-value of 0.000545 was significant and thus, there was significant difference between at least two of the groups.

3.10. TSS

Initially, on day 0, the recorded TSS was almost close in all the samples, implying that there exist no substantial changes at the commencement of the experiment. Nonetheless, with the advancement in the storage days, significant changes were observed. By 5 days, the control (T0) showed a sharp decrease in TSS whereas the coated samples, especially T3, possessed more or less stable levels of TSS and this determined the effectiveness of salicylic acid in extending shelf life of the round gourds. This preservation property of salicylic acid was particularly notable on the latter parts of storage, and the evidence shows that it can be used as a coating agent to increase shelf life of round gourd. Total soluble solids (TSS) were considered in Brix, and its analysis of variance (AOV) was achieved through a completely randomized analysis to measure the influence of the alternative treatments, the salicylic acid coatings on the round gourd samples.

The analysis showed that the effect of treatment was significant with F-value of 5.468 and the corresponding P-value of 0.003 and in this case the treatments significant effect was at 0.05 level on TSS.

3.11. Dry matter content

The figure displayed the influence of coating salicylic acid on the dry matter content on round gourd during storage. The dry matter content is represented as a percentage value in the graph against the storage days (T0, T1, T2, T3). The plot indicated a proportional increase of dry matter content of round gourd along with storage time, whereas an increase of dry matter content was more explicit in the samples of the salicylic acid coated round gourd samples. In the salicylic acid treated samples, there is the highest dry matter content, which is viewed at T3. This implied that salicylic acid coating could be used to maintain and even raise the dry matter level of round gourd in the process of storage. The dry matter content on the one hand is a measure of the solid content of a food and is very crucial in setting the quality and shelf life of a food. Hence, there are advantages of high contents of dry matter quality and shelf life of round gourd to maintain. In the coating of round gourds with salicylic acid the ANOVA results stated that there was significant effect in the content of dry matter.

3.12. Ash

The graph illustrated the influence it had on ash content of round gourd during storage when the surface of the round gourd was subjected to salicylic acid coating. Ash content is usually expressed as a percent and is the inorganic mineral quantity contained within something. In the food context, it indicated the mineral content which can affect different nutritional values and quality parameters. The graph indicated the ash contents of round gourd and this has a tendency of rising with storage period and has the highest option with the salicylic acid coating. The salicylic acid-treated samples are found to have the highest ash content at T3. This indicated that higher ash content can be maintained or even improve ash content of round gourd during storage at lower temperatures. A higher ash content may demonstrate a superior mineral profile that may make a contribution to the total nutritional value of the vegetable. These results implied that the total ash content of round gourds was considerably affected by the salicylic acid coating, where at least one of the coated groups was unlike the control. This was indicated by the high F-value that signified that the concentrations of salicylic acid used on the round gourds during a storage had different effects on ash content during a storage indicating that salicylic acid had the potential of further treatment as preservative to modulate ash stability in round gourds.

3.13. Fat

The amount of initial fat content at T0 was seen to be comparatively low. Generally, a trend of rising fat content was observed as the storage proceeded, and the most of them were at T3. The error bars appeared to be spread more widely in fat content at the later stages of storage. Subsequent stimulating action of salicylic acid on lipid metabolism may have faded the prolonged period of temporal application, and the natural aging that takes place in the course of storage may also be an explanation to these results. The activation and oxidation of long-chain fatty acids have been demonstrated to be blocked by salicylic acid, hence its inhibitory effect on the metabolism of lipids. It also does it through sequestering of co enzyme. The ANOVA analysis gave a substantial difference between the samples of round gourd which had the coating of salicylic acid. Salicylic acid is reported to affect lipid metabolism by preventing the degradation and oxidation of fatty acids, and it does this possibly by binding to and sequestering coenzyme A-an essential molecule in catabolism of fatty acids (Simaei et al., 2011). The existence of salicylic acid interferes with the early phases of fatty acids breakdown so that long-chain fatty acids cannot be effectively broken down to be used by the mitochondria, hence slowing its breakdown and eventually may cause the fat deposition as seen in the increase in fat over time (Martinez et al., 2019). There are also more general physiological effects of salicylic acid on plants that help to bring stress resistance and maintaining quality. As an example, it has been revealed to increase plant stress tolerance by increasing antioxidant capacity, which in turn confers antioxidant protection in plant cells (Khan et al., 2015). It has also been shown that application of salicylic acid to fruits and vegetables can be used to delay the ripening process and this may potentially increase the shelf life with minimizing the loss of nutritional value of the stored fruits and vegetables (Srivastava and Dwivedi, 2000). Moreover, the overall yield and quality can be boosted with the intervention of such coatings as they regulate the metabolic and stressful processes inside the plant to help it during long-term storage and maintaining shelf life (Yazdanpanah et al., 2012).

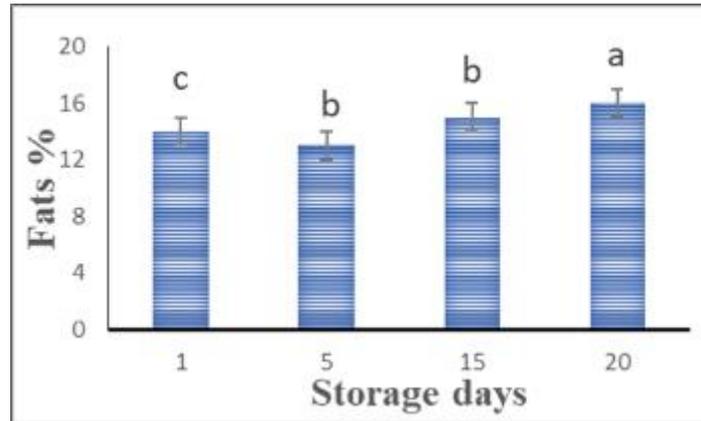


Figure 3 Fat (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.14. Crude fiber

There is a general trend showing that round gourd samples tend to record lower crude fiber content in samples stored longer. Salicylic acid coating seems to exhibit favorable effects on the content of crude fiber. The samples treated with salicylic acid (T1, T2, T3) contains a higher level of crude fiber than the control (T0) at the same storage time. Storage Time. The level of crude fiber is decreasing faster in the sample of the control (T0) than in the sample of the treatment (T1, T2, T3). This implies that the fiber content is maintained in times of storage through salicylic acid coating. Salicylic acid is a plant hormone, which is known to have several broad beneficial effects on plant growth and development. In the case of round gourd, it appears to play a role in preserving the nutritional value i.e. the presence of crude fiber, as it helps in the storage of round gourd. Salicylic acid is a strong antioxidant. It might scavenge the reactive oxygen species that would otherwise disrupt the decay of the cell wall constituents such as fiber. Salicylic acid may cause modification in the cell wall structure hence covering it up more effectively in storage. Consequently, determined the existence of statistically significant differentiation on the level of crude fiber level.

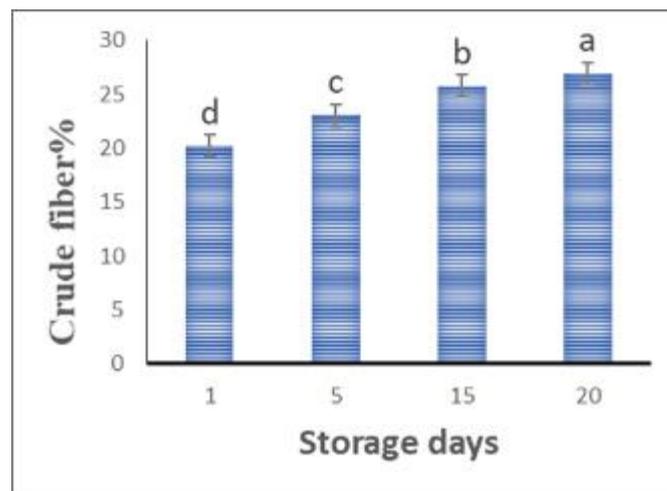


Figure 4 Crude fiber (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.15. Crude protein

The crude protein content in round gourd samples generally increases with increasing storage time. Salicylic acid coating appears to have a positive impact on maintaining crude protein content. The samples treated with salicylic acid (T1, T2, T3) show higher protein levels compared to the control (T0) at the same storage time. The crude protein content increases more in the treated samples (T1, T2, T3) than in the control sample (T0). This suggested that salicylic acid coating helps to preserve the protein content during storage. Salicylic acid, a plant hormone, is known for its various beneficial effects on plant growth and development. Therefore, concluded that there was a statistically significant difference in the crude protein content between the four groups.

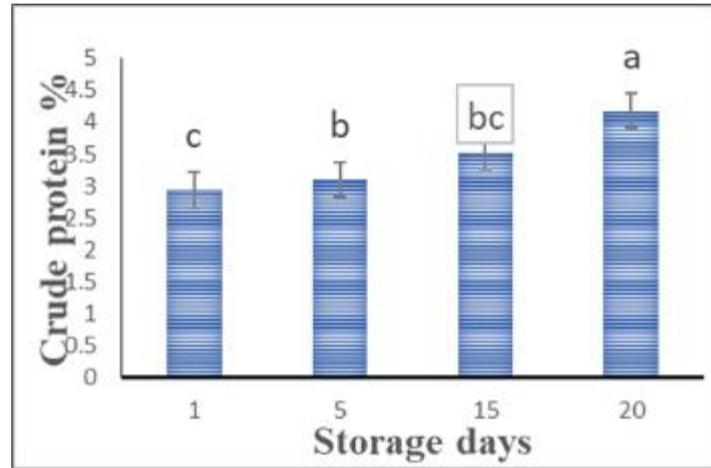


Figure 5 Crude protein (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.16. Reducing sugar

The data showed that reducing sugar content generally increased with storage time. Samples treated with salicylic acid (T1, T2, T3) consistently exhibited higher reducing sugar levels than the untreated control (T0) at comparable storage periods. This indicated that salicylic acid coating had a positive impact on preserving reducing sugar content during storage. Salicylic acid, a plant hormone, was recognized for its beneficial effects on plant growth and development. In the case of round gourd, it appeared to help maintain nutritional quality, particularly by preserving reducing sugar levels. The results indicated that salicylic acid coating was a promising technique in order to maintain reducing sugar content in the round gourd during storage along with nutritional value. Taken in the perspective of application to salicylic acid coating on round gourd samples, this ANOVA finding implied that the salicylic acid treatments used had significant effect on the outcome variable that is being measured, whether it could be reduction in sugar content or reduction in protein content, among other probable parameters.

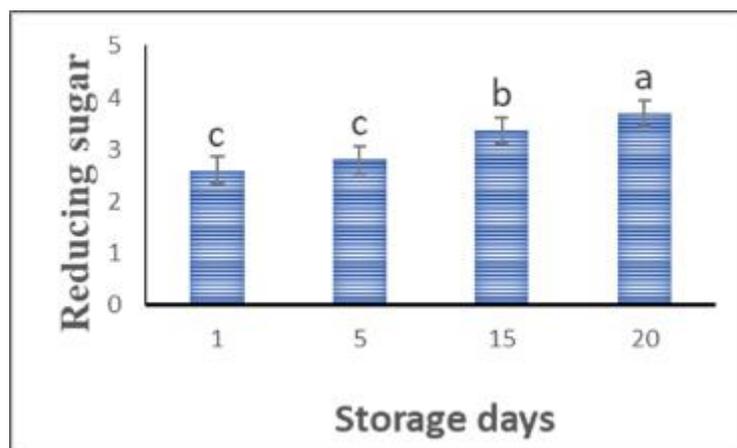


Figure 6 Reducing sugar (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.17. Non-reducing sugar

The data showed that non-reducing sugar content generally increased with storage time. Samples treated with salicylic acid (T1, T2, T3) consistently exhibited higher non-reducing sugar levels compared to the control (T0) at the same storage periods. The non-reducing sugar content increased more in the treated samples (T1, T2, T3) than in the control sample (T0). This suggested that salicylic acid coating helped preserve the non-reducing sugar content during storage. Salicylic acid, a plant hormone, was known for its various beneficial effects on plant growth and development. In the context of round gourd, it appeared to play a role in maintaining nutritional value, specifically the non-reducing sugar content, during storage. Acting as a potent antioxidant, salicylic acid likely scavenged reactive oxygen species that could degrade non-reducing sugars. The analysis revealed a significant difference among the groups, with a p-value of 0.0009.

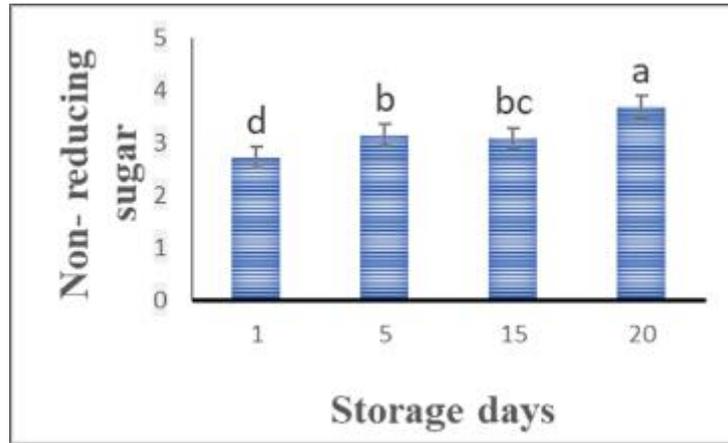


Figure 7 Non-reducing sugar (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.18. Total reducing sugar

The total reducing sugar content in round gourd samples generally increased with increasing storage time. Salicylic acid coating appeared to have a positive impact on maintaining total reducing sugar content. The samples treated with salicylic acid (T1, T2, T3) exhibited higher total reducing sugar levels compared to the control (T0) at the same storage time. The total reducing sugar content increased more in the treated samples (T1, T2, T3) than in the control sample (T0). This indicated that salicylic acid coating helped preserve the total reducing sugar content during storage. Salicylic acid, a plant hormone, was known for its various beneficial effects on plant growth and development. In the context of round gourd, it appeared to play a role in maintaining the nutritional value, specifically the total reducing sugar content, during storage. As a potent antioxidant, salicylic acid might have scavenged reactive oxygen species that could degrade reducing sugar. It might also have influenced gene expression related to carbohydrate metabolism, leading to increased total reducing sugar accumulation. The ANOVA analysis indicated a significant difference among the treatment groups ($p < 0.0001$), suggesting that salicylic acid treatments had a significant impact on the outcome variable.

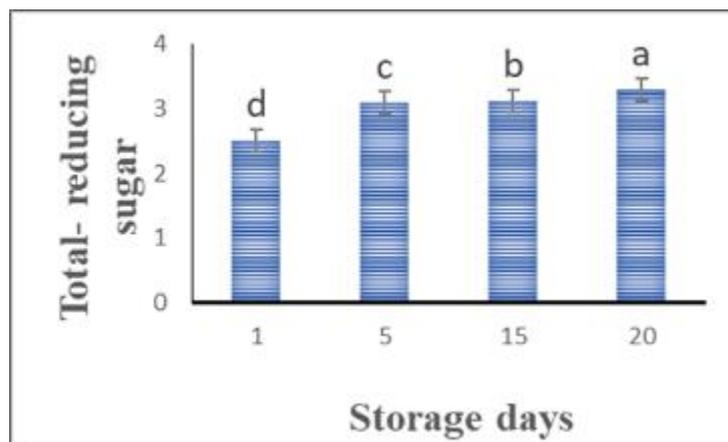


Figure 8 Total-reducing sugar (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.19. NFE%

The application of salicylic acid (SA) coating significantly influenced the Non-Fiber Extract (NFE%), a measure indicative of the nutritional value of round gourd. The following trends were observed: T0 (Control): Initial storage conditions without SA coating showed lower NFE% values compared to coated samples. T1, T2, T3 (SA-coated samples): These samples exhibited a progressive increase in NFE%, suggesting SA coating effectively preserved the carbohydrate content and nutritional quality during storage. The increase in NFE% indicates a protective role of SA in minimizing nutrient degradation under storage conditions. The SA coating contributed to reducing oxidative stress and maintaining cellular integrity in round gourd. Hassan, F. A., et al. (2017). This can be attributed to SA's ability to act as: An antioxidant, reducing free radical damage to the tissues. A defense activator, inhibiting microbial activity that contributes to

postharvest deterioration. SA coating slowed down physiological processes like respiration and ethylene production, which are primary drivers of postharvest ripening and spoilage. The ANOVA table revealed a statistically significant difference between the mean values of the round gourd samples treated with salicylic acid coating. The low p-value (0.000439) strongly suggested that the variation observed between the groups was not due to random chance. This finding supported the hypothesis that salicylic acid coating had a significant impact on the round gourd, likely influencing factors such as shelf life, nutritional content, or other relevant parameters.

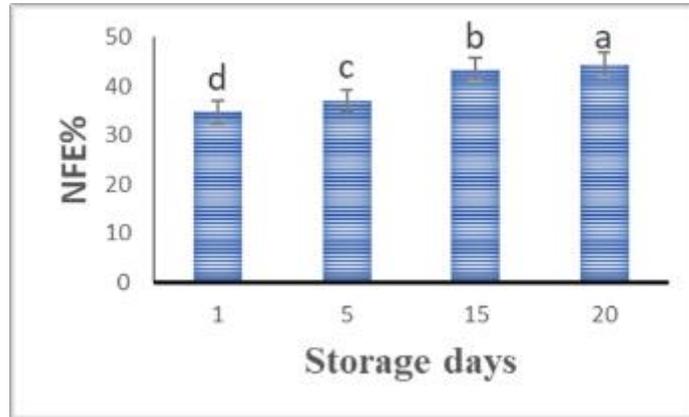


Figure 9 NFE (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean

3.20. Determination of ascorbic acid

The ascorbic acid content was measured as a percentage and plotted against the number of days of storage (T0, T1, T2, T3). The graph showed that the ascorbic acid content of round gourd increased with storage time and this increase was more pronounced in the samples treated with salicylic acid. The highest ascorbic acid content was observed at T3 in the samples treated with salicylic acid. This suggested that salicylic acid coating help maintain or even increase the ascorbic acid content of squash during storage (Kazemi et al. 2013).

Ascorbic acid is an important antioxidant and plays a role in various physiological processes. Therefore, maintaining a high ascorbic acid content is beneficial for the nutritional quality and shelf life of round squash. The ANOVA table shows a statistically significant difference between the means of the salicylic acid-treated pumpkin samples. The low p-value (0.000349) strongly indicated that the variation observed between groups was unlikely to be due to chance. These findings supported the hypothesis that salicylic acid coating or other relevant parameters. The results indicate that salicylic acid coating is a viable postharvest treatment to maintain the nutritional quality of round gourd by stabilizing or increasing the ascorbic acid content, which could improve consumer health benefits and extend shelf life and reduce food waste.

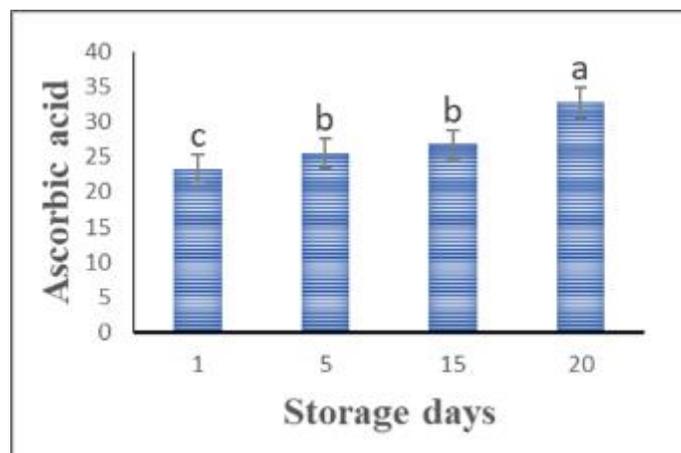


Figure 10 Ascorbic acid (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean.

3.21. Elemental analysis

The mineral composition of the gourd was shown in the elemental analysis table: this vegetable contains large amounts of calcium, magnesium, iron, potassium and phosphorus. These minerals play a vital role in many bodily functions, including bone health, energy metabolism, blood pressure regulation, oxygen transport, etc. Including round gourd in a balanced diet can promote overall health and well-being. The ANOVA table showed the results of a statistical analysis comparing the means of several groups. The significant p-value of 0.002393 indicated that there was a significant difference between at least two groups. A versatile vegetable, round gourd is a rich source of essential minerals. Studies have shown it contains high amounts of calcium, magnesium, iron, potassium and phosphorus. These minerals play an important role in various body functions. Calcium and phosphorus are essential for bone health, magnesium supports muscle function and nerve transmission, iron is essential for oxygen transport in the blood, and potassium helps regulate blood pressure and fluid balance. By including pumpkin in a balanced diet, people can benefit from its mineral content and maintain overall health.

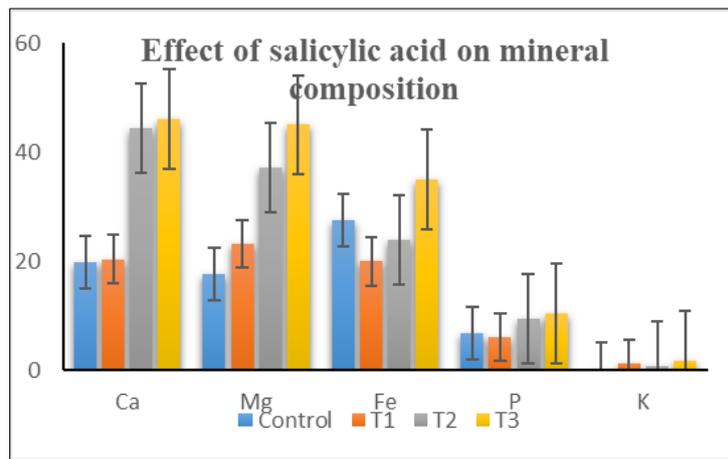


Figure 11 Elemental analysis (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean.

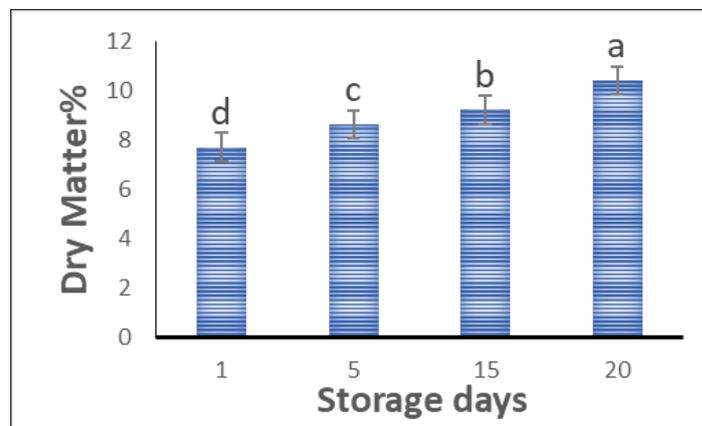


Figure 12 Dry matter (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean.

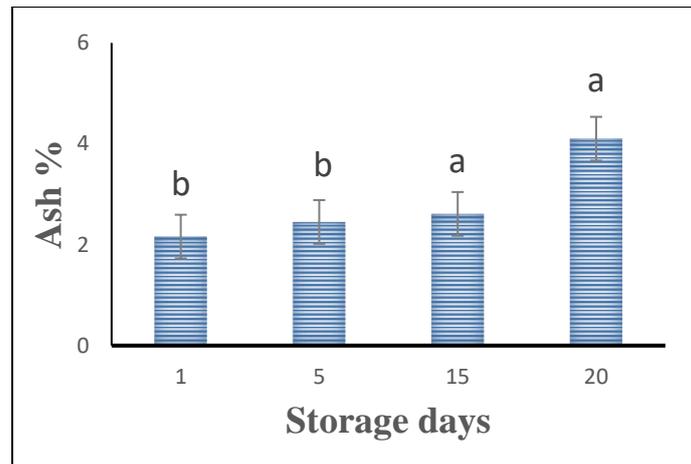


Figure 13 Ash (%) in round gourd after storage, under four different salicylic acid treatments (0 mM, 2 mM, 6 mM, and 10 mM). Vertical bars indicated the S.E of mean.

3.22. ATR-FTIR spectral analysis

3.22.1. At 0m M Concentration

The FTIR analysis revealed significant chemical changes in salicylic acid-coated round gourd samples over time. On Day 1, the spectra showed clear peaks for functional groups like O-H ($3300\text{--}3500\text{ cm}^{-1}$), C-H (2900 cm^{-1}), and C=O (1700 cm^{-1}), reflecting the samples' original chemical structure (Gohil and Patel, 2019). By Days 5 and 9, increased transmittance across the spectrum indicated ongoing chemical changes due to storage (Khan et al., 2021). Further alterations were observed on Days 13 and 17, particularly in the 1700-1800 cm^{-1} region. Although the salicylic acid coating helped slow down degradation, it was not fully effective in preserving the chemical integrity of the gourds, pointing to the need for improved post-harvest preservation methods (Patel et al., 2020).

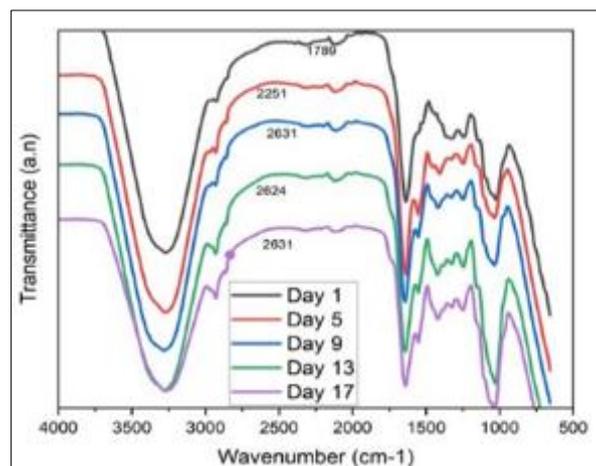


Figure 14 FTIR spectrum of round gourd at 0 mM salicylic acid, showing characteristic peaks for key functional groups as a baseline reference

3.22.2. At 2m M Concentration

The FTIR graph displayed the transmittance spectra of round gourd samples coated with 2 mM salicylic acid and examined over multiple storage days (Days 2, 6, 10, 14, and 18). The x-axis represented wavenumbers (cm^{-1}), indicating the frequencies of molecular bond absorption, while the y-axis showed transmittance values (a.u.), reflecting how much infrared radiation passed through the sample. On Day 2 (black line), the spectrum captured the initial chemical structure of the gourd, with distinct peaks linked to various functional groups. As storage continued to Days 6 (red) and 10 (blue), slight variations in transmittance appeared, indicating chemical changes. By Days 14 (green) and 18 (purple), further shifts were noted, particularly at key wavenumbers ($2087, 2102, 2094\text{ cm}^{-1}$), suggesting molecular degradation or transformation influenced by the salicylic acid coating. Peaks around $3300\text{--}3500\text{ cm}^{-1}$ (O-H/N-H stretches), 2900 cm^{-1}

(C-H stretches), and the fingerprint region ($1000\text{--}1500\text{ cm}^{-1}$) confirmed alterations in functional groups over time. Overall, the 2 mM salicylic acid coating moderately slowed down degradation, but the chemical profile of the gourd continued to change during storage.

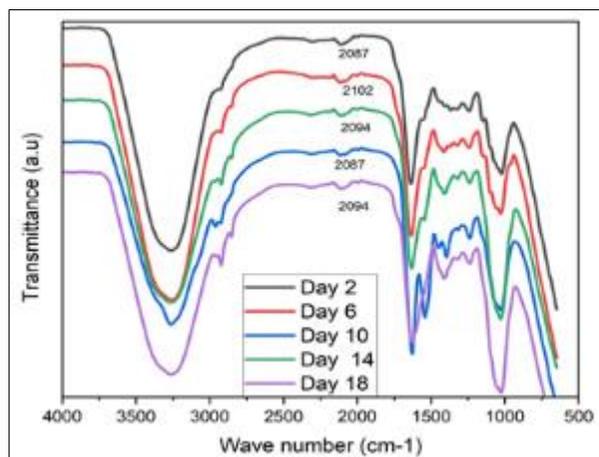


Figure 15 FTIR spectrum of round gourd at 2 mM salicylic acid, showing characteristic peaks for key functional groups as a baseline reference

3.22.3. At 6m M Concentration

The FTIR graph illustrated the transmittance spectra of round gourd samples coated with 6 mM salicylic acid and stored over several days (Day 3, 7, 11, 15, and 19). The x-axis showed wavenumbers (cm^{-1}) indicating infrared absorption by chemical bonds, while the y-axis reflected transmittance levels. Over time, noticeable shifts in the spectra indicated chemical changes within the samples, likely due to degradation or compositional alterations during storage. Key spectral changes occurred at specific wavenumbers (e.g., $2072\text{--}2139\text{ cm}^{-1}$), and peaks in regions like $3300\text{--}3500\text{ cm}^{-1}$, 2900 cm^{-1} , and $1000\text{--}1500\text{ cm}^{-1}$ suggested modifications in functional groups. Overall, the data showed that the salicylic acid coating did not fully prevent chemical changes in the gourd samples over time.

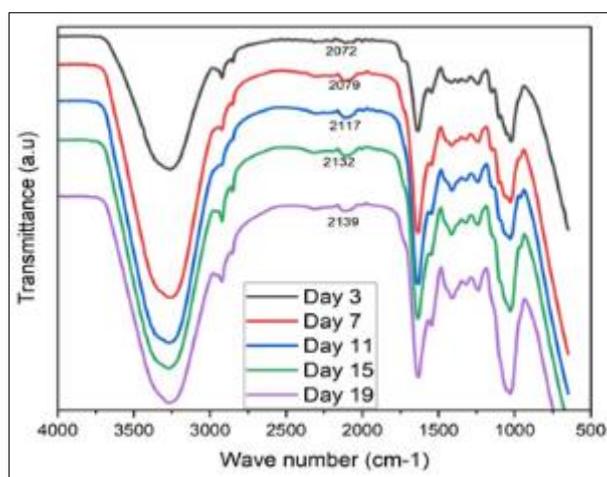


Figure 16 FTIR spectrum of round gourd at 6 mM salicylic acid, showing characteristic peaks for key functional groups as a baseline reference

3.22.4. At 10m M Concentration

The FTIR analysis revealed surface chemical changes in round gourd samples treated with 10 mM salicylic acid over 20 days. A noticeable decrease in the broad O-H stretching peak ($3000\text{--}3500\text{ cm}^{-1}$) over time suggests interactions between salicylic acid and hydroxyl groups on the gourd's surface. Meanwhile, the C=O stretching peak around 1650 cm^{-1} remained consistent, indicating the gourd's core structure was largely unaffected. The changes observed in the FTIR spectra suggested that the salicylic acid coating successfully interacted with the round gourd surface. These

findings suggest effective surface interaction of the coating, though further investigation is required to fully understand its implications.

4. Conclusion

Round gourd coating with salicylic acid (SA) was very effective in retaining postharvest quality of round gourd by preserving its nutritional value and inhibition of postharvest weight loss. The results were improved in SA-treated samples, mainly by retaining essential nutrients like protein, ascorbic acid, TSS and sugars and enhancing sensory characteristics like aroma, taste, firmness, and texture. The treatment also resulted in a successful decrease in the incidence of the disease, a factor that led to enhanced marketability. Biochemical stability of SA- treated samples through storage was also confirmed by element analysis (calcium, magnesium, iron, potassium, and phosphorus) and FTIR analysis. The best results were observed in 10 mM SA, and therefore as far as the concentrations that have been tested are concerned, the concentration 10 mM SA will be specified as one of the candidates that might be used as an optimal concentration to increase the shelf life and sustain quality. These results emphasize the use of SA coating as a useful postharvest management method in the agricultural sector which leads to improved and enhanced nutritional and sensory quality of food to consumers with less wastage in the postharvest areas.

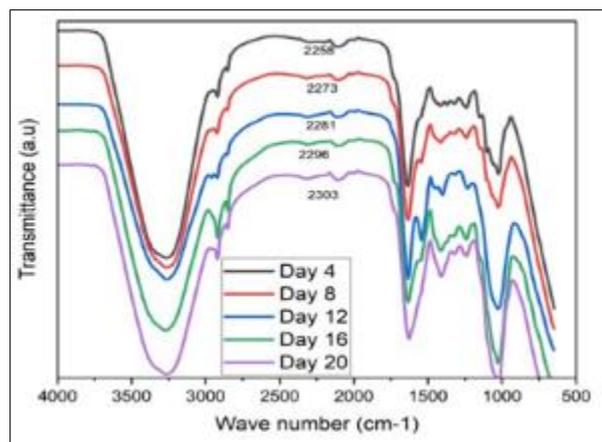


Figure 17 FTIR spectrum of round gourd at 10 mM salicylic acid, showing characteristic peaks for key functional groups as a baseline reference

Compliance with ethical standards

Disclosure of conflict of interest

No conflict-of-interest to be disclosed.

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