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Unlocking the Preservation Potential of Strawberry through Osmotic Dehydration: Quality Optimization, Bioactive Retention, and Shelf-Life Extension

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A B S T R A C T

Strawberry (*Fragaria* × *ananassa*) is a highly perishable fruit with a limited shelf life of approximately 3–4 days under ambient conditions. Drying is an important preservation technique for extending the shelf life of seasonal fruits and vegetables, reducing post-harvest losses, and improving their availability beyond the production season. In the present investigation, strawberry fruits were cut into halves and subjected to osmotic dehydration using sucrose solutions at 15, 25 and 35 °Brix and glycerol at 15, 25 and 35%, followed by drying. The dried products were evaluated for changes in physicochemical, nutritional, microbiological and sensory attributes during 90 days of storage. A progressive reduction in moisture content was observed during storage, with the overall mean decreasing from 13.46 to 11.79%. Significant variations were observed among the treatments for titratable acidity, reducing sugars, total sugars, ascorbic acid, total phenolic content and anthocyanin content. Initially, the highest titratable acidity (0.43%), reducing sugar (29.98%) and total sugar (37.57%) contents were recorded in T4 (35 °Brix sucrose + 2% $CaCl_2$), whereas the corresponding minimum values of 0.34, 9.93 and 13.15%, respectively, were observed in the control (T1). The highest initial ascorbic acid (58.58 mg/100 g), total phenolic content (119.51 mg/100 g) and anthocyanin content (125.01 mg/100 g) were recorded in T3 (25 °Brix sucrose + 2% $CaCl_2$). Across the storage period, the overall mean reducing sugar content increased from 15.73% initially to 17.75% after 90 days. No detectable microbial growth was observed in any of the treatments throughout the 90-day storage period, indicating satisfactory microbiological stability of the dried strawberry products under the storage conditions employed. Sensory evaluation revealed a significant decline in overall acceptability during storage, with the mean score decreasing from 7.82 initially to 7.36 after 90 days. Among the treatments, T4 recorded the highest initial acceptability score (8.63), while the control (T1) recorded the lowest score (7.09). Overall, T4 (35 °Brix sucrose + 2% $CaCl_2$) exhibited superior performance in maintaining desirable physicochemical and nutritional characteristics and retaining sensory acceptability during storage. The findings demonstrate that osmotic dehydration followed by drying, particularly using sucrose in combination with $CaCl_2$, can be an effective approach for extending the storage stability of strawberries while retaining their nutritional and sensory quality. The developed process offers potential for reducing post-harvest losses, improving product shelf life and creating value-added strawberry products with enhanced marketability.

Introduction

Strawberry (*Fragaria* × *ananassa*) is an economically important non-climacteric berry belonging to the family Rosaceae and is widely cultivated and consumed because of its appealing appearance, characteristic aroma, pleasant sweet–tart flavor and high nutritional value. In addition to its sensory attributes, strawberry is recognized as a nutrient-dense fruit with relatively low energy value. Approximately 100 g of fresh strawberry provides 64.0

mg vitamin C, 0.61 g protein, 0.37 g fat, 7.02 g carbohydrates, 2.3 g dietary fibre, 14.0 mg calcium, 166.0 mg potassium, 13 mg magnesium and 24 mg phosphorus, together with appreciable amounts of vitamin A (Vishwakarma *et al.,* 2024). The nutritional significance of strawberry is further enhanced by the presence of a diverse array of phytochemicals, including anthocyanins, flavonoids, phenolic acids, carotenoids and ellagic acid. These compounds contribute substantially to the antioxidant potential of the fruit and are associated with biological activities relevant to protection against oxidative stress and inflammation.

Despite its nutritional and functional potential, strawberry is highly susceptible to post-harvest deterioration owing to its high moisture content, delicate epidermal structure, soft texture and susceptibility to mechanical injury and microbial spoilage. The fruit generally contains more than 90% moisture and consequently exhibits a very short shelf life, typically only a few days under ambient storage conditions. Post-harvest water loss, tissue softening, discoloration and microbial deterioration rapidly compromise its marketability and nutritional quality (Xu *et al.,* 2023). These characteristics result in substantial post-harvest losses, particularly when production exceeds immediate fresh-market demand. Consequently, the development of efficient preservation technologies capable of extending shelf life while retaining the physicochemical, nutritional and functional attributes of strawberry is of considerable importance.

Drying represents one of the most established approaches for stabilizing fruits and vegetables by reducing water activity and inhibiting microbial and enzymatic deterioration. In addition to extending shelf life, dehydration substantially decreases product weight and volume, thereby offering potential advantages in packaging, transportation, handling and storage. However, conventional hot-air drying may expose fruit tissues to prolonged thermal stress, resulting in undesirable changes in colour, texture, flavour and nutritional quality and degradation of heat-sensitive bioactive compounds. The loss of phenolic constituents, anthocyanins and antioxidant activity during thermal processing is particularly relevant in strawberry because these compounds are major contributors to its functional value (Hussain *et al.,* 2024). Therefore, preservation strategies that reduce thermal exposure while facilitating effective moisture removal are required for the development of high-quality dried strawberry products.

Osmotic dehydration (OD) is a promising pre-treatment and partial dehydration technology based on the immersion of fruit tissues in a hypertonic solution, generating a concentration gradient that promotes water migration from the fruit matrix into the surrounding solution, accompanied by the transfer of selected solutes into the fruit. Unlike direct high-temperature drying, OD can be conducted at relatively mild temperatures and therefore has considerable potential for minimizing structural and quality deterioration. The process can reduce the initial moisture load, shorten subsequent drying time and improve dryer productivity while contributing to the retention of colour, flavour, texture and selected nutritional attributes (Kaur *et al.,* 2022; Macedo *et al.,* 2023). The effectiveness of OD is governed by several interacting variables, including osmotic-agent concentration, solution-to-fruit ratio, temperature, immersion duration, tissue geometry and mass-transfer characteristics.

Sucrose remains the most widely investigated osmotic agent for fruit dehydration because of its availability, affordability, high osmotic potential and established technological performance (Janowicz *et al.,* 2021). Nevertheless, increasing consumer interest in reduced-sugar and nutritionally optimized fruit products has stimulated research into alternative osmotic agents. Polyols such as glycerol, sorbitol, erythritol, maltitol and xylitol have attracted attention because of their distinctive physicochemical properties and potential to modify mass transfer and product quality during osmotic dehydration. In particular, glycerol possesses high hygroscopicity and favourable water-binding characteristics, which can influence water loss, solid gain and moisture redistribution within fruit tissues. Previous investigations have indicated that the type and concentration of osmotic agent can substantially alter dehydration kinetics and the physicochemical characteristics of the final product (Dermesonlouoglou *et al.,* 2018; Macedo *et al.,* 2022). Therefore, comparative evaluation of conventional sucrose and alternative osmotic agents such as glycerol may provide useful insights into the optimization of strawberry dehydration.

The mass-transfer phenomena occurring during OD involve simultaneous water loss and solute uptake and are strongly dependent on osmotic-agent characteristics, concentration, temperature, immersion time and the structural properties of the fruit matrix. These variables directly influence dehydration kinetics, moisture reduction, solid gain, shrinkage, colour retention, texture

and the subsequent drying behaviour of the product. Although OD has demonstrated considerable potential as a pre-treatment for fruit preservation, information regarding the combined influence of different osmotic agents on the quality attributes and bioactive potential of dehydrated strawberry remains comparatively limited. In particular, systematic comparison of sucrose and glycerol under controlled dehydration conditions could provide valuable information for developing a quality-oriented drying process.

Accordingly, the present study was undertaken to investigate the effect of sucrose- and glycerol-assisted osmotic dehydration followed by drying on the physicochemical, nutritional, bioactive and quality attributes of strawberry. The study was designed to evaluate the influence of the selected osmotic treatments on moisture removal and product quality, with particular emphasis on the preservation of colour, bioactive compounds and desirable sensory characteristics. The findings are expected to contribute to the development of an efficient dehydration strategy for converting highly perishable strawberry into a shelf-stable, value-added product while minimizing quality deterioration associated with conventional drying.

Material and Methods

Preparation of Osmo dried strawberries

Freshly harvested, fully ripe strawberry fruits (*Fragaria* × *ananassa*) with uniform red colour and without visible physiological or mechanical defects were procured from R.S. Pura, Jammu, India, and immediately transported to the Food Processing Laboratory for further processing. Fruits exhibiting bruising, cuts, decay, deformities or other visible defects were discarded. The selected fruits were thoroughly washed under running potable water to remove adhering dirt and extraneous matter. The calyx and stalks were manually removed using stainless-steel knives, and the fruits were subsequently cut longitudinally into two approximately equal halves.

The prepared strawberry halves were subjected to osmotic dehydration using sucrose and glycerol as osmotic agents. For sucrose treatments, osmotic solutions of 15, 25 and 35 °Brix were prepared, whereas glycerol solutions were prepared at concentrations of 15, 25 and 35%. The strawberry halves were completely immersed in the respective osmotic solutions and maintained for 24 h under controlled conditions. The treatment combinations used in the study are presented in Table 1. Following osmotic treatment, the fruit samples were removed from the solutions and allowed to drain adequately to eliminate excess surface solution.

The osmotically treated strawberry halves were then uniformly arranged in a single layer on stainless-steel drying trays and subjected to convective drying in a cabinet dryer at 50 ± 5 °C. Drying was continued until the desired moisture level was attained. The dried samples were cooled to ambient temperature, weighed to determine the final product yield and subsequently packed in aluminium-laminated pouches to minimize moisture and oxygen transmission. The packaged osmo-dehydrated strawberry samples were stored under ambient conditions for 90 days.

Quality evaluation of the stored products was carried out at 30-day intervals (0, 30, 60 and 90 days). Samples were withdrawn at each sampling interval and evaluated for selected physicochemical, bioactive and sensory attributes to determine the influence of osmotic treatment and storage period on product quality. The overall experimental workflow is presented schematically in Fig. 1.

Physico-Chemical Analysis of Dried Strawberries

Moisture Content

Moisture content of the strawberry samples was determined using the gravimetric oven-drying method as described by AOAC (2012). Approximately 10 g of homogenized sample was accurately weighed into a previously dried and pre-weighed moisture dish. The sample was dried in a hot-air oven at 105 ± 2 °C until a constant weight was obtained. After drying, the dish containing the dried sample was transferred to a desiccator, allowed to cool to room temperature, and weighed accurately. Moisture content was expressed as percentage on a fresh-weight basis and calculated using the following equation:

$$\text{Moisture content (\%)} = \frac{\text{Moisture loss}}{\text{Sample weight}} \times 100$$

Titratable Acidity

Titratable acidity of the strawberry samples was determined by the standard titrimetric method described

by AOAC (2012). A known volume of the prepared strawberry extract/juice was titrated against standardized 0.1 N sodium hydroxide (NaOH) solution using phenolphthalein as the indicator. Titration was continued until the appearance of a persistent faint pink colour, indicating the endpoint. The volume of NaOH consumed was recorded, and titratable acidity was calculated and expressed as percentage citric acid equivalent using the following equation:

$$\text{Titratable acidity (\%)} = \frac{\text{Titer value} \times \text{Normality of NaOH} \times \text{Vol. made up} \times \text{Eq.wt of acid}}{\text{Vol. of aliquot taken for sample} \times 1000} \times 100$$

Determination of Reducing Sugar

Reducing sugar content of the strawberry samples was determined by the Lane–Eynon titrimetric method as described by Ranganna (2014). Briefly, 5 g of homogenized sample was accurately weighed into a 250 mL volumetric flask, and approximately 100 mL of distilled water was added. The sample suspension was neutralized using 40% sodium hydroxide (NaOH) solution in the presence of phenolphthalein as an indicator. Clarification was subsequently carried out by adding 2 mL of 45% lead acetate solution, and the mixture was allowed to stand for approximately 30 min.

The excess lead ions were precipitated by adding 5 mL of 22% potassium oxalate solution. The volume was then made up to 250 mL with distilled water and the contents were thoroughly mixed. The extract was filtered through Whatman No. 4 filter paper, and the clear filtrate was used for estimation of reducing sugars.

For titration, 10 mL of standard Fehling's solution was taken in a conical flask and heated to boiling. The clarified sample extract was gradually titrated against the boiling Fehling's solution in the presence of methylene blue as the redox indicator. The end point was indicated by the disappearance of the blue colour and formation of a characteristic brick-red precipitate of cuprous oxide. The reducing sugar content was calculated from the titre value and expressed as percentage reducing sugars.

$$\text{Reducing sugar} = \frac{0.5 \times \text{Volume made up}}{\text{Titre value} \times \text{Weight of sample}} \times 100$$

Determination of Total Sugar

Total sugar content of the strawberry samples was determined by the Lane–Eynon titrimetric method as described by Ranganna (2014). An aliquot of 100 mL of the previously prepared and clarified sample filtrate was transferred into a 250 mL volumetric flask and hydrolysed by adding 10 mL of 50% hydrochloric acid (HCl). The hydrolysis mixture was maintained at room temperature for approximately 24 h to facilitate the conversion of non-reducing sugars into reducing sugars.

Following hydrolysis, the solution was carefully neutralized with 40% sodium hydroxide (NaOH) using phenolphthalein as the indicator. The neutralized solution was then diluted to the 250 mL mark with distilled water and thoroughly mixed. An appropriate aliquot of the resulting solution was titrated against standard Fehling's solution following the Lane–Eynon procedure. The endpoint was determined by the disappearance of the characteristic blue colour of the Fehling's solution and the formation of a brick-red cuprous oxide precipitate. The total sugar content was calculated from the titre value and expressed as percentage total sugars.

Determination of Ascorbic Acid

Ascorbic acid content of the strawberry samples was determined by the 2,6-dichlorophenol-indophenol (DCPIP) titrimetric method described by Sadasivam and Manickam (2008). A representative quantity of the sample was homogenized with 3% oxalic acid, and the extract was quantitatively transferred and made up to a final volume of 100 mL. The homogenate was thoroughly mixed and filtered to obtain a clear extract. A measured aliquot of the filtrate was titrated against 0.025% 2,6-dichlorophenol-indophenol dye solution until the appearance of a persistent pale pink colour, which was taken as the endpoint. The ascorbic acid content was calculated based on the titre value and expressed as mg ascorbic acid per 100 g of sample (mg/100 g) using the following equation:

Dye factor = 0.5/Titre

$$\text{Ascorbic acid } \left(\frac{\text{mg}}{100\,\text{g}}\right) = \frac{\text{Titre value} \times \text{dye factor} \times \text{Volume made up}}{\text{Aliquot extract taken for estimation} \times \text{weight of sample}} \times 100$$

Determination of Total Phenol Content

The total phenolic content (TPC) of the strawberry samples was determined using the Folin–Ciocalteu colorimetric method with slight modifications, following the procedure described by Icier (2012). Briefly, 1 g of sample was accurately weighed into a screw-capped vial,

and 10 mL of distilled water was added. The mixture was heated at 100 °C for 5 min to facilitate the extraction of phenolic compounds. The extract was subsequently cooled to room temperature and filtered through filter paper to obtain a clear filtrate.

An aliquot of the filtrate was mixed with 0.5 mL of Folin–Ciocalteu reagent and allowed to react at room temperature for 7 min. Subsequently, 1.5 mL of 20% (w/w) sodium carbonate (Na_2CO_3) solution was added, and the reaction mixture was thoroughly mixed and incubated in the dark for 2 h at room temperature. The absorbance of the resulting blue-coloured complex was measured at 756 nm using a UV–Visible spectrophotometer (UV-1650 PC, Shimadzu, Japan). A calibration curve was prepared using an appropriate concentration range of gallic acid, and the total phenolic content was calculated from the corresponding regression equation. The results were expressed as mg gallic acid equivalents per 100 g of sample (mg GAE/100 g). All analyses were performed in triplicate, and the results were expressed as mean ± standard deviation.

Estimation of Anthocyanin Content

Anthocyanin content of the osmo-dehydrated strawberry samples was determined using the acidified ethanol extraction method described by Ranganna (2009), with appropriate modifications. Briefly, 10 g of sample was accurately weighed and homogenized with 10 mL of acidified ethanol, prepared by mixing 95% ethanol and 1.5 N hydrochloric acid (HCl) in an 85:15 ratio (v/v). The homogenate was quantitatively transferred to a 100 mL volumetric flask and the extraction volume was adjusted with the same acidified ethanol.

The extract was maintained at 4 °C overnight to facilitate the extraction of anthocyanin pigments while minimizing their degradation. The resulting extract was filtered through Whatman No. 1 filter paper using a glass funnel. The extraction container and residue were repeatedly rinsed with acidified ethanol, and the washings were combined with the primary filtrate. The pooled extract was finally made up to 100 mL with acidified ethanol.

The absorbance of the appropriately diluted extract was measured at 535 nm using a UV–Visible spectrophotometer (UV-1650 PC, Shimadzu, Japan), with acidified ethanol used as the blank. Anthocyanin content was calculated from the measured absorbance and expressed as mg/100 g of sample.

Sensory Evaluation

Sensory quality of the osmo-dehydrated strawberry samples was evaluated using a 9-point hedonic scale following the procedure described by Meilgaard *et al.,* (2016). A semi-trained panel of 9–10 judges evaluated the samples for colour, texture, taste and overall acceptability. Samples were coded and presented to the panelists under controlled conditions to minimize potential bias. The hedonic scale ranged from 9 (“like extremely”) to 1 (“dislike extremely”), with intermediate scores representing varying degrees of preference.

The sensory scores obtained for each attribute were recorded and used to assess the acceptability of the osmo-dehydrated strawberry products. A mean score of ≥5.5 was considered indicative of an acceptable product (Meilgaard *et al.,* 2016). The sensory evaluation was conducted at the designated storage intervals to monitor changes in consumer acceptability during storage.

Microbial Analysis

The microbiological quality of the osmo-dehydrated strawberry samples was assessed using the spread-plate technique following the method described by Pelczar and Chan (1997), with appropriate modifications. Under aseptic conditions, 1 g of sample was transferred into a sterile test tube containing 9 mL of sterile distilled water and thoroughly homogenized to obtain the initial 10^{-1} dilution. Serial ten-fold dilutions were subsequently prepared by transferring 1 mL of the preceding dilution into 9 mL of sterile diluent, with vigorous mixing at each dilution step.

An appropriate dilution was selected for enumeration, and 0.1 mL of the diluted sample was aseptically transferred onto pre-solidified potato dextrose agar (PDA) plates and uniformly distributed over the agar surface using a sterile spreader. The inoculated plates were incubated under the conditions appropriate for the target microbial group.

Following incubation, plates containing countable colonies were selected for enumeration, and the microbial load was calculated by considering the dilution factor and expressed as colony-forming units per gram (CFU/g) of sample. Microbial counts were determined at the specified storage intervals to monitor changes in the microbiological quality of the osmo-dehydrated strawberry samples during storage.

Microbial Load = N×1/V×D
N= No. of colonies counted
V= Volume of inoculum
D= Dilution factor

Statistical Analysis

The experimental data were expressed as mean ± standard deviation (SD) and analyzed using analysis of variance (ANOVA) to determine the effects of osmotic treatment and storage period on the measured quality attributes. Statistical significance was evaluated at $p < 0.05$. Where significant differences among treatment means were observed, appropriate post-hoc multiple comparison procedures were applied. Graphical representations were prepared using Microsoft Excel, with error bars representing ±SD.

Results and Discussion

Moisture Content and Titratable Acidity

As illustrated in Fig. 2, the moisture content of the osmo-dehydrated strawberry samples exhibited a gradual decline throughout the 90-day storage period. At the beginning of storage, moisture content varied considerably among the treatments, with the lowest value (12.52%) recorded for T_7 (35% glycerol + 2% $CaCl_2$), whereas the highest value (15.26%) was observed in T_1 (control). This variation indicates that the composition of the osmotic treatment influenced the extent of moisture removal during processing, with the higher glycerol concentration promoting greater water loss from the strawberry tissue.

Across the storage period, the mean moisture content decreased (14.46% initially to 12.79%) after 90 days. The progressive reduction may be attributed to the continued redistribution and migration of residual moisture within the dried fruit matrix, together with moisture exchange with the surrounding environment during storage. The magnitude of this change may also depend on the hygroscopic characteristics of the osmotic solutes and the moisture-barrier properties of the packaging material.

The interaction between osmotic treatment and storage period was significant ($p< 0.05$), indicating that the magnitude of moisture changes during storage was dependent on the type and concentration of osmotic treatment applied. Overall, the results demonstrate that osmotic pre-treatment, particularly at higher glycerol concentration, contributed to lower residual moisture in the dehydrated strawberry product and influenced its moisture stability during storage.

Titratable Acidity

The titratable acidity of the osmo-dehydrated strawberry samples was significantly influenced by the osmotic treatment and storage duration (Fig. 3). Among the treatments, the highest titratable acidity (0.53%) was recorded in T_4 (35 °Brix sucrose + 2% $CaCl_2$), followed by 0.51% in T_3 (25 °Brix sucrose + 2% $CaCl_2$). In contrast, the lowest acidity (0.44%) was observed in T_1 (control). The relatively higher acidity observed in the sucrose–$CaCl_2$ treatments may be associated with differences in mass transfer during osmotic dehydration and the retention of organic acids within the fruit matrix.

A progressive decline in titratable acidity was observed during the 90-day storage period, with the overall mean value decreasing from 0.50% at the beginning of storage to 0.45% at the end of the storage period. The reduction in acidity during storage may be attributed to the gradual utilization or degradation of organic acids through metabolic and oxidative reactions, together with possible changes in the physicochemical equilibrium of the dehydrated fruit matrix. Such changes can alter the concentration and availability of titratable organic acids during prolonged storage.

The observed decline in titratable acidity indicates that storage duration had a measurable influence on the chemical stability of the osmo-dehydrated strawberry products. Nevertheless, the higher acidity retained by the sucrose $CaCl_2$ treatments suggests that osmotic pretreatment may contribute to improved retention of acidity and, consequently, preservation of the characteristic flavour profile of the dehydrated fruit during storage.

Effect on Reducing Sugar and Total Sugar Content

Reducing Sugar

The reducing sugar content of osmo-dehydrated strawberries was significantly influenced by the osmotic treatment and storage period (Fig. 4). Initially, the

highest reducing sugar content (30.98%) was recorded in treatment T4 (35 °Brix sucrose + 2% $CaCl_2$), whereas the control (T1) exhibited the lowest value (10.93%). The higher reducing sugar content observed in sucrose-treated samples may be attributed to the incorporation of soluble sugars into the fruit matrix during osmotic dehydration, with the extent of sugar uptake being influenced by the concentration of the osmotic medium.

A progressive increase in reducing sugar content was observed throughout the 90-day storage period. At the end of storage, T4 retained the highest reducing sugar content (32.24%), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$) with 22.91%, while the control recorded the lowest value (12.01%). Considering the overall storage means, reducing sugar content increased significantly from 16.73% at the beginning of storage to 18.75% after 90 days. This increase may be associated with the hydrolysis of non-reducing sugars into reducing sugars during storage, together with concentration effects arising from changes in moisture content. The significant treatment × storage period interaction indicates that the magnitude of changes in reducing sugar content during storage depended on the osmotic treatment applied. Overall, the greater retention of reducing sugars in sucrose-treated samples, particularly T4, demonstrates the pronounced influence of osmotic concentration on the sugar profile of dried strawberries.

Total Sugar Content

Total sugar content also exhibited a significant increase during storage (Fig. 5). At the beginning of storage, T4 (35 °Brix sucrose + 2% $CaCl_2$) recorded the highest total sugar content (38.67%), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$) with 28.87%, whereas the lowest value (14.15%) was observed in the control (T1). The higher total sugar concentration in sucrose-treated samples can primarily be attributed to the uptake of sucrose from the osmotic solution during dehydration, resulting in greater sugar incorporation into the fruit tissue.

The overall mean total sugar content increased significantly from 23.64% initially to 26.30% after 90 days of storage. The increase during storage may reflect progressive conversion of non-reducing sugars into reducing sugars and associated changes in the chemical equilibrium of the stored product. The significant interaction between treatment and storage period further demonstrates that changes in total sugar content were dependent on the osmotic treatment. Among the treatments, T4 consistently exhibited the highest total sugar content throughout storage, indicating that the higher sucrose concentration in the osmotic medium promoted greater sugar uptake and contributed to the maintenance of a higher soluble sugar concentration in the osmo-dehydrated strawberries.

Effect on Ascorbic Acid and Total Phenol Content

Ascorbic Acid

The ascorbic acid content of osmo-dehydrated strawberries was significantly influenced by the osmotic treatment and storage duration (Fig. 6). Initially, the highest ascorbic acid content (59.58 mg/100 g) was recorded in T3 (25 °Brix sucrose + 2% $CaCl_2$), whereas the control (T1) exhibited the lowest value (47.43 mg/100 g). The higher retention of ascorbic acid in the osmotically treated samples may be associated with the protective effect of the osmotic medium and reduced exposure to thermal stress during subsequent drying.

A marked decline in ascorbic acid content was observed during storage. After 90 days, T3 retained the highest ascorbic acid concentration (38.84 mg/100 g), while the lowest value (21.62 mg/100 g) was recorded in the control (T1). The overall mean ascorbic acid content decreased significantly from 53.78 mg/100 g at the beginning of storage to 32.33 mg/100 g after 90 days. The observed reduction may be attributed primarily to the oxidative degradation of ascorbic acid during prolonged storage, as this vitamin is particularly susceptible to oxidation and subsequent chemical degradation. Nevertheless, the comparatively higher retention observed in T3 indicates that moderate sucrose concentration combined with $CaCl_2$ was more effective in preserving ascorbic acid than the untreated condition. These findings highlight the potential of osmotic pretreatment to improve the retention of thermolabile nutrients in dried strawberries during storage.

Total Phenolic Content

The total phenolic content (TPC) of osmo-dehydrated strawberries varied significantly among treatments and declined progressively during storage (Fig. 7). Initially, the highest TPC (120.51 mg/100 g) was recorded in T3 (25 °Brix sucrose + 2% $CaCl_2$), whereas the lowest value (93.77 mg/100 g) was observed in T5 (15% glycerol +

2% $CaCl_2$). The higher phenolic content in T3 suggests that the osmotic treatment may have contributed to better retention of phenolic constituents during dehydration, although treatment-specific differences in mass transfer and matrix interactions may also have influenced the measured values.

A significant reduction in TPC was observed during storage, with the overall mean decreasing from 107.33 mg/100 g initially to 82.53 mg/100 g after 90 days. The decline in phenolic compounds during prolonged storage may be associated with oxidation and other degradation reactions, potentially enhanced by exposure to oxygen and other environmental factors. Despite the progressive reduction, the treatment-dependent differences indicate that osmotic pretreatment influenced the preservation of phenolic compounds in the dried fruit matrix. The relatively higher TPC observed in T3 throughout the storage period suggests that 25 °Brix sucrose combined with 2% $CaCl_2$ provided comparatively better protection of phenolic constituents under the conditions investigated.

Effect on Anthocyanins Content

The anthocyanin content of osmo-dehydrated strawberries varied considerably among the treatments and exhibited a progressive decline during storage (Fig. 8). Initially, the highest anthocyanin content (126.01 mg/100 g) was recorded in T3 (25 °Brix sucrose + 2% $CaCl_2$), whereas the lowest value (94.32 mg/100 g) was observed in T7 (35% glycerol + 2% $CaCl_2$). The comparatively higher anthocyanin retention in T3 indicates that the moderate sucrose concentration combined with $CaCl_2$ was more favourable for preserving anthocyanin pigments during osmotic dehydration. After 90 days of storage, T3 continued to exhibit the highest anthocyanin content (110.53 mg/100 g), while the control (T1) recorded the lowest value (48.11 mg/100 g). Considering the overall storage means, anthocyanin content decreased from 108.99 mg/100 g at the beginning of storage to 85.55 mg/100 g after 90 days. The progressive decline in anthocyanin concentration during storage may be attributed to pigment degradation and oxidation, which can occur during prolonged storage and may be influenced by oxygen exposure, temperature, moisture conditions, and interactions with other constituents of the fruit matrix.

Despite the overall reduction, the substantially higher anthocyanin content retained by T3 at the end of storage demonstrates the potential of osmotic pretreatment with 25 °Brix sucrose and 2% $CaCl_2$ to enhance the stability of strawberry anthocyanins during storage. The results further indicate that the choice and concentration of the osmotic medium are important determinants of pigment retention in osmo-dehydrated strawberries.

Microbial Analysis

No detectable microbial growth was observed in any of the osmo-dehydrated strawberry samples throughout the 90-day storage period (Fig. 9). Accordingly, no appreciable increase or decrease in microbial count was recorded during storage. The absence of detectable microbial growth throughout the storage period indicates satisfactory microbiological stability of the osmo-dehydrated strawberries under the storage conditions employed. This microbial stability may be associated with the combined effects of reduced moisture availability resulting from osmotic dehydration and drying, together with the protective role of the packaging system. Overall, the results demonstrate that the processing and storage conditions adopted in the present investigation were effective in maintaining the microbiological quality of the product for up to 90 days.

Sensory Evaluation

The sensory attributes of osmo-dehydrated strawberries were significantly influenced by the osmotic treatment and storage duration (Table 6). For taste, the highest score (9.80) was recorded for T4 (35 °Brix sucrose + 2% $CaCl_2$), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$) with a score of 9.41, whereas the control (T1) received the lowest score (8.20). The superior taste scores of the sucrose-treated samples may be associated with the incorporation of soluble sugars during osmotic dehydration, which could have contributed to a more desirable balance of sweetness and characteristic strawberry flavour.

A gradual decline in taste scores was observed with increasing storage duration, with the overall mean score decreasing from 8.93 initially to 8.19 after 90 days. This reduction may be attributed to progressive changes in flavour and chemical constituents during storage, including oxidation and other quality changes associated with prolonged storage. Nevertheless, the relatively high taste scores recorded throughout the storage period indicate good consumer acceptability of the osmo-dehydrated strawberries.

Colour

Colour scores also differed among treatments and declined progressively during storage (Table 6). Initially, T4 (35 °Brix sucrose + 2% $CaCl_2$) received the highest colour score (9.70), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$), whereas the lowest score (8.02) was recorded for the control (T1). The higher colour acceptability of the osmotically treated samples suggests better preservation of the characteristic appearance of strawberry following dehydration.

After 90 days of storage, T4 retained the highest colour score (8.99), whereas the control exhibited the lowest score (7.94). The overall mean colour score decreased significantly from 8.85 at the beginning of storage to 8.47 after three months. The decline in colour acceptability during storage may be associated with gradual pigment degradation, oxidative reactions, and other physicochemical changes occurring during prolonged storage.

The comparatively higher colour scores observed in T4 throughout the storage period indicate that treatment with 35 °Brix sucrose and 2% $CaCl_2$ was particularly effective in maintaining the visual quality and consumer acceptability of osmo-dehydrated strawberries.

Sensory Evaluation of osmo-dried strawberries

Texture

Texture scores varied among the osmotic treatments, with the control (T1) recording the lowest score (8.05), while T4 (35 °Brix sucrose + 2% $CaCl_2$) exhibited the highest score (9.40), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$) with a score of 9.21 (Table 7). The higher texture scores observed for the sucrose–$CaCl_2$ treatments suggest that osmotic dehydration, particularly in combination with $CaCl_2$, contributed to better textural characteristics of the dried fruit. Calcium ions may interact with pectic substances in the fruit tissue and contribute to the maintenance of structural integrity during processing. A gradual decline in texture scores was observed during storage, with the overall mean decreasing from 8.70 initially to 8.42 after 90 days. This reduction may be related to progressive moisture redistribution and structural changes within the dried fruit matrix during storage. Nevertheless, the relatively high scores indicate that the product retained acceptable textural characteristics throughout the storage period.

Overall Acceptability

The overall acceptability of osmo-dehydrated strawberries was influenced by both osmotic treatment and storage duration (Table 7). Initially, the highest overall acceptability score (9.63) was recorded for T4 (35 °Brix sucrose + 2% $CaCl_2$), followed by T3 (25 °Brix sucrose + 2% $CaCl_2$), whereas the lowest score (8.09) was observed for the control (T1).

A significant decline in overall acceptability was observed during the 90-day storage period, with the overall mean score decreasing from 8.82 initially to 8.36 at the end of storage. After 90 days, T4 continued to receive the highest overall acceptability score (9.29), followed by T3 (9.07), whereas the control recorded the lowest score (7.91).

The consistently higher sensory scores obtained for T4 and T3 suggest that sucrose-based osmotic dehydration in combination with $CaCl_2$ provided more desirable sensory characteristics than the untreated control. The retention of comparatively high overall acceptability scores throughout storage further demonstrates the suitability of these treatments for producing an acceptable shelf-stable strawberry product.

Osmotic dehydration is accompanied by complex mass-transfer and biochemical phenomena, principally involving water removal, solute uptake, redistribution of soluble constituents, and possible migration or degradation of endogenous compounds. These changes collectively influence the nutritional, physicochemical and sensory characteristics of fruits during subsequent storage. In the present study, marked treatment-dependent differences were observed in moisture content, titratable acidity, sugars, ascorbic acid, phenolic compounds, anthocyanins and sensory attributes, demonstrating the important role of the osmotic medium in determining the quality and stability of osmo-dehydrated strawberries.

The moisture content was highest in the untreated control (T1), whereas the lowest value was consistently observed in the glycerol-based treatment T7 (35% glycerol + 2% $CaCl_2$). The greater moisture reduction in glycerol-treated samples may be related to the strong hygroscopicity and polyhydric nature of glycerol, which can facilitate water binding and mass transfer during osmotic dehydration. Glycerol contains multiple hydroxyl groups capable of interacting with water

through hydrogen bonding, thereby influencing water migration from the fruit tissue (Ladika *et al.,* 2024). A progressive decline in moisture content was also observed during storage, with glycerol-treated samples maintaining comparatively lower values (Table 2). Similar observations were reported by Bashir *et al.,* (2025) in osmo-dehydrated aonla slices, where glycerol-based treatments promoted greater moisture loss than sugar-based treatments. The observed behaviour may therefore reflect differences in osmotic pressure, solute–water interactions and hygroscopicity of the osmotic agents.

Titratable acidity is an important determinant of flavour balance and chemical stability in fruit products. In the present investigation, the sucrose-treated samples, particularly T4 (35 °Brix sucrose + 2% $CaCl_2$), exhibited comparatively higher acidity, whereas glycerol-treated samples showed lower values. The lower acidity observed in glycerol-treated fruit may partly be associated with greater mass transfer during osmotic dehydration and the possible migration of water-soluble organic acids into the osmotic medium. Such treatment-dependent differences are consistent with the observation that osmotic pretreatment can alter the distribution of organic acids within the fruit matrix. Yulni *et al.,* (2024), in a meta-analysis of osmotic pretreatment, similarly reported changes in acidity following osmotic dehydration of fruits.

Titratable acidity subsequently declined during storage, although T4 and T3 retained comparatively higher acidity (Table 2). This reduction may be associated with progressive degradation or transformation of organic acids during storage. Similar changes in acidity have been reported during the storage of osmotically dehydrated berries (Kowalska *et al.,* 2023).

The sensory characteristics followed a similar treatment-dependent pattern. Taste, colour, texture and overall acceptability showed a gradual decline during storage; nevertheless, sucrose-based treatments, particularly T4 (35 °Brix sucrose + 2% $CaCl_2$), consistently received higher sensory scores than the glycerol-based treatments and control (Tables 6 and 7). The superior taste scores of sucrose-treated samples may be related to greater sucrose uptake during osmotic dehydration, resulting in a favourable sweetness profile and improved flavour balance. The higher colour and texture scores may additionally reflect better pigment retention and maintenance of tissue structure. Calcium ions are known to interact with pectic substances and may contribute to maintaining cellular integrity and firmness during processing. The decline in overall acceptability during storage may be associated with gradual changes in acidity, pigment stability, oxidation of ascorbic acid and modifications in the physicochemical properties of the fruit matrix. Similar improvements in sensory quality following sucrose-based osmotic treatment have been reported by Mousa *et al.,* (2024). Reshi *et al.,* (2026) also reported improved retention of texture and flavour in sugar-treated pumpkin during ambient storage, whereas Ladika *et al.,* (2024) observed comparatively less desirable texture and mouthfeel in glycerol-treated products. Collectively, these findings suggest that sucrose served a dual function as an osmotic agent and a quality-modifying solute, contributing to desirable sweetness and improved sensory characteristics.

Ascorbic acid exhibited a pronounced decline during storage across all treatments. The highest initial and final retention was observed in T3 (25 °Brix sucrose + 2% $CaCl_2$), indicating comparatively better preservation of vitamin C in this treatment. Ascorbic acid is highly susceptible to oxidation and degradation during processing and storage because of its sensitivity to oxygen, temperature and other environmental factors. The comparatively greater retention observed in sucrose-treated samples may be related to differences in mass transfer and the protective effect of the osmotic environment, although this mechanism should not be considered exclusive without direct measurements of oxidative conditions.

Glycerol-treated samples showed comparatively lower ascorbic acid retention, consistent with previous observations reported for osmotic dehydration systems (Haneef *et al.,* 2024; Saleena *et al.,* 2021; Mahima *et al.,* 2020). The progressive reduction in ascorbic acid during storage (Table 4) may also involve oxidation and diffusion-related losses from the fruit tissue, as reported by Gulzar *et al.,* (2018) in dried mango slices.

Phenolic compounds and anthocyanins are important contributors to the functional and antioxidant characteristics of strawberries. In the present study, total phenolic content (TPC) was comparatively higher in sucrose-treated samples, with T3 recording the highest value, whereas glycerol-based treatments exhibited lower values (Table 4).

Table.1 Treatment details for preparation of osmo-dried strawberries

Treatment Details

Treatments	Concentration
T1	Control
T2	15 °Brix sucrose + 2% $CaCl_2$
T3	25 °Brix sucrose + 2% $CaCl_2$
T4	35 °Brix sucrose + 2% $CaCl_2$
T5	15% glycerol + 2% $CaCl_2$
T6	25% glycerol + 2% $CaCl_2$
T7	35% glycerol + 2% $CaCl_2$

Table.2 The experiment was laid out in a Completely Randomized Design (CRD) with three replications the details of the experiment.

Crop	**Strawberries (*Fragaria* × *ananassa*)**
Variety	Chandler
Treatments	Seven
Replication	Four
Design	Completely Randomized Design Factor 1: Storage Factor 2: Osmo-dehydrating Agents
Base material	15 °Brix sucrose + 2 % $CaCl_2$ 25 °Brix sucrose + 2 % $CaCl_2$ 35 °Brix sucrose + 2 % $CaCl_2$ 15 % glycerol + 2 % $CaCl_2$ 25 % glycerol + 2 % $CaCl_2$ 35 % glycerol + 2 % $CaCl_2$
Functional Properties	Phenols, Anthocyanin, Ascorbic Acid, moisture content, Microbial count and overall acceptability
Season	April - May

Table.3 Effect of treatments and storage period on taste score and colour value of osmo-dried strawberries

Treatment	Taste Score (9-point hedonic scale)				Colour Value (9-point hedonic scale)			
	Storage Period (Days)				Storage Period (Days)			
	0	30	60	90	0	30	60	90
T_1 (Control)	8.20	7.98	7.75	7.31	8.02	8.00	7.97	7.94
T_2 (15°Brix sugar + 2% $CaCl_2$)	9.01	8.98	8.54	8.34	9.30	9.11	8.80	8.77
T_3 (25°Brix sugar + 2% $CaCl_2$)	9.41	9.20	8.98	8.68	9.57	9.23	8.90	8.87
T_4 (35°Brix sugar + 2% $CaCl_2$)	9.80	9.42	9.23	8.98	9.70	9.61	9.30	8.99
T_5 (15% glycerol + 2% $CaCl_2$)	8.45	8.21	8.05	7.85	8.23	8.19	8.15	8.10
T_6 (25% glycerol + 2% $CaCl_2$)	8.72	8.48	8.21	8.00	8.25	8.21	8.19	8.12
T_7 (35% glycerol + 2% $CaCl_2$)	8.95	8.73	8.48	8.22	8.90	8.71	8.62	8.51
L.S.D. (*P≤0.05*)	T= 0.04 S= 0.03 T×S= 0.08				T= 0.03 S= 0.02 T×S= 0.06			
$S.E_{(mean)}$	T= 0.006 S= 0.005 T×S= 0.013				T= 0.005 S= 0.003 T×S=0.01			

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period

Table.4 Effect of treatments and storage period on texture scores and overall acceptability scores of osmo-dried strawberries

E	Texture Scores (9-point hedonic scale)				Overall Acceptability Scores			
	Storage Period (Days)				Storage Period (Days)			
	0	30	60	90	0	30	60	90
T_1 (Control)	8.05	8.01	7.97	7.81	8.09	7.99	7.89	7.68
T_2 (15°Brix sugar + 2% $CaCl_2$)	9.00	8.97	8.91	8.74	9.10	9.02	8.75	8.61
T_3 (25°Brix sugar + 2% $CaCl_2$)	9.21	9.02	8.93	8.88	9.39	9.15	8.93	8.81
T_4 (35°Brix sugar + 2% $CaCl_2$)	9.40	9.11	9.03	8.94	9.63	9.38	9.18	8.97
T_5 (15% glycerol + 2% $CaCl_2$)	8.15	8.13	8.02	7.91	8.27	8.17	8.07	7.95
T_6 (25% glycerol + 2% $CaCl_2$)	8.20	8.15	8.09	8.00	8.39	8.28	8.16	8.04
T_7 (35% glycerol + 2% $CaCl_2$)	8.89	8.85	8.83	8.69	8.91	8.76	8.64	8.47
L.S.D. (*P≤0.05*)	T= 0.03 S= 0.02 T×S= 0.07				T= 0.04 S= 0.01 T×S= 0.06			
$S.E_{(mean)}$	T= 0.005 S= 0.003 T×S= 0.011				T= 0.006 S= 0.001 T×S=0.01			

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period

Fig.1 Preparation of Osmo Dried Strawberries

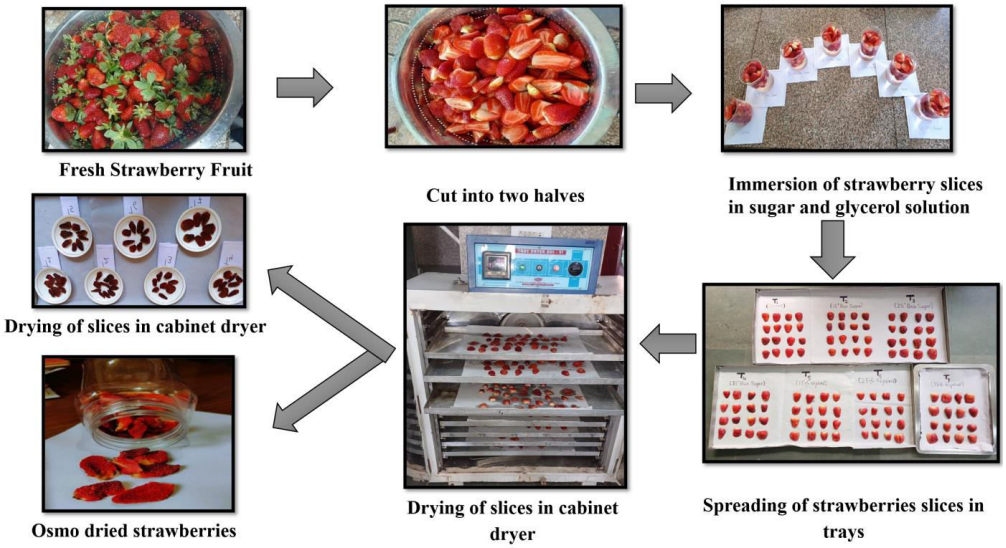


Fig.2 and **Fig.3** Effect of treatments and storage period on moisture content and titratable acidity of osmo-dried strawberries

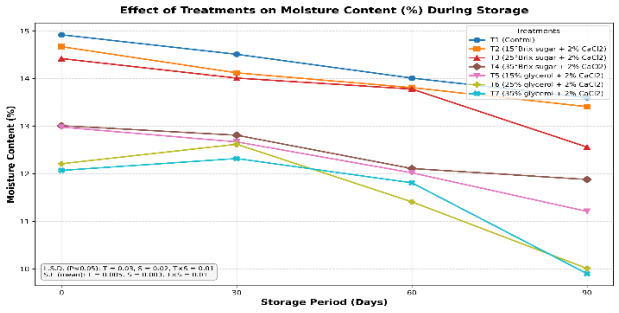


Fig.2

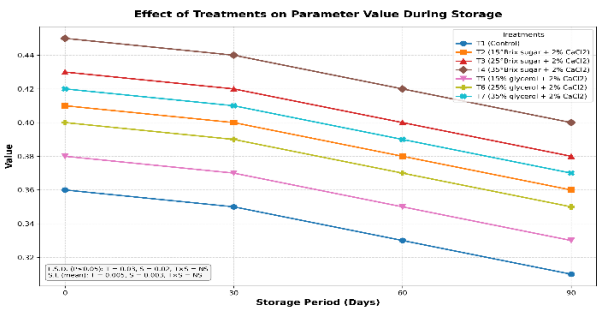


Fig.3

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period

Fig.4 and **Fig.5** Effect of treatments and storage period on reducing sugar and total sugar of osmo-dried strawberries

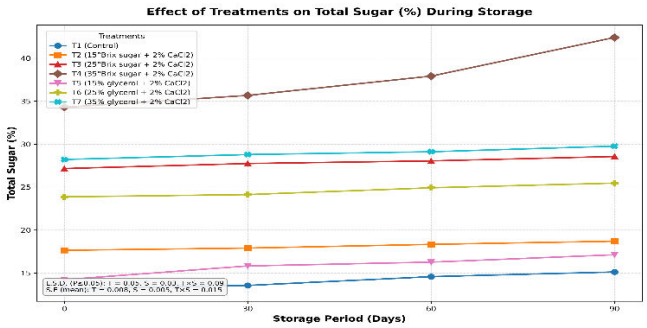


Fig.4

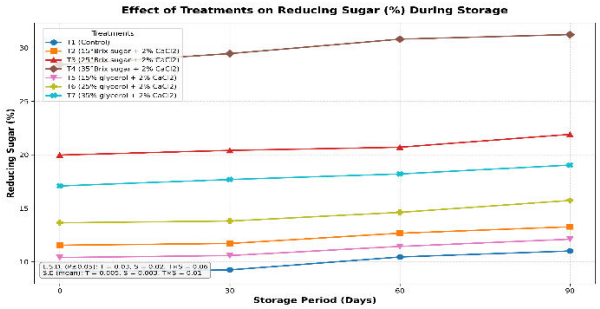


Fig.5

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period

Fig.6 and **Fig.7** Effect of treatments and storage period on ascorbic acid and total phenol content of osmo-dried strawberries

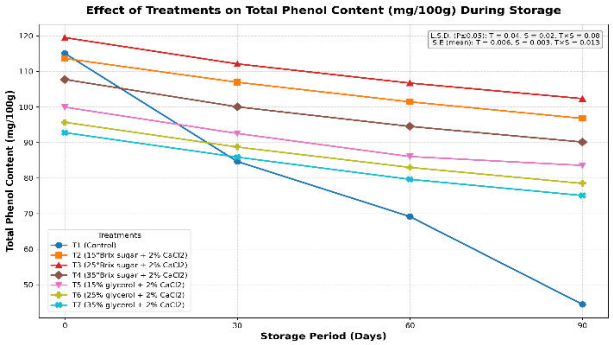


Fig.6

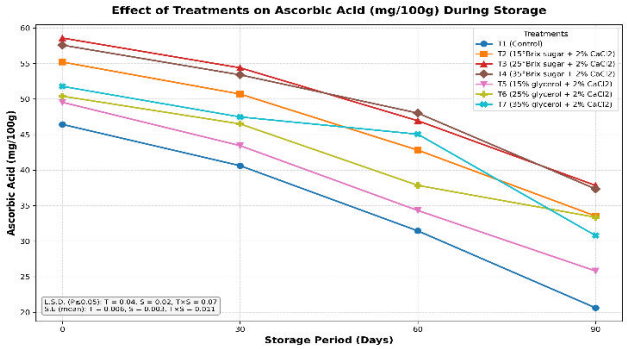


Fig.7

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period.

Fig.8 and **Fig.9** Effect of treatments and storage period on anthocyanins content and total plate count of osmo-dried strawberries

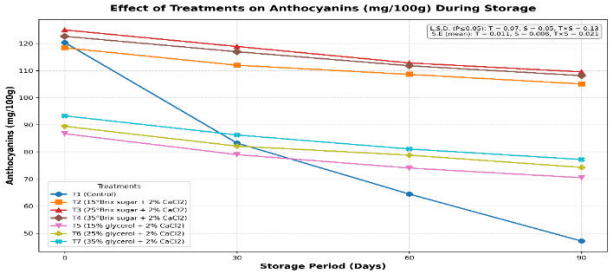


Fig.8

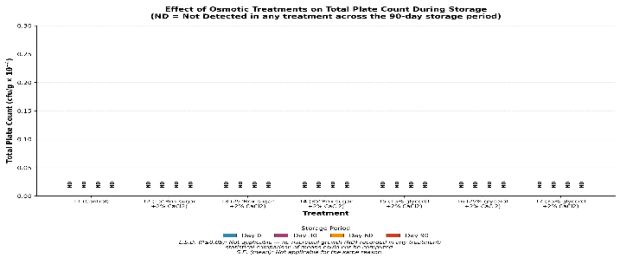


Fig.9

*T= Treatment; S= Storage Period; T×S= Interaction between treatment and storage period

Differences among osmotic agents may arise from their effects on water removal, solute uptake, cellular structure and the diffusion of soluble phenolic constituents. The lower TPC observed in glycerol-treated samples may partly reflect migration of water-soluble phenolic compounds into the osmotic medium; however, direct measurement of the osmotic solutions would be required to confirm leaching as the

predominant mechanism. The subsequent decline in TPC during storage may be attributed to oxidation, enzymatic reactions and other transformations of phenolic constituents. Jankawat *et al.,* (2026) similarly reported progressive reductions in phenolic content during storage of fruit products.

Anthocyanins, which contribute substantially to the characteristic red colour of strawberries, also demonstrated clear treatment-dependent variation. T3 (25 °Brix sucrose + 2% $CaCl_2$) exhibited the highest anthocyanin content, whereas lower values were observed in glycerol-treated samples (Table 5). Similar reductions in anthocyanin concentration following osmotic dehydration have been reported in berries (Reshi *et al.,* 2026). Because anthocyanins are water-soluble pigments, some loss during immersion may occur through migration into the osmotic medium. The extent of pigment loss may depend on osmotic concentration, treatment duration, tissue permeability and the composition of the osmotic solution. Salar *et al.,* (2022) reported that sucrose at appropriate concentrations may contribute to anthocyanin protection, although the magnitude of this effect can vary with processing conditions. Khubber (2020) also associated pigment losses during osmotic treatment with mass transfer and water removal. In the present study, anthocyanin content declined significantly during 90 days of storage. This reduction may be associated with oxidative and structural degradation of anthocyanins during prolonged storage, together with possible thermal or enzymatic effects depending on the residual moisture and storage environment. Comparable anthocyanin losses attributed to leaching, oxidation and degradation have been reported by Sherzad *et al.,* (2017).

Reducing and total sugars exhibited a contrasting trend, increasing progressively during storage, with the highest concentrations generally observed in the sucrose-treated samples, particularly T4 (Table 3). The initially higher sugar concentrations in sucrose-treated strawberries can primarily be attributed to sucrose uptake from the osmotic medium during dehydration. The subsequent increase in reducing sugars during storage may be associated with hydrolysis of non-reducing sugars and other carbohydrate transformations. Changes in moisture content may also contribute to apparent increases in sugar concentration through a concentration effect. Mahima *et al.,* (2026) reported similar increases in sugar concentration during storage of osmo-dehydrated palash flowers, associated increasing sugar levels in dehydrated products with moisture loss and carbohydrate hydrolysis. Glycerol-treated samples showed comparatively lower sugar concentrations, which is expected because glycerol is a polyol rather than a saccharide and therefore does not contribute directly to the measured sugar fraction or sucrose-derived sweetness (Saleena *et al.,* 2021).

The microbiological quality of all samples remained stable throughout the 90-day storage period, with no detectable microbial growth under the analytical conditions employed (Table 5). The absence of detectable growth indicates satisfactory microbiological stability of the product under the storage conditions investigated. This stability may be associated with the combined effects of moisture reduction during osmotic dehydration and drying, reduced water availability, and the protective packaging system. The presence of $CaCl_2$ may also have contributed indirectly to product stability through maintenance of tissue integrity; however, its specific antimicrobial contribution cannot be established from the present data alone. Similar improvements in the storage stability of dehydrated fruit products have been associated with reduced water availability following osmotic dehydration (Verma *et al.,* 2023).

Overall, the findings demonstrate that the choice of osmotic agent and its concentration strongly influenced the quality attributes of osmo-dehydrated strawberries. Among the treatments evaluated, T3 (25 °Brix sucrose + 2% $CaCl_2$) showed particularly favourable retention of ascorbic acid, total phenolics and anthocyanins, whereas T4 (35 °Brix sucrose + 2% $CaCl_2$) consistently produced superior sugar accumulation and sensory characteristics. Although gradual reductions in bioactive compounds and sensory scores occurred during storage, the sucrose–$CaCl_2$ treatments generally exhibited better quality retention than the glycerol-based treatments and untreated control. These results indicate that appropriately formulated sucrose-based osmotic dehydration, particularly when combined with $CaCl_2$, has considerable potential for producing nutritionally and sensorially acceptable shelf-stable strawberry products.

In conclusion, the present study demonstrated that osmotic dehydration is an effective approach for extending the storage stability and maintaining the quality of strawberries. Among the treatments evaluated, T4 (35 °Brix sucrose + 2% $CaCl_2$) exhibited the most favourable overall performance, particularly with respect to sugar retention and sensory attributes, and

consistently maintained desirable colour, texture, taste and overall acceptability throughout 90 days of storage. Treatment T3 (25 °Brix sucrose + 2% $CaCl_2$) showed comparatively better retention of important bioactive constituents, including ascorbic acid, total phenolic compounds and anthocyanins. Thus, the optimum treatment may depend on the desired quality attribute rather than a single treatment being superior for all parameters.

Glycerol based treatments promoted greater moisture reduction, reflecting their strong hygroscopic and osmotic properties; however, they were comparatively less effective in retaining sensory quality and selected bioactive compounds. The combined use of sucrose and $CaCl_2$ therefore provided a favourable balance between moisture removal, structural stability, nutritional quality and consumer acceptability. Despite gradual reductions in ascorbic acid, phenolic compounds, anthocyanins and sensory scores during storage, the osmo-dehydrated strawberries remained microbiologically stable and acceptable for up to 90 days under the conditions investigated.

Overall, the findings highlight the potential of sucrose-based osmotic dehydration in combination with $CaCl_2$ as a promising strategy for producing shelf-stable, value-added strawberry products. Adoption of this approach could contribute to reducing post-harvest losses, improving product diversification and creating opportunities for enhanced utilization and marketing of highly perishable strawberries.

Author Contribution

Conceptualization: Kamakshi Sharma, Anju Bhat ; Methodology: Kamakshi Sharma, Anju Bhat, Neeraj Gupta, Harish, Gyan Singh; Resources: Mahital Jamwal, Sushma Sharma; Supervision: Anju Bhat, Mahital Jamwal, Neeraj Gupta; Writing original draft: Kamakshi Sharma, Anju Bhat, Monica Reshi; Writing, review and editing: Monica Reshi.

Conflicts of Interest

The authors declare they have no conflicting interests.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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