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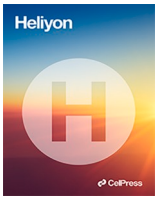

Research article

Transforming the preservation of tomato derivatives: Innovations in packaging and storage

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ABSTRACT

The production and consumption of vegetables, such as tomatoes, have been growing in recent years, due to the combination of several factors, such as market demand, investment in research, education and awareness about health benefits, as well as government incentives and improvements in cultivation technology. The combination of these factors results in an increasing demand for products that offer health benefits, such as tomatoes rich in antioxidants, which help combat free radicals in cells. To maintain most of the nutritional and sensory properties characteristic of the fresh product, it is important to identify the parameters that will help in maintenance. Thus, the study aims to characterize the influence of different packages and storage times with the variables of tomato. The experiment examined the storage of two tomato derivatives (atomized tomato and chips) using various packaging types and storage durations. It utilized a factorial design (2 × 4) with an extra control treatment, comprising 3 replications. Packaging options included low-density polyethylene plastic bags and laminated plastic bags with aluminum foil, while storage durations ranged from 10 to 40 days. Parameters related to color (°Hue and chroma), flavor (pH, titratable acidity, soluble solids, and maturation index), and bioactive compounds (lycopene and β-carotene) of two tomato derivatives (atomized tomato and chips) were analyzed. After the analyzes, it was observed that the transparent package was the one that allowed the best conservation among the studied variables of the atomized tomato derivative, the same happened for the laminated packaging for the derivative chips. Regarding storage time, 20 days showed the best results regarding the conservation of flavor and bioactive compounds.

1. Introduction

Tomatoes have assumed functional food status due to their high levels of vitamin A [1], in addition to containing antioxidant substances such as lycopene, β-carotene, ascorbic acid, and phenolic compounds, with lycopene being a substance considered efficient in the prevention of prostate cancer and strengthening the immune system [2].

As a climacteric fruit, tomato has high metabolic activities in the post-harvest period, which leads to physiological and biochemical changes, causing a high rate of losses [3,4]. Therefore, the development of techniques such as drying becomes important, as it involves a method of removing excess moisture through evaporation, resulting in a reduction of enzymatic reactions [5].

The food drying process presents itself as an alternative for tomato processing and consequent reduction of these losses, as in

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addition to adding value, it offers advantages such as: increased product life, concentration of food value, low storage cost, ease of transport and marketing, and maintenance of quality for longer periods, in addition to being sold at any time of the year [6].

Through the drying technique, various derivatives such as peeled tomatoes, sun-dried tomatoes, juice, puree, concentrated pulp, extract, and ketchup can be obtained. In addition to these products, there is tomato powder, which is less commercially known but offers advantages in terms of food preparation time due to its ease of rehydration and mixing [7].

Tomato chips are another derivative gaining prominence due to being considered healthy and low in calories as they do not undergo the frying process. The term "chips" refers to its presentation, in thin slices with thicknesses ranging from 1 to 4 mm, which undergo the dehydration process [8].

To preserve a significant portion of the nutritional and sensory properties of the derivatives, it's crucial to utilize suitable packaging. This factor significantly influences product quality and is often regarded as the primary means of marketing and establishing a product's brand identity. Packaging serves as consumers' initial encounter with the product, playing a fundamental role in their decision-making process and purchasing behavior [9].

Between the packaging used, LDPE (Low-Density Polyethylene) is a type of plastic widely used in the manufacturing of flexible packaging. It is renowned for its strength and flexibility properties, making it ideal for a variety of applications, including food packaging. LDPE provides an effective barrier against moisture and gases, helping to maintain the freshness and quality of packaged products. Additionally, it is a safe material for use in direct contact with food, as it is inert and non-toxic. Its versatility allows it to be easily molded and sealed, providing convenient and practical packaging for consumers. For these reasons, LDPE is a popular choice in the food packaging industry [10].

Plastic bags laminated with aluminum foil are a widely used option for food packaging due to their numerous benefits. They provide excellent barrier properties, protecting food products from moisture, heat, light, and gases, thus ensuring preservation. Additionally, these bags offer customization options for branding purposes and are compliant with the Food and Drug Administration regulations for direct food contact, guaranteeing safety. Their durability and features like reclosability and tamper-evident closures enhance convenience for consumers while maintaining product quality and freshness. Moreover, their versatility in advertising and information display serves as an effective marketing tool, contributing to an enhanced brand image and overall customer experience [11].

Several attributes are analyzed to study the quality of a product. These attributes may include product features, price, packaging and label design, brand, convenience features, sensory properties, safety and health, origin, environmental sustainability and production processes [12]. Knowing that physical-chemical and bioactive analyzes provide a greater volume of results, more complex data analysis techniques are necessary from a mathematical point of view. The multivariate technique identifies similar and dissimilar clusters through the information analyzed simultaneously [13,14].

This study aims to characterize the influence of different packaging, storage times, and an additional treatment as a control concerning the physicochemical and bioactive quality variables of tomato derivatives (chips and atomized tomato) of the Italian group and ripe subgroup through multivariate analysis.

Fig. 1. Dried tomato chips in an oven with forced air circulation at 60 °C.

2. Material and methods

2.1. Location

The experiment was conducted at the Laboratories of Drying and Storage of Plant Products and Post-Harvest, both at the State University of Goiás, Central Campus of Exact and Technological Sciences, in Anápolis - GO. The tomato fruits were harvested at the Japhanato farm in the region of Silvânia - GO and chosen from the [15] classification based on the group (Italian) and subgroup (Ripe). The fruits were harvested at the ripe stage of maturity, which corresponds to fruits showing more than 90 % of their red coloration.

2.2. Experimental design

An experiment was set up in a completely randomized design for each tomato derivative in a factorial scheme with an additional control treatment (2 × 4+1). Each treatment consisted of a combination of two types of packaging (low-density polyethylene plastic bag with zip-type closure weighing 120 g m^{-1} and plastic bag laminated with aluminum foil with zip-type closure weighing 100 g m^{-1}), four storage times (10, 20, 30, and 40 days) plus an additional treatment as a control (storage time 0 of the derivatives chips and atomized tomato), with three replications.

Tomato chips (Fig. 1) were obtained from 250 fruits cut into 3 mm thick slices, as proposed by Ref. [16]. Subsequently, they were dried in an oven (Solab brand) with forced air circulation at a temperature of 60 °C until reaching hygroscopic equilibrium. The best slice thickness and temperature choice were determined according to Ref. [17].

The atomized tomato was obtained using the Spray Dryer equipment, model LM MSD 1.0 by Labmaq. First, the juice of approximately 220 tomato fruits was extracted with a Mondial Juicer centrifuge. Subsequently, filtering was carried out in organza, and for the preparation of the derivative, a temperature of 100 °C was used, a flow rate of 0.5 L h^{-1}, a spray tip of 1.2 mm and a concentration of maltodextrin from the Malto Drydyn brand at 15 % (drying agent), and the temperature and concentration of maltodextrin were determined according to Ref. [18].

The physicochemical analyzes were carried out on the same day of preparation (storage time 0) to proceed with the characterization of each derivative with the quality, and the rest of the samples were stored for 40 days in their respective packages at room temperature (27.8 °C) for subsequent physicochemical and bioactive analyzes (Figs. 2 and 3).

Derivatives (atomized tomato and chips) were evaluated regarding Hue angle, chroma, hydrogen potential, soluble solids, titratable acidity, maturation index, and lycopene and β-carotene levels.

2.3. Coloring

Determined by using the Konica Minolta CR-400 colorimeter, where the a* coordinate is related to the intensity from green (- a) to red (+ a) and the b* coordinate is related to the intensity from blue (- b) to yellow (+ b). The following were calculated from the a* and b* coordinates: Chroma (color purity) and °Hue (color hue).

2.4. Potential of hydrogen (pH)

Determined using a pHmeter, K39-0014P-Kasvi, with a precision of ±0.06 and automatic temperature compensation, calibrated

Fig. 2. Atomized tomato stored in transparent packaging.

Fig. 3. Tomato chips stored in laminated packaging.

with a pH 7 buffer solution, according to the [19].

2.5. Soluble solids

Performed by direct refractometric reading, in °Brix, with a Reichert Brix/RI-Check refractometer, with measurements from 0 to 62° Brix, as recommended by the [19], and the results were expressed in percentage.

2.6. Titratable acidity

Determined by titration of a 5 g sample diluted in 95 mL of distilled water, with a solution of 0.1 mol L^{-1} of standardized NaOH, using 1 % phenolphthalein as an indicator, following the recommendation of the [19]. The titratable acidity was expressed as a percentage of citric acid.

2.7. Maturation index

Relationship between soluble solids content and titratable acidity.

2.8. Lycopene and β-carotene

Homogenized pulp was weighed (1.0 g), adding 20 mL of 80 % acetone. The mixture was placed in a tube covered with aluminum foil and a lid and in a refrigerator at 3 °C, where it remained for 1 h until complete depigmentation. Then, 20 mL of 80 % acetone was added and filtered through Whatman Nº2 filter paper. For the determination of lycopene and β-carotene, the sample was added to the cuvettes, and readings were performed at wavelengths of 503 ηm for lycopene and 450 ηm for β-carotene in an Instrutherm UV-2000A spectrophotometer. The β-carotene and lycopene contents were calculated according to Refs. [20,21], and the results were expressed in μg g^{-1}.

2.9. Multivariate analysis

Based on the treatments, a matrix (18 × 9) was generated consisting of 18 samples in the line and 8 quality attributes as variables, and an additional column for identifying treatments. For better visualization of the results and grouping of treatments (packaging x time) about the analyzed quality variables, multivariate analysis was carried out through principal component analysis [22] and cluster analysis [23].

The variables were standardized with a mean equal to 0 and a variance equal to 1 to minimize the discrepancy between the

variances of the studied variables, as these have different scales or units of measurement and cannot be compared in this way [24]. From determining the principal components, the eigenvalues, eigenvectors, and scores could be calculated for each sample element [25].

The selection of the main components was based on the Kaiser criterion, that is, only the components related to eigenvalues ≥1 were kept in the system, and the percentage of explained variance was considered [26]. Eigenvectors represent the weight of each variable in each component, ranging from −1 to +1. The criterion for classification described by Ref. [27] was that eigenvectors ≤0.30 are classified as little significant, between 0.30 and 0.49 as medium significant, and eigenvectors ≥0.50 as significant.

The scores generated by the principal component analysis were used to perform the grouping analysis cluster to define clusters of similar treatments. The Ward grouping method was used, which searches for partitions that minimize the loss associated with each grouping [28], and as a measure of dissimilarity, the Euclidean distance, which refers to the geometric distance in the multidimensional space [29]. The analyzes were performed using the R software version 4.0.5 [30].

3. Results and discussion

The quality attributes of tomato derivatives stored at different times and packages were evaluated using the principal component analysis (PCA) (Table 1). The eight variables generated eight principal components collaborating to obtain information that explained the relationship between the variables and the quality of the analyzed treatments.

The total accumulated variance is 100 % explained by the eight main components, according to the different derivatives, storage times, and packaging. It was verified that the two first components (PC1 and PC2) explained 94.05 % of the total variance, with PC1 representing 82.40 % and PC2 11.64 %.

According to the [26], the selection of principal components should be based on eigenvalue. Components that have an eigenvalue ≥1 are retained in the analysis. The first component complies with this criterion and may be responsible for explaining the result.

[31] analyzed the application of the technique by principal components in the application of digital image processing techniques and found that the first principal component explained 93.81 % of image bands 1, 2, and 3 and 98.15 % for image bands 5 and 7 of the total variance and decided to use this first component [32] analyzing the surface water quality data sets obtained from the Huaihe River segment of Bengbu (HRSB) and generated during 2 years (2011–2012) monitoring of 19 parameters at 7 sampling sites, found that the first principal component explained 94.89 %, being thus used as it explains a large part of the total variance.

In the case of the multivariate technique, each principal component is constituted by the linear combination of the original variables, and the combination coefficients are called weights, representing how much each original variable contributes to a given principal component. The greater the weight, the better the representation of the variable in the graph formation [33].

Based on the classification criteria described by Ref. [27], it can be noted that the variable soluble solids (0.384) and maturation index (0.3804) showed a positive correlation, while the variable chroma (−0.379) and β-carotene (- 0.377) showed a negative correlation with PC1 (Table 2). According to the author, eigenvectors ≤0.30 are classified as slightly significant, between 0.30 and 0.49 as moderately significant and eigenvectors ≥0.50 as significant.

After determining the principal components, their numerical values, called scores, are calculated for each sample element. The scores represent the coordinates of the samples in the system of axes formed by the principal components. The score chart showed the relationship between the elements, allowing us to understand which variables contributed most to the groupings [34]. Table 3 presents the numerical values (scores) of the first principal component for the treatments analyzed.

According to Ref. [35], the smaller the distance between the scores with the axis of the Cartesian plane, the smaller the values of the scores and their contribution to explaining the phenomenon; on the other hand, the greater the distance between the score and the axis, the greater the score values and their contribution to explaining the phenomenon.

It can be observed that the treatments P.10.T (powder, storage time ten, and transparent packaging), P.40.L (powder, storage time forty, and laminated packaging), and P.40.T (powder, storage time forty, and transparent packaging) contributed positively, while treatments C.30.L (chips, storage time, and transparent packaging), C.30.T (chips, storage time, and transparent packaging), and C.40.L (chips, storage time and laminated packaging) contributed negatively, being more related to the variables soluble solids, maturation index, chroma, and β-carotene because these were the ones that presented the highest correlation with PC1 (Table 3).

The atomized tomato derivative stored in transparent packaging had the highest average of soluble solids, while the opposite

Table 1
Principal components (PC's), eigenvalues, explained variance, and cumulative explained variance involving the quality attributes of atomized tomatoes and chips stored at different times and packages.

Principal Components	Eigenvalues	Explained Variance (%)	Accumulated Explained Variance (%)
PC1	2.568	82.400	82.400
PC2	0.965	11.640	94.050
PC3	0.533	3.550	97.600
PC4	0.318	1.270	98.870
PC5	0.245	0.750	99.620
PC6	0.153	0.290	99.920
PC7	0.075	0.070	99.990
PC8	0.026	0.000	100.000

Table 2
Correlation of quality variables with the first principal component.

Variables	Principal Component
	PC1
°Hue	0.360
Chroma	**−0.379**
Hydrogenionic Potential	−0.158
Titratable Acidity	−0.356
Soluble Solids	**0.384**
Maturation Index	**0.380**
Lycopene	−0.373
β- carotene	**−0.377**

Table 3
Treatment score values (derived, storage time, and packaging) in the first principal component (PC1).

Variables	Principal Component
	PC1
C.0.N	−1.811
C.10.T	−1.203
C.10.L	−1.635
C.20.T	−2.557
C.20.L	−2.342
C.30.T	**−3.181**
C.30.L	**−3.183**
C.40.T	−2.693
C.40.L	**−3.298**
P.0.N	1.711
P.10.T	**2.555**
P.10.L	2.272
P.20.T	2.362
P.20.L	2.335
P.30.T	2.383
P.30.L	2.481
P.40.T	**2.750**
P.40.L	**2.996**

C.0.N - Chips Zero days None; C.10.T- Chips, Ten days, Transparent; C.10.L – Chips, Ten days, Laminated; C.20.T – Chips, Twenty days, Transparent; C.20.L – Chips, Twenty days, Laminated; C.30.T – Chips, Thirty days, Transparent; C.30.L – Chips, Thirty days, Laminated; C.40.T – Chips, Forty days, Transparent; C.40.L – Chips, Forty days Laminated; P.0.N – Powder, Zero days, None; P.10.T – Powder, Ten days, Transparent. P.10.L – Powder, Ten days, Laminated; P.20.T – Powder, Twenty days, Transparent/; P.20.L – Powder, Twenty days, Laminated; P.30.T – Powder, Thirty days, Transparent; P.30.L – Powder, Thirty days, Laminated; P.40.T – Powder, Forty days, Transparent; P.40.L – Powder, Forty days, Laminated.

happened with the maturation index variable, in which the highest average was observed in laminated packaging. As for the derivative chips stored for 40 days for both packages, this one had the highest average for the chroma variable.

Cluster analysis was performed to facilitate the visualization of groups formed by principal component analysis (Fig. 4). The Ward hierarchical method was used to define the clusters to form a two-dimensional diagram, which can also be called a Dendrogram or Tree Diagram.

The formation of four distinct groups resulting from the k-means method with the Ward grouping can be verified (Fig. 4). The first group comprises treatments: P.10.L (powder, ten days of storage, and laminated packaging), P.20.T (powder, twenty days of storage, and transparent packaging), P.20.L (powder, twenty days of storage, and laminated packaging), P.10.T (powder, ten days of storage, and transparent packaging), P.40.T (powder, forty days of storage, and transparent packaging), and P.40.L (powder, forty days of storage, and laminated packaging).

The second group is composed of treatments: P.0.N (powder, zero days of storage, and no packaging), P.30.T (powder, thirty days of storage, and transparent packaging), and P.30.L (powder, thirty days of storage, and laminated packaging).

The third group includes the following treatments: C.10.L (chips, ten days of storage, and laminated packaging), C.40.T (chips,

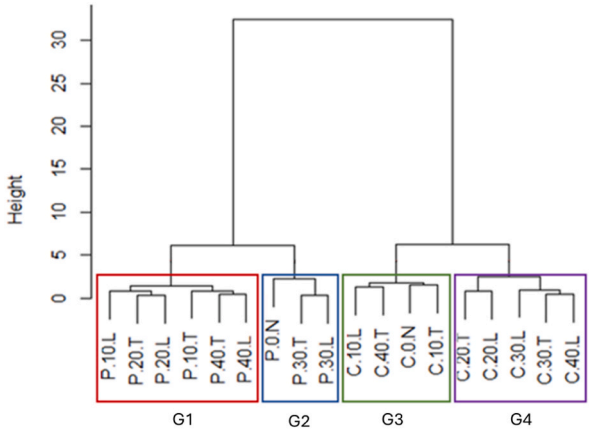

Fig. 4. Cluster analysis for PC1 scores using the Ward method and the Euclidean distance measure.
C.0.N - Chips Zero days None; C.10.T- Chips, Ten days, Transparent; C.10.L – Chips, Ten days, Laminated; C.20.T – Chips, Twenty days, Transparent; C.20.L – Chips, Twenty days, Laminated; C.30.T – Chips, Thirty days, Transparent; C.30.L – Chips, Thirty days, Laminated; C.40.T – Chips, Forty days, Transparent; C.40.L – Chips, Forty days Laminated; P.0.N – Powder, Zero days, None; P.10.T – Powder, Ten days, Transparent. P.10.L – Powder, Ten days, Laminated; P.20.T – Powder, Twenty days, Transparent/; P.20.L – Powder, Twenty days, Laminated; P.30.T – Powder, Thirty days, Transparent; P.30.L – Powder, Thirty days, Laminated; P.40.T – Powder, Forty days, Transparent; P.40.L – Powder, Forty days, Laminated. G1: Groupe 1; G2: Groupe 2; G3: Groupe 3 and G4: Groupe 4.

forty days of storage, and transparent packaging), C.0.N (chips, zero days of storage, and no packaging), and C.10.T (chips, ten days of storage, and transparent packaging).

The fourth group comprises the remaining treatments, which include C.20.T (chips, twenty days of storage, and transparent packaging), C.20.L (chips, twenty days of storage, and laminated packaging), C.30.L (chips, thirty days of storage, and laminated packaging), C.30.T (chips, thirty days of storage, and transparent packaging), and C.40.L (chips, forty days of storage, and laminated packaging).

The formation of distinct groups based on the k-means method with Ward grouping, as depicted in Fig. 4, reflects underlying patterns in the data related to storage time, packaging type, and product derivative (atomized tomato or chips).

The constituent treatments of the first and second groups belong to the same derivative, atomized tomato, the first being the one that grouped the treatments at times 10, 20, and 40 days of storage for both packages. Chip derivatives were present in the third and fourth groups. So, this differentiation suggests that the processing method and initial form of the product play a significant role in the clustering pattern.

Groups I and II (Fig. 4) showed a high correlation with the variable °Hue, soluble solids, and maturation index, indicating similarities in color, sweetness, and ripeness among treatments within these groups, and a low correlation with titratable acidity, chroma, β-carotene, and lycopene. The constituents of these groups come from the atomized tomato derivative. This discrepancy can be attributed to factors such as oxidation of organic acids during processing and degradation of antioxidants like lycopene due to high temperatures, justifying the negative correlation of this attribute, causing an increase in °Hue and, consequently, a less reddish color [36,37].

Groups III and IV (Fig. 4) correlated with the variables titratable acidity, chroma, β-carotene, and lycopene, respectively, constituted by treatments of the chip derivative, presenting negative correlation with the variable °Hue, soluble solids, and maturation index. In this sense, groups III and IV had higher lycopene contents, acidity, and redder color. According to Ref. [38], tomato drying must be carried out at temperatures below 65 °C to preserve color and flavor. The chip derivative was prepared in an oven at 60 °C, which may have influenced this low value in the °Hue attribute, resulting in a redder color and higher lycopene content.

The results of the principal component analysis allowed the evaluation of variables correlation according to the angles formed between them. If the angle formed between two variables is close to zero, the correlation is very high and positive; if it is close to 180°, the correlation is also high but negative; finally, if the angle is about 90°, the variables are weakly related.

The variable °Hue forms an angle of 180° with titratable acidity and lycopene being strongly negatively correlated [39] evaluating the quality of dried tomatoes through osmotic dehydration and drying, found that the lycopene content reduced with storage time for both packages, with air and vacuum. Since lycopene is responsible for the red color of tomatoes, this led to a loss of intensity and color change, a decrease in the chroma coordinate, and an increase in °Hue.

The clustering and correlation analyses reveal intricate relationships between storage time, packaging type, processing method, and product attributes. Understanding these dynamics is crucial for optimizing processing conditions, preserving product quality, and meeting consumer preferences for color, flavor, and nutritional content in food products.

4. Conclusions

Considering the better conservation of the atomized tomato derivative about attributes related to color, it is concluded that storage

was not the best alternative. Regarding attributes related to flavor, the best storage time was 30 days. And in the case of bioactive compounds, the indicated storage time was 20 days. Considering the packages analyzed, it is clear that the transparent one allowed better conservation among the studied variables.

As for the conservation of derivative chips with attributes related to color, it is concluded that the indicated storage time was 40 days. Regarding attributes related to flavor, the best storage time was 20 days. And in the case of bioactive compounds, the indicated time was 20 days. Considering the packages analyzed, it is clear that the laminated package allowed the best conservation among the studied variables.

Four groups were formed through the multivariate analysis from the cluster analysis associated with the Ward method. The first and second group belonging to the atomized tomato derivative with a strong relationship with the °Hue variable, the third and fourth group belonging to the chips derivative with a strong relationship with the titratable acidity and lycopene variables.

Availability of data and materials

All available data generated by experiments mentioned in this article are included either in the manuscript or in the supplementary material. Raw datasets used and/or analyzed during the current study are available from the corresponding authors upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors have given their consent for publication. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

CRediT authorship contribution statement

Sielly Lobo Pereira: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Cristiane Maria Ascari Morgado:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **André José de Campos:** Writing – review & editing, Methodology. **Ivano Alessandro Devilla:** Writing – review & editing, Supervision, Investigation, Conceptualization. **Sueli Martins de Freitas Alves:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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