LWT - Food Science and Technology 92 (2018) 442–450

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Stability of β-carotene rich sweet potato chips packed in different packaging systems

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ARTICLE INFO

Keywords:
Snack
Biofortified sweet potato
Carotenoids
Flexible packaging
Shelf life

ABSTRACT

The development of β-carotene rich sweet potato products, such as chips, provides a healthy consumption option with a long shelf life. The objective of this study was to evaluate the influence of the packaging systems on the stability of the chips. The chips were processed and packaged with nitrogen in PET(polyester)/Al(aluminum foil)/LDPE(low density polyethylene), metallized PET/LDPE, BOPP(biaxially oriented polypropylene)/metallized BOPP and BOPP/metallized BOPP with an oxygen scavenger; and also without nitrogen in BOPP/metallized BOPP, and stored at 25 °C and 75% RH. The shelf life of the chips packed in BOPP/metBOPP without nitrogen was 153 days, losing 61% of the β-carotene, and leading to sensory alterations in the flavor, odor and color. The shelf life of the chips packaged with nitrogen in PETmet/LDPE was defined as 184 days due to sensory alterations involving the loss of crispness. The chips packaged with nitrogen in PET/Al/LDPE, BOPP/metBOPP and BOPP/metBOPP with an oxygen scavenger retained 90%, 83% and 80% respectively of the β-carotene, and showed no significant sensory alterations during 207 days of storage.

1. Introduction

The sweet potato (*Ipomoea batatas* (L.) *Lam.*) is one of the vegetables most cultivated throughout the world. It is a rustic culture, easily handled, and widely adaptable to different climatic conditions and soils, resisting drought and showing low production costs (Burri, 2011). It is considered to be a basic food source for the populations of various developing countries, since it is an energy-rich high carbohydrate food (Bovel-Benjamin, 2007; Burri, 2013; Mosta, Modi, & Mabhaudhi, 2015).

With a view to increasing the availability of micronutrients, sweet potato cultures rich in pro-vitamin A carotenoids are being developed, this being a potential food to combat vitamin A deficiency. The cultivar *Beauregard* presents mean values of $115\,\mu g\,g^{-1}$ of β-carotene and $185\,\mu g\,g^{-1}$ of total carotenoids in the fresh roots (Rodriguez-Amaya, Nutti, & Carvalho, 2011).

Having developed a sweet potato variety with a high carotenoid content, the raw material must be processed in order to increase its shelf life and add value to the product. For example, the dehydration process can give rise to sweet potato flakes, flour and/or chips (Bechoff, Westby, Menya, & Tomlins, 2011; Huang & Zhang, 2012). Being products already present in the everyday of the people, but developed with a more nutritious raw material when compared to the sweet potatoes of white pulp.

Dehydrated sweet potato chips, when processed from high β-carotene content roots, become a healthy, easy-to-eat product. In addition, β-carotene presents benefits to human health, such as an increase in immunity, and decreases in degenerative diseases such as cancer, heart disease and cataract (Moura, Miloff, & Boy, 2015; Saini, Nile, & Park, 2015).

However, since this is a carotenoid rich product, care must be taken during processing, since the carotenoids are susceptible to degradation during processing, which is influenced by the time, temperature, oxygen availability and enzyme activity.

Various papers can be found in the literature evaluating the effects of different types of processing (cooking, frying, sun drying, ovens with and without air circulation) in the retention of the sweet potato carotenoids (Bechoff et al., 2009; Bengtsson, Namutebi, Alminger, &

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https://doi.org/10.1016/j.lwt.2018.02.066
Received 20 November 2017; Received in revised form 22 February 2018; Accepted 26 February 2018
Available online 27 February 2018
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Svanberg, 2008; Van Jaarsveld, Marais, Harmse, Nestel, & Rodriguez-Amaya, 2006).

However, information concerning the influence of the packaging on the loss of carotenoids from the products during storage is scarce and sometimes conflicting or little explored, although the following aspects are basically the relevant ones: oxygen availability in the head space of the package, oxygen dissolved in the product, oxygen permeability through the packaging material, light transmission, faults in the hermiticity of the seal, and the storage time and temperature (Lesková et al., 2006; Rodrigues-Amaya, 1999).

Commercial fried potato chips are packaged in BOPP/metBOPP packs with atmospheric air (21% O_2), practicing an average shelf life of 90 days. Therefore, the objective of this study was to evaluate the influence of the packaging material and packaging system on the stability of dehydrated carotenoid-rich sweet potato chips, and evaluate which packaging system provided the longest shelf life.

2. Material and methods

2.1. Specifications of the packaging materials

The packaging materials were previously evaluated under a white light source, without the aid of magnification in order to identify the presence of visual defects on the surface of the materials, such as discontinuation of metallization and absence of micro-holes, as described by Sarantópulos and Teixeira (2017) because this type of defect can directly impact on the barrier properties of materials. In addition, the materials used are in the lowest thickness available on the market, as the permeability of the materials is conferred by metallization and aluminum foil. However, as the materials had low permeability values, I assumed that the metallization was uniform and there were no micro-holes in the aluminum foil. Table 1 shows the specifications of the PET/Al/LDPE, PETmet/LDPE and BOPP/metBOPP films used to package the biofortified sweet potato chips.

The choice of packaging materials was due to their barrier characteristics and their applicability in the market, being materials used in the packaging of dehydrated products that are sensitive to moisture gain and to products that are susceptible to oxidation reactions. The packages were made manually with dimensions of 30 × 15 cm, using an electric pulse sealer (Haramura – H-Soberana 40, São Paulo, Brazil). The heat sealing has occurred inside the material being sealable LDPE materials in the PET/Al/LDPE and PETmet/LDPE, and metBOPP (side: non-metallized) for BOPP/metBOPP. The visual aspect and integrity of the heat seals of the packages were evaluated in order to define the sealing time/temperature conditions.

Table 1
Characterization of the packaging materials used to pack the bio-fortified sweet potato chips.

Packaging material	Thickness* (µm)		OTR** (mL (STP) m^{-2} dia^{-1})	WVTR*** (g water m^{-2} dia^{-1})
PET/Al/LDPE	Total	106	< 0.05(1)	< 0.01(1)
	Partial	15/8/83		
PETmet/LDPE	Total	72	0.45	1.09
	Partial	14/58		
BOPP/metBOPP	Total	39	18.69	0.31
	Partial	19/20		

Values referring to (*) twenty five. (**) two and (***) four determinations.
OTR (Oxygen transmission rate) at 23 °C and 1 atm. of partial gas pressure gradient (ASTM D 3985–05 (2010)) using the OXTRAN equipment (Mocon - model 2/20. Minneapolis. USA).
WVTR (Water vapor transmission rate) at 38 °C/90% RH (ASTM F 1249–13 (2013)) using the PERMATRAN equipment. (Mocon - model W3/31. Minneapolis. USA).
(1)- Corresponding to quantification of the method under the analytical conditions used.
PET - polyester, Al - aluminum foil, LDPE - low density polyethylene, BOPP - biaxially oriented polypropylene and met - metallized.

2.2. Processing of the biofortified sweet potato chips

The orange colored sweet potatoes of the *Beauregard* variety were cultivated in the city of Campinas - Brazil. The batch used in this study was harvested after 4 months and processed in the form of dehydrated chips, as described below.

The sweet potatoes were washed, peeled and sliced with a thickness between 1.0 and 2.0 mm. The slices were blanched for 10 min in a steam tunnel (100 °C) with a line pressure of 4 ± 1 kgf cm^{-2} and then dehydrated in a tray dryer (Proctor & Schwartz - model K13964, Lexington, USA) at 65 °C for 5 h with an air circulation flow of 1 m s^{-1}. The sweet potato chips were cooled to room temperature and packed in the different packaging systems, according to item 2.3.

2.3. Packaging systems

The chips were packaged in five different packaging systems, as described below:

- PET/Al/LDPE with nitrogen;
- PETmet/LDPE with nitrogen;
- BOPP/metBOPP with nitrogen;
- BOPP/metBOPP with nitrogen and an oxygen scavenger;
- BOPP/metBOPP without nitrogen (in atmospheric air with 21% oxygen).

The chips packed with nitrogen were packaged using a vacuum sealer (Selovac – 200, São Paulo, Brazil), whereby the oxygen was removed from the head space by way of vacuum followed by injection of super-dry nitrogen and sealing of the package, the process being optimized to obtain less than 0.5% residual oxygen. In the BOPP/metBOPP with nitrogen and oxygen scavenger packaging system, two oxygen scavenger sachets (Multisorb - FreshPax® S, New York, USA) were previously added, followed by the same procedure described above for nitrogen injection and sealing. For the BOPP/metBOPP without nitrogen packaging system, the product was placed in the package and sealed using an electric impulse sealer (Haramura – H-Soberana 40, São Paulo, Brazil). The use of nitrogen in the packaging was to minimize the reactions of oxidation of carotenoids throughout the storage and the packing in atmospheric air was evaluated because it is the system used in the market of chips.

2.4. Shelf life study

The packed products were maintained in a storage chamber at 25 ± 3 °C and 75 ± 5% RH in the absence of light. The oxygen content in the head space and the integrity of the heat seal of the packages were evaluated throughout storage and the chips were evaluated for their moisture content, water activity (Aw), total carotenoid and β-carotene contents and a sensory evaluation, according to the following methods.

2.4.1. Heat seal integrity

The packages were evaluated using the colored solution penetration method, based on the capacity of a low surface tension solution (0.15% erythrosine) to penetrate through small faults and micropores, as described by Arndt (2001), chap. 22. The colored solution was applied to the inside of the heat seal so that the entire heat seal region was in contact with the solution. The packages were kept in a vertical position for 3 h, on white paper, where they were evaluated for stains on the paper to detect leaks, later the packages were evaluated visually on the outside of the heat seal, seeking to detect the presence of colored solution.

2.4.2. Moisture content and water activity

The moisture content of the sweet potato chips was determined in quadruplicate according to AOAC method No. 984.25^{16} in a cabinet oven with air circulation (Fanem – 515/4-C, Garulhos, Brazil), drying for 16 h at 103 ± 1 °C to constant weight, determined using an analytical balance (Mettler Toledo – XP504, Barueri, Brazil) with an accuracy of 0.0001. The results were expressed as % on a dry weight basis (d.b.).

The water activity was determined in a hygrometer based on psychrometry (Aqualab$^{®}$ - Decagon Devices Inc., Pullman, USA) with a resolution of 0.0001. The analysis was carried out with four replicates at 25.0 ± 0.3 °C (DECAGON …, s.d.).

2.4.3. Oxygen content of the head space

Throughout storage the oxygen content of the head space was evaluated in triplicate. Aliquots of the head space gas were removed using a hermetic syringe through a silicon septum, and the gas subsequently identified and quantified using a gas chromatograph (Agilent Technologies - 7890, Wilmington, USA), operating with a thermal conductivity detector at 150 °C, column (X13 molecular sieve) at 50 °C, injector at 70 °C, and stripping gas of 99.99% pure argon at a flow rate of 30 mL min^{-1}, according to the method described by Sarantópulos and Teixeira (2017). Results were expressed as % v/v.

2.4.4. Carotenoid content

The total carotenoids and β-carotene of the sweet potato chips were quantified as described by Rodriguez-Amaya (2001). For the analysis, 1 g of the sample was added to hyflosupercel (Synth, Brazil) hydrated with 10 mL of water. The pigments were sequentially extracted in a disintegrator (Marconi - MA 102, Piracicaba, Brazil) with 50 mL volumes of acetone, until the sample was colorless. The extract was then transferred to petroleum ether and the final volume adjusted to 50 mL.

To determine the total carotenoids, an aliquot was diluted in petroleum ether and the absorbance read at 453 nm in a UV-VIS spectrophotometer (Cary 50, Varian, Santa Clara, USA) and quantified using the absorption coefficient of 2592 (absorbance units).

The β-carotene content was determined in a chromatograph (Agilent, Infinity 1260, Apple Valley, USA) using a diode array detector at 452 nm. The carotenoids were separated on a Poroshell 120 EC-18, 4.6 × 50 mm, 2.7 μm column (Agilent, Apple Valley, USA), with a mobile phase composed of acetonitrile: methanol: ethyl acetate: triethylamine (79.95:10:10:0.05, v/v/v/v), in an isocratic system with a flow rate of 0.5 mL min^{-1}. Quantification was done by external standardization with 95% trans-β-carotene C4582 (Sigma-Aldrich, USA). The concentration of the trans-β-carotene solution was confirmed by reading at 453 nm, using an absorption coefficient of 2592.

The assays were carried out with three repetitions and all extraction steps were protected from the light. The methanol, acetonitrile and ethyl acetate used in the chromatographic process were of chromatographic grade (Tedia, USA) and the other reagents were of analytical grade.

The retentions of total carotenoids and trans-β-carotene during storage were calculated as described by Murphy, Criner, and Gray (1975), based on the following equation:

$$\%\ Retention = \frac{Carotenoid\ content\ per\ g\ of\ chips\ at\ time\ x\ (d.\ b.\ )}{Carotenoid\ content\ per\ g\ of\ chips\ at\ time\ 0\ (d.\ b.\ )}\ x\ 100$$

2.4.5. Sensory evaluation

The sensory profile was determined using 15 individuals all above 18 years of age, recruited from the Packaging Technology Center (CETEA) of the Institute of Food Technology (ITAL), Brazil. The panelists were selected based on their availability, interest, and ability to express and identify the sensory attributes, and trained to evaluate the attributes which determined the sensory quality of the chips (color, flavor, odor and texture).

The sensory profile of each sample was determined by trained panelists using the QDA method (Quantitative Descriptive Analysis) described by Stone and Sidel (2004).

Training was carried out using potato chips available on the market and with biofortified sweet potato chips, in order to form the sensory memory by way of direct contact of the individuals with the maximum and minimum references for each attribute.

The score cards used a 9 cm non-structured scale, and a score of ≥4.5 was defined for product rejection.

The samples were coded with three digit numbers using a completely balanced block design (Macfie & Bratchell, 1989).

The extremes of the scales for each attribute were described as follows:

- Characteristic color (0 = intense orange and 9 = light yellow);
- Characteristic odor (0 = characteristic and 9 = odd);
- Oxidation odor (0 = absent and 9 = strong);
- Characteristic flavor (0 = characteristic and 9 = not characteristic);
- Oxidation flavor (0 = absent and 9 = strong);
- Crispness (0 = crunchy and 9 = limp);
- Overall quality (0 = excellent and 9 = dreadful).

2.4.6. Statistical analysis

The following tests were carried out: Shapiro-Wilk and Anderson-Darling normality test, Bartlett and Levene and Fisher variance analysis, the two sample *t*-test, ANOVA, and Welch's ANOVA. In addition, several paired comparisons of Tukey averages, Games-Howell, Tamhane's T2 were done (Addinsoft, 2015; Portal Action).

3. Results and discussion

3.1. Heat seal integrity

No faults were found in the heat seals of the systems PET/Al/LDPE, PETmet/LDPE and BOPP/metBOPP with nitrogen and BOPP/metBOPP without nitrogen used during the study, therefore, these seals were considered hermetic. In the BOPP/metBOPP packages with nitrogen and oxygen scavenger, used up to 154 days of storage time, were hermetic. However, minimal and isolated faults (a small hole in each package analyzed) were detected in the BOPP/metBOPP packages with nitrogen and oxygen absorber evaluated during a period of 207 days of storage. This type of failure is a critical point because, through this small hole in the package, the O_2 content of the head space can increase, and depending on the amount of O_2 available in the head space the oxidation reactions of β-carotene can be favored, resulting in a negative impact on the quality of sweet potato chips. Therefore, this type of defect should be avoided.

3.2. Moisture content and water activity

Increases in both the moisture content and water activity of the chips packaged in PETmet/LDPE were found throughout storage, and to a lesser extent by the samples in BOPP/metBOPP. The moisture content and water activity of the chips packaged in PET/Al/LDPE remained stable (Table 2).

Table 2
Water activity and Moisture content of the biofortified sweet potato chips packaged in different packaging systems throughout storage.

Water activity (Aw)								
Packaging systems	Storage Time (day)							
	0	31	62	91	122	153	184	207
PET/Al/LDPE with N_2	$0.394 \pm 0.004^{a/AB}$	$0.383 \pm 0.002^{b/C}$	$0.370 \pm 0.003^{d/D}$	$0.361 \pm 0.002^{c/E}$	$0.371 \pm 0.002^{d/D}$	$0.388 \pm 0.002^{d/BC}$	$0.399 \pm 0.001^{d/A}$	$0.393 \pm 0.005^{d/AB}$
PETmet/LDPE with N_2	$0.394 \pm 0.004^{a/E}$	$0.393 \pm 0.001^{a/E}$	$0.440 \pm 0.003^{a/D}$	$0.456 \pm 0.006^{a/D}$	$0.451 \pm 0.002^{a/D}$	$0.495 \pm 0.001^{a/C}$	$0.502 \pm 0.001^{a/B}$	$0.525 \pm 0.001^{a/A}$
BOPP/metBOPP with N_2	$0.394 \pm 0.004^{a/EF}$	$0.392 \pm 0.001^{a/F}$	$0.401 \pm 0.003^{c/DE}$	$0.401 \pm 0.001^{b/DE}$	$0.406 \pm 0.003^{c/D}$	$0.416 \pm 0.001^{c/C}$	$0.426 \pm 0.002^{c/B}$	$0.434 \pm 0.001^{c/A}$
BOPP/metBOPP with N_2 and oxygen scavenger	$0.394 \pm 0.004^{a/E}$	$0.375 \pm 0.001^{c/F}$	$0.404 \pm 0.002^{bc/D}$	$0.402 \pm 0.005^{b/D}$	$0.403 \pm 0.001^{c/D}$	$0.417 \pm 0.003^{c/C}$	$0.428 \pm 0.001^{c/B}$	$0.442 \pm 0.001^{b/A}$
BOPP/metBOPP without N_2	$0.394 \pm 0.004^{a/E}$	$0.383 \pm 0.002^{b/F}$	$0.408 \pm 0.002^{b/C}$	$0.401 \pm 0.002^{b/D}$	$0.411 \pm 0.002^{b/C}$	$0.429 \pm 0.004^{b/B}$	$0.437 \pm 0.001^{b/A}$	$0.436 \pm 0.002^{c/A}$
Moisture content (%)								
PET/Al/LDPE with N_2	$6.96 \pm 0.06^{a/AB}$	$7.39 \pm 0.18^{a/A}$	$6.85 \pm 0.09^{b/B}$	$7.36 \pm 0.06^{b/A}$	$7.04 \pm 0.08^{d/AB}$	$7.37 \pm 0.08^{d/A}$	$7.40 \pm 0.10^{d/A}$	$7.15 \pm 0.05^{d/AB}$
PETmet/LDPE with N_2	$6.96 \pm 0.06^{a/F}$	$7.39 \pm 0.07^{a/E}$	$8.08 \pm 0.08^{a/D}$	$8.70 \pm 0.05^{a/C}$	$8.70 \pm 0.05^{a/C}$	$9.79 \pm 0.05^{a/B}$	$10.50 \pm 0.12^{a/A}$	$10.60 \pm 0.03^{a/A}$
BOPP/metBOPP with N_2	$6.96 \pm 0.06^{a/C}$	$7.28 \pm 0.07^{a/C}$	$6.82 \pm 0.05^{b/C}$	$7.37 \pm 0.09^{b/C}$	$7.66 \pm 0.09^{c/B}$	$7.76 \pm 0.06^{cd/BC}$	$7.95 \pm 0.07^{c/A}$	$7.99 \pm 0.12^{c/A}$
BOPP/metBOPP with N_2 and oxygen scavenger	$6.96 \pm 0.06^{a/B}$	$6.80 \pm 0.11^{b/B}$	$7.40 \pm 0.19^{ab/B}$	$7.90 \pm 0.60^{ab/AB}$	$7.73 \pm 0.11^{c/B}$	$7.84 \pm 0.07^{c/B}$	$8.10 \pm 0.07^{c/A}$	$8.29 \pm 0.07^{b/A}$
BOPP/metBOPP without N_2	$6.96 \pm 0.06^{a/C}$	$7.34 \pm 0.36^{a/BC}$	$7.13 \pm 0.07^{ab/C}$	$7.80 \pm 0.11^{b/B}$	$8.02 \pm 0.23^{b/AB}$	$8.13 \pm 0.09^{b/A}$	$8.30 \pm 0.08^{b/A}$	$7.93 \pm 0.15^{c/AB}$

* Mean values of four determinations ± standard deviation.

$^{a, b, c}$ Comparison between samples for the same storage period: averages followed by the same lowercase letters in the column do not differ at the 95% confidence level ($p < 0.05$).

$^{A, B, C}$ Comparison between storage periods for the same sample: averages followed by the same uppercase letter in the row do not differ at the 95% confidence level ($p < 0.05$).

PET - polyester, Al - aluminum foil, LDPE - low density polyethylene, BOPP - biaxially oriented polypropylene and met - metallized.

These results were due to water vapor permeation through the packaging materials, since PETmet/LDPE has a WVTR 3.5 times greater than that of BOPP/metBOPP, and there was practically no moisture permeation through PET/Al/LDPE (Table 1). The slight variations found during storage in the water activity (Aw) results for the chips packaged in PET/Al/LDPE were probably due to variations in the drying of the product, and were not significant at the 95% confidence level ($p < 0.05$) when the storage times of 0 and 207 days were compared.

The chips packaged in PETmet/LDPE showed increases in water activity and moisture content during storage, which differed significantly at the 95% confidence level ($p < 0.05$), resulting in a loss of crispness and leading to rejection of the product after 207 days of storage at 25 °C/75% RH, as shown in Fig. 1.

The chips packaged in the BOPP/metBOPP packages with and without nitrogen and oxygen scavenger presented similar values for water activity and moisture content when compared for the same period, although for some periods the results differed at a 95% level of confidence ($p < 0.05$) probably due to variations in the batch of the product.

3.3. *Oxygen content in the head space*

The chips packed with nitrogen in PET/Al/LDPE and PETmet/LDPE presented similar O_2 contents throughout the shelf life period studied (Table 3), with no significant difference at the 95% confidence level ($p < 0.05$), This is proof of the excellent oxygen barrier properties of these two structures, of adequate nitrogen injection and of hermetic seals.

The systems BOPP/metBOPP packages with nitrogen and with and without an oxygen scavenger showed an increase in the O_2 content in the head space during the shelf life due to permeation of oxygen through the material, which was not consumed in oxidation reactions. In addition, the system BOPP/metBOPP with nitrogen and oxygen scavenger showed a small failure in the packages evaluated in the period of 207 days of storage (item 3.1), which favored the increase of O_2 content in head space in the last period evaluation.

When packing of the product in BOPP/metBOPP with nitrogen and oxygen scavenger was compared with packing in BOPP/metBOPP with nitrogen and without oxygen scavenger, the oxygen contents in the head space of the system with oxygen scavenger were smaller during storage up to 184 days of storage, but the result was inverted after 207 days as a result of the small fault found in the hermetic seal, although the systems presented no statistically significant differences between them at the 95% confidence level ($p < 0.05$).

According to Robertson (2013), the greatest effectivity of the use of oxygen scavengers is obtained when using high oxygen-barrier packaging material allied with the use of modified atmosphere and hermetic sealing. Thus the use of oxygen scavengers in packaging with nitrogen in BOPP/metBOPP maintained low O_2 levels up to 62 days of storage, statistically equal ($p < 0.05$) to the results obtained with the PET/Al/LDPE system with nitrogen. After this period there was a constant increase in the O_2 content as a function of the oxygen permeability rate of the BOPP/metBOPP film used.

It can be seen that the oxygen content in the head space of the chips packed in BOPP/metBOPP without nitrogen was very close to that of atmospheric air (21% O_2), due to the greater OTR as compared to the other materials studied. Thus even if the oxygen was consumed in oxidation reactions, it would be compensated by oxygen permeating through the material, and hence significant variations in the oxygen level were not observed during storage at a 95% confidence level ($p < 0.05$).

3.4. Carotenoids content

The initial total carotenoid and β-carotene contents of the biofortified sweet potato chips were 613 μg g^{-1} and 490 μg g^{-1} (d.b.), respectively.

The total carotenoid contents of the chips packed in PET/Al/LDPE with nitrogen showed no statistical difference during storage at the 95% confidence level ($p < 0.05$), retaining 80% of the carotenoids after 207 days of storage at 25 °C/75% RH (Table 4).

The samples packed in PETmet/LDPE with nitrogen did not present differences between them at a 95% confidence level ($p < 0.05$) up to 122 days of storage when compared with the initial carotenoid content. After this period, the total carotenoid contents decreased showing differences between them at the 95% confidence level ($p < 0.05$), retaining 78% of the total carotenoids after 207 days.

The chips packed in BOPP/metBOPP with nitrogen, with and without oxygen scavenger, did not present significant differences between them at the 95% confidence level ($p < 0.05$) up to 62 days of storage. However, the system with oxygen scavenger resulted in a smaller loss up to 153 days of storage, showing the effectiveness of the oxygen scavengers in minimizing degradation of the carotenoids during storage. The two systems presented 75% total carotenoid retention, at the end of storage.

The BOPP/metBOPP without nitrogen packaging system showed the highest total carotenoid losses during storage when compared to the other systems used, this result being attributed to the presence of oxygen in the head space of the packages, leading to oxidation of the carotenoids, with only 42% retention after 207 days.

In general total carotenoid retentions in the chips packed in systems with nitrogen were similar, these systems presenting total carotenoid retention superior to that of chips packed in BOPP/metBOPP without nitrogen.

With respect to the β-carotene contents, the chips packed with nitrogen in PET/Al/LDPE, PETmet/LDPE and BOPP/metBOPP did not show significant differences between them at the 95% confidence level ($p < 0.05$) when compared to the initial value (0 day), retaining 90%, 90% and 83% at the end of storage (207 days).

The samples packed in the BOPP/metBOPP system with nitrogen and oxygen scavenger showed lower β-carotene contents at the end of the storage period, differing statistically at the 95% confidence level ($p < 0.05$) from the initial value, probably as a function of the small fault found in the seal in the packages used for the period of 207 storage days (item 3.1). Despite the decrease in the β-carotene concentration, this system showed retention of 80%, close to that of the other systems with nitrogen, representing a satisfactory retention value.

Therefore, the BOPP/metBOPP flexible packaging material, due to its oxygen permeability rate, allowed maintenance of the O_2 content of the system without nitrogen, which favored the greater degradation of the total carotenoid and β-carotene. The systems with and without oxygen absorber in BOPP/metBOPP presented increase in O_2 content during storage as a function of material permeability, in addition, the system with oxygen scavenger presented a higher O_2 content in the period of 207 days of storage, due to the failure presented in the heat sealing, these factors contributed to the degradation of carotenoids of the sweet potato chips.

According to Bechoff et al. (2010a) & Li et al. (2012), the storage of sweet potato chips has shown problems, since the storage time and temperature, the type of packaging material used, and the atmosphere surrounding the product resulted in considerable pro-vitamin A carotenoid degradation.

According to Bechoff et al. (2010b) the effect of the water activity of dehydrated orange-pulp sweet potato chips interferes directly with the degradation velocity of the carotenoids, leading to greater β-carotene losses at Aw values between 0.13 and 0.30, the degradation velocity of the carotenoids being lower at Aw values between 0.30 and 0.70. Ferreira (2011) evaluated the influence of water activity in the β-carotene degradation velocity in microencapsulated pitanga pulp and observed that at lower Aw values (0.23) the degradation velocity was greater, and that with an Aw of 0.41, the degradation velocity was 6.75 times smaller. In the present study, the Aw of the chips was not a critical factor in the degradation of the carotenoids, since the water activity values of the chips were in the range from 0.37 to 0.52 during the 210 days of the study.

The carotenoid losses observed during storage can be attributed to the amount of oxygen available in the head space of the package. Bechoff et al. (2010b) evaluated the β-carotene degradation rate in orange sweet potato chips packed in different oxygen concentrations (0%, 2.5%, 10% and 21%) and concluded that the greater the availability of oxygen the greater the β-carotene degradation rate. These results are in agreement with those observed in the present study for the chips packed in BOPP/metBOPP without nitrogen (21% O_2), where the retention was 39% after 207 days of storage, inferior to the retentions with all the materials with nitrogen, as shown in Table 4.

Bechoff, Tomlins, Dhuique-Mayer, Dove, and Westby (2011) obtained 21.4% retention of β-carotene in sweet potato chips of the variety *Resisto*, packaged in polyethylene, after storage for 4 months at room temperature (20–31 °C). In another study Bechoff et al. (2010a) obtained β-carotene retentions of 34.8% and 35.3% in sweet potato chips of the varieties *Ejumula* and *Kakamega*, respectively, when packaged in transparent polyethylene at room temperature (19.1–27.7 °C and 42.8–86.5% RH) for 4 months. When the results for the retention of β-carotene in the *Beauregard* variety sweet potato chips (present study) were compared with those of Bechoff et al. (2010a; 2011), the five packaging systems evaluated in the present study were superior to those of Bechoff et al. (2010a; 2011) throughout the 207 days of storage, which was to be expected, since these authors used PE packaging, which is highly permeable to oxygen (Robertson, 2013). Thus the material used by Bechoff et al. (2010a; 2011) favored oxygen permeation, allowing for the carotenoid degradation reaction and resulting in less retention during storage, explaining the reason why laminated structures with superior oxygen barrier properties were chosen for use in the present study.

3.5. Sensory evaluation

Fig. 1 shows the results obtained for the sensory attributes of the biofortified sweet potato chips packed in different packaging systems during the storage period.

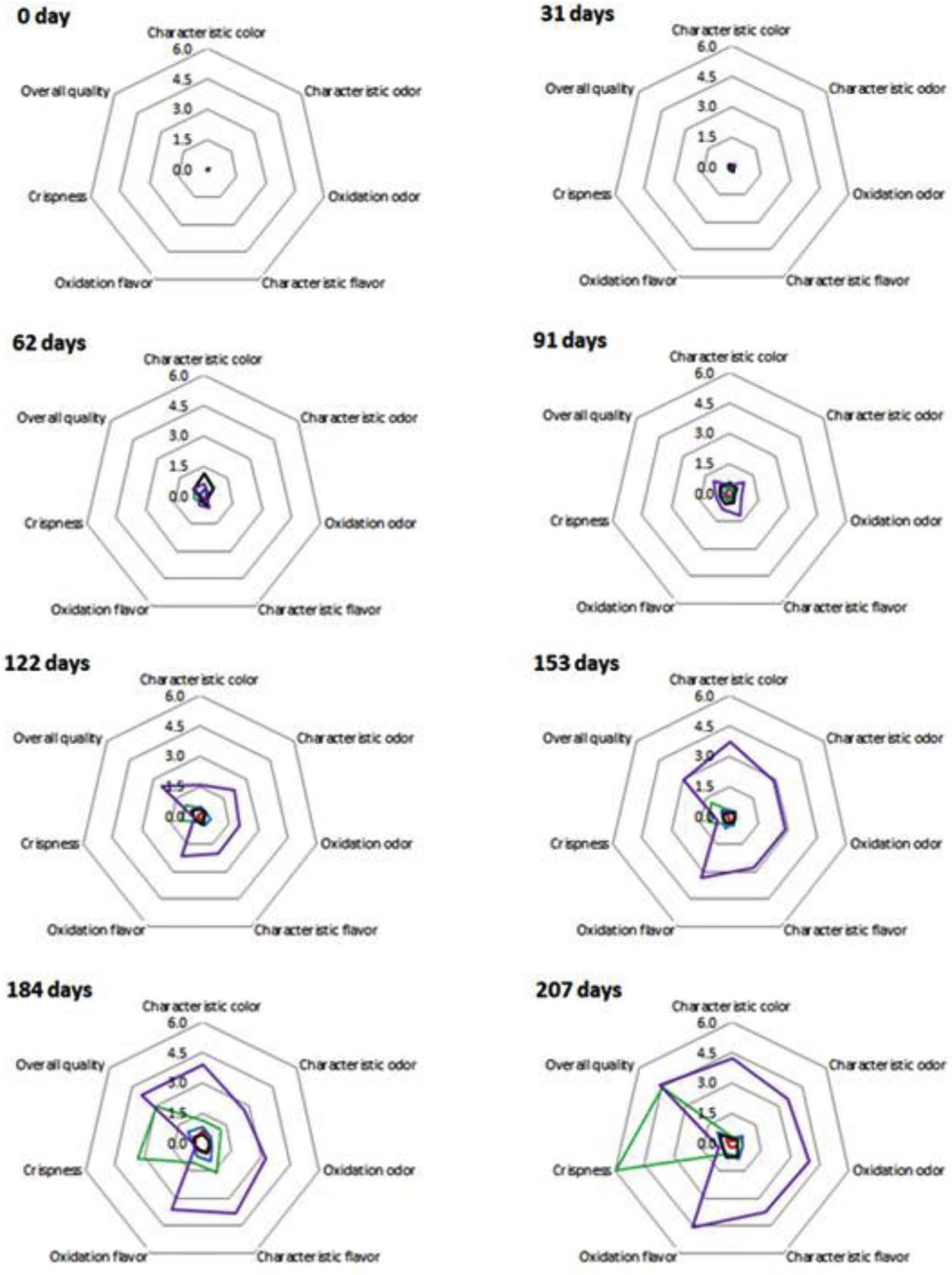

Fig. 1. Sensory profile of biofortified sweet potato chips packed in different packaging systems and stored at 25 °C/75% RH (n = 15). PET/Al/LDPE with N_2 (red); PETmet/LDPE with N_2 (green); BOPP/metBOPP with N_2 (blue); BOPP/metBOPP with N_2 and oxygen scavenger (black); BOPP/metBOPP without N_2 (purple). PET - polyester, Al - aluminum foil, LDPE - low density polyethylene, BOPP - biaxially oriented polypropylene and met – metallized. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

It can be seen that the five packaging systems maintained the scores awarded at zero time for the sensory attributes for up to 62 days, indicating that the packaging systems used were efficient in maintaining the quality of the chips during 62 days of storage at 25 °C/75% RH with minimal alterations.

After 91 days of storage, the chips packed in systems with nitrogen maintained the scores awarded at zero time for the sensory attributes, but the scores awarded to those packed in BOPP/metBOPP without nitrogen indicated a loss of quality for the attributes of characteristic color, characteristic odor, oxidized odor, characteristic flavor, oxidized flavor and overall quality. After 207 days of storage, the mean score awarded for the attribute of characteristic color was 4.20, indicating a loss of color of the product. The changes in color of the sweet potato chips were due to the presence of oxygen in the head space of the

Table 3
Oxygen content in the head space during storage of the packaged biofortified sweet potato chips.

Packaging systems	Storage Time (day)							
	0	31	62	91	122	153	184	207
PET/Al/LDPE with N_2	$0.40 \pm 0.06^{b/AB}$	$0.31 \pm 0.11^{b/B}$	$0.26 \pm 0.09^{c/B}$	$0.32 \pm 0.18^{c/B}$	$0.26 \pm 0.05^{c/B}$	$0.38 \pm 0.10^{c/AB}$	$0.61 \pm 0.03^{c/A}$	$0.20 \pm 0.05^{c/B}$
PETmet/LDPE with N_2	$0.41 \pm 0.04^{b/AB}$	$0.33 \pm 0.06^{b/B}$	$0.36 \pm 0.06^{c/B}$	$0.40 \pm 0.04^{c/B}$	$0.46 \pm 0.11^{c/AB}$	$0.38 \pm 0.10^{c/B}$	$0.61 \pm 0.10^{c/A}$	$0.38 \pm 0.02^{c/B}$
BOPP/metBOPP with N_2	$0.27 \pm 0.09^{b/E}$	$2.94 \pm 1.13^{b/D}$	$3.14 \pm 0.54^{b/D}$	$3.91 \pm 0.46^{b/CD}$	$3.57 \pm 0.70^{b/D}$	$5.35 \pm 0.25^{b/BC}$	$5.80 \pm 0.14^{b/AB}$	$7.39 \pm 0.49^{b/A}$
BOPP/metBOPP with N_2 and oxygen scavenger	$0.33 \pm 0.04^{b/E}$	$0.26 \pm 0.07^{b/E}$	$1.01 \pm 0.23^{c/D}$	$2.59 \pm 0.18^{b/C}$	$2.53 \pm 0.79^{bc/C}$	$3.12 \pm 1.26^{bc/C}$	$5.44 \pm 1.21^{bc/B}$	$12.21 \pm 1.97^{b/A}$
BOPP/metBOPP without N_2	$20.10 \pm 0.01^{a/A}$	$20.01 \pm 0.26^{a/A}$	$20.32 \pm 0.24^{a/A}$	$20.12 \pm 0.04^{a/A}$	$21.13 \pm 1.81^{a/A}$	$19.99 \pm 0.36^{a/A}$	$20.15 \pm 0.32^{a/A}$	$20.15 \pm 0.79^{a/A}$

* Mean values of three determinations ± standard deviation.

[a. b. c] Comparison between samples for the same storage period: averages followed by the same lowercase letters in the column do not differ at the 95% confidence level ($p < 0.05$).

[A. B. C] Comparison between storage periods for the same sample: averages followed by the same uppercase letter in the row do not differ at the 95% confidence level ($p < 0.05$).

PET - polyester, Al - aluminum foil, LDPE - low density polyethylene, BOPP - biaxially oriented polypropylene and met - metallized.

package, resulting in oxidation of the pigments (carotenoids) which confer the intense orange color on the chips. These results corroborate with the results for total carotenoid and β-carotene retention presented earlier in Table 4.

The scores for the attributes of characteristic odor, oxidized odor, characteristic flavor and oxidized flavor also showed changes, with mean values of 3.57, 3.96, 3.78 and 4.60 after 207 days of storage. The losses in characteristic odor and flavor and development of oxidized odor and flavor were a function of the oxidation of the carotenoids which occurred in this system as a function of the high oxygen concentration in the head space of the package, as shown in Table 3. According to Bechoff et al., 2010a,b, the degradation of carotenoids during storage results in the formation of norisoprenoids (β-ionone), which are compounds formed during the degradation of β-carotene, which result in the development of an oxidized odor.

No loss in crispness of the chips packed in BOPP/metBOPP without nitrogen was noted during storage, since this material shows good water vapor barrier properties (Table 1).

The loss in quality of the chips packed in BOPP/metBOPP without nitrogen started as from 91 days of storage, and after 207 days the mean score for overall quality was 4.67 due to the changes in color, flavor and odor which occurred during storage as a function of the carotenoid degradation reactions due to the higher O_2 concentration in the head space of these packages (Table 3).

After 122 days of storage the chips packed in PETmet/LDPE with nitrogen started to lose their crispness, which intensified after 153, 184 and 207 days of storage, presenting a mean score of 5.97 after 207 days, leading to rejection of the product. This loss in crispness was a function of the increase in water activity and moisture content of these chips, as shown in Table 2, as a consequence of the low water vapor barrier capability of the structure used, as compared to the other materials used, and the relative humidity (75% RH) of the storage chamber. The results for crispness were reflected in a loss of overall quality during storage, with a mean score of 4.67 after 207 days.

The chips packed with nitrogen in PET/Al/LDPE, BOPP/metBOPP and BOPP/metBOPP with oxygen scavenger, maintained mean scores for all attributes close to the values awarded at zero time, during the 207 days of the study, showing that these systems were efficient in maintaining the sensory quality of the product throughout the period studied.

It should be noted that the BOPP/metBOPP system without nitrogen as a function of the oxygen permeability rate of the material is higher than the other materials (Table 1) resulted in sensory alterations as a function of the maintenance of O_2 content available in the head space. However, systems with nitrogen using the same material did not show changes in the sensorial quality of the chips due to the lower O_2 content available in the head space, even in the chips packed during 207 in the system BOPP/metBOPP with nitrogen and oxygen scavenger which presented a an small orifice in the heat sealing.

4. Conclusions

The factors determining the shelf life of the chips depended on the carotenoid oxidation reactions, which led to a loss in vitamin activity and sensory alterations of the color, odor and flavor. In addition, increases in moisture content led to a loss of crispness of the chips.

The main cause of quality loss in the chips packed in BOPP/metBOPP without nitrogen was the carotenoid oxidation reaction, leading to sensory alterations in the color, odor and flavor, and resulting in a shelf life of 5 months at 25 °C/75% RH. This system retained 59% of the total carotenoids and 72% of the β-carotene after 5 months of storage.

The chips packed in PETmet/LDPE with nitrogen showed a loss of crispness due to the water vapor permeability rate of this material, which determined a shelf life of 6 months for these chips. The total carotenoid retention of the system was 78% after 7 months of storage at 25 °C/75% RH, and 90% for β-carotene retention.

The stability evaluation trials of the biofortified sweet potato chips packed in PET/Al/LDPE with nitrogen showed high total carotenoid and β-carotene retention values of 80% and 90%, respectively, and the sensory alterations were minimal up to 7 months at 25 °C/75% RH. Thus this system has the potential to provide an even longer shelf life than the period studied as a function of the good barrier properties of the material.

The chips packed in BOPP/metBOPP with nitrogen and BOPP/metBOPP with nitrogen and oxygen scavenger showed practically no sensory alterations throughout storage and also showed high total carotenoid retention values of 75%, and high β-carotene retention values of 83% and 80%, respectively, for up to 7 months of storage at 25 °C/75% RH. Hence these systems could also allow for a shelf life superior to the period studied. However the use of oxygen scavengers did not contribute to an increase in the shelf life as compared to the BOPP/metBOPP with nitrogen system.

Thus one can use the packaging systems with nitrogen with the

Table 4
Content and retention (%) of total Carotenoids and β-carotene in biofortified sweet potatoes throughout storage.

Total carotenoids μg.g^{-1} (% b.s.)							
Packaging systems	Storage Time (day)						
	0	31	62	91	122	153	207
PET/Al/LDPE with N_2	613.34 ± 6.66$^{a/A}$ (100%)	646.34 ± 86.95$^{a/A}$ (105%)	575.41 ± 24.21$^{a/A}$ (94%)	513.24 ± 12.49$^{a/A}$ (84%)	502.98 ± 15.29$^{a/A}$ (82%)	501.69 ± 3.19$^{ab/A}$ (82%)	493.38 ± 6.94$^{a/A}$ (80%)
PETmet/LDPE with N_2	613.34 ± 6.66$^{a/A}$ (100%)	606.41 ± 54.80$^{a/AB}$ (99%)	528.98 ± 37.20$^{ab/AB}$ (86%)	520.85 ± 27.08$^{a/AB}$ (85%)	494.05 ± 26.35$^{a/AB}$ (81%)	489.29 ± 4.76$^{ab/B}$ (80%)	478.86 ± 8.65$^{ab/B}$ (78%)
BOPP/metBOPP with N_2	613.34 ± 6.66$^{a/A}$ (100%)	667.35 ± 92.09$^{a/ABC}$ (109%)	523.40 ± 30.67$^{ab/ABC}$ (85%)	511.00 ± 11.93$^{a/BC}$ (83%)	510.35 ± 10.87$^{a/C}$ (83%)	471.87 ± 13.91$^{b/BC}$ (77%)	462.92 ± 3.86$^{b/B}$ (75%)
BOPP/metBOPP with N_2 and oxygen scavenger	613.34 ± 6.66$^{a/A}$ (100%)	682.05 ± 81.38$^{a/AB}$ (111%)	536.57 ± 44.04$^{ab/ABC}$ (87%)	525.68 ± 32.53$^{a/ABC}$ (86%)	516.50 ± 3.39$^{a/B}$ (84%)	514.04 ± 10.40$^{a/B}$ (84%)	462.76 ± 8.65$^{b/C}$ (75%)
BOPP/metBOPP without N_2	613.34 ± 6.66$^{a/A}$ (100%)	641.44 ± 26.22$^{a/A}$ (105%)	457.11 ± 28.80$^{b/B}$ (75%)	380.99 ± 12.31$^{b/B}$ (62%)	371.65 ± 9.37$^{b/B}$ (61%)	363.25 ± 18.15$^{c/B}$ (59%)	254.93 ± 13.33$^{c/C}$ (42%)
β-carotene μg.g^{-1} (% b.s.)							
PET/Al/LDPE with N_2	490.23 ± 30.00$^{a/A}$ (100%)	388.56 ± 2.34$^{a/A}$ (79%)	418.42 ± 12.14$^{a/A}$ (85%)	424.77 ± 55.48$^{a/A}$ (87%)	430.27 ± 27.47$^{bc/A}$ (88%)	412.58 ± 11.61$^{b/A}$ (84%)	440.52 ± 12.11$^{a/A}$ (90%)
PETmet/LDPE with N_2 (100%)	490.23 ± 30.00$^{a/A}$ 372.40 ± 11.63$^{a/B}$ (76%)	399.87 ± 11.68$^{a/AB}$ (82%)	474.38 ± 17.50$^{a/A}$ (97%)	429.21 ± 45.17$^{bc/AB}$ (88%)	468.33 ± 25.36$^{ab/A}$ (96%)	440.70 ± 17.96$^{a/AB}$ (90%)	
BOPP/metBOPP with N_2	490.23 ± 30.00$^{a/A}$ (100%)	388.74 ± 38.52$^{a/BC}$ (79%)	374.39 ± 48.28$^{a/C}$ (76%)	472.60 ± 12.77$^{a/AB}$ (96%)	436.52 ± 9.17$^{b/ABC}$ (89%)	441.47 ± 11.44$^{ab/ABC}$ (90%)	405.89 ± 30.64$^{a/ABC}$ (83%)
BOPP/metBOPP with N_2 and oxygen scavenger	490.23 ± 30.00$^{a/A}$ (100%)	406.25 ± 24.99$^{a/ABC}$ (83%)	328.89 ± 64.77$^{a/C}$ (67%)	472.34 ± 23.01$^{a/AB}$ (96%)	469.94 ± 4.08$^{a/AB}$ (96%)	474.31 ± 7.27$^{a/AB}$ (97%)	391.89 ± 14.97$^{a/BC}$ (80%)
BOPP/metBOPP without N_2	490.23 ± 30.00$^{a/A}$ (100%)	368.28 ± 12.66$^{a/B}$ (75%)	312.56 ± 24.68$^{a/C}$ (64%)	320.35 ± 26.49$^{b/BC}$ (65%)	300.19 ± 2.60$^{c/C}$ (61%)	351.97 ± 10.10$^{c/BC}$ (72%)	190.21 ± 9.69$^{b/D}$ (39%)

[*] Mean values of three determinations ± standard deviation.

[a, b, c] Comparison between samples for the same storage period: averages followed by the same lowercase letters in the column do not differ at the 95% confidence level ($p < 0.05$).

[A, B, C] Comparison between storage periods for the same sample: averages followed by the same uppercase letter in the row do not differ at the 95% confidence level ($p < 0.05$).

PET - polyester, Al - aluminum foil, LDPE - low density polyethylene, BOPP - biaxially oriented polypropylene and met - metallized.

structures of PET/Al/LDPE, BOPP/metBOPP or BOPP/metBOPP with oxygen scavenger to obtain a shelf life of 7 months at 25 °C/75% RH, the packaging system of BOPP/metBOPP with nitrogen showing the greatest cost benefit due to the lower cost of the packaging material, which is also the material most used on the market for chips in general.

The five packaging systems used in the present study provided shelf lives to the product superior to that currently in practice for the regular potato chip market, which is of 90 days.

Acknowledgments

The authors are grateful to the Coordination for the Improvement of Higher Level Personnel (CAPES) for the master's degree scholarship, to the Institute of Food Technology for the financial support and development of this research, to EMBRAPA for the raw material, to FRUTHOTEC - Fruits and Vegetables Technology Center, CCQA - Food Science and Quality Center and CETEA - Packaging Technology Center for assisting in the development of this research, to Daisy Moitinho for her contribution in the statistical analyses, and to the companies Multisorb, Diadema and Converplast for supplying the packaging materials.

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