The effect of packaging material and storage period on microwave-dried potato (*Solanum tuberosum* L.) cubes

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Abstract The effect of three packaging materials (transparent biaxially oriented polypropylene laminate (BOPP); semi-transparent BOPP; polyethylene-polyamide (PE-PA) laminate) in three packaging conditions (vacuum, N₂, natural atmosphere) and in two temperature treatments (blanching in hot water; steam) on microwave-dried potato (*Solanum*

tuberosum L.; Solanaceae) cubes was studied. After storage for 60 and 120 days, the amount of ascorbic acid (AA), shrinkage and rehydration were determined. Dried potato cubes packaged under N₂ atmosphere had the highest rehydration value (3.142 %). Since there is a direct relationship between the amount of water loss and shrinkage, samples packaged in PE-PA laminate packages under vacuum showed 4.947 % less shrinkage than transparent BOPP or semi-transparent BOPP due to low permeability of these packages. Potatoes stored for 120 days resulted in 7.89 % more shrinkage than those stored for 60 days. The least loss in AA occurred in PE-PA laminate packaging. The shelf-life of potato cubes can be increased and their quantitative and qualitative characteristics can be best preserved by package-drying in PE-PA laminate under vacuum conditions.

Keywords Ascorbic acid · Packaging · Potato cubes · Rehydration · Shrinkage · Water absorbance percentage

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Introduction

The importance of potato (*Solanum tuberosum* L.; Solanaceae), the fourth most important vegetable crop in the world, was celebrated in 2008 as the International year of the potato (Troncoso and Pedreschi 2007; Yee and Bussell 2009; Blanda et al. 2010). One of the most important aspects of potato biotechnology is postharvest storage. The harvest season of potato is limited, so high quality storage is essential (Sotomea et al. 2009). Dehydration is as an effective method to produce unique food structures (Troncoso and Pedreschi 2007; Rocculi et al. 2009). Microwave drying, which is important in the drying industry, allows for drying to be better controlled and results in a high rate of drying, and improved product quality, flavor, color and texture (Orsat and Raghavan 2007; Haghi and Amanifard 2008; Sotomea et al. 2009). Modified atmospheric packaging (MAP)

is “the packaging of [a] product that spoils rapidly in an atmosphere that is other than that of air” (Waghmare and Annapure 2013) and is an important way to preserve the quality of potato (Suryawanshi 2008; Mangaraj and Goswami 2009).

Plastic packaging can help to increase the storage life of perishables and processed products (Suryawanshi 2008). In MAP, a suitable polymeric film is used to package the product under different modified atmospheres and is achieved by removing the air around the product (vacuum packaging), by injecting a predefined composition of gases into the packages (active packaging) or by a gradual change of gas composition in the packages due to product respiration (passive MAP) (Sandhya 2010). A suitable protective atmosphere around products in MAP can help to control (or limit) product deterioration (Li et al. 2013). Consequently, the produce mass/surface ratio, package dimensions and permeability are important factors in the design of a MAP (Xanthopoulos et al. 2012). Nitrogen, carbon dioxide, and oxygen are the gases most commonly used in MAP (Siracusa 2012).

MAP has been used to extend the shelf-life of different products but to do so requires an understanding of the correct composition of gases in a package (Mangaraj and Goswami 2009). Thus, the type of product, temperature and headspace gas composition, as well as the permeability of the packaging materials needs to be considered when designing a MAP (Oliveira et al. 2012).

The plastic films used for vacuum packaging and MAP must prevent the entry of gas and moisture, and have suitable shrinkage and sealing properties to ensure the quality and prolong the shelf life of fresh produce (Costa et al. 2011; Muizniece-Brasava et al. 2013).

Blanching and freezing pre-drying treatments strongly affect the properties (including shrinkage, porosity, biopolymer structure, and biochemical activity) of plant tissues but blanching at low and high temperatures affect tissue properties in different ways (Sotomea et al. 2009). The inhibition of water induces swelling and builds up swelling stresses while damage to the tissue structure – due to pre-drying treatment and drying – results in limited water absorption and leakage of solutes (Madamba et al. 1994).

Processed potatoes (peeled, cored or sliced) in a suitable package can decrease excessive losses of soluble and sensitive nutrients (Rocha et al. 2003). The content of ascorbic acid (AA), an anti-browning agent that can preserve fresh produce due to its lower tendency to oxidize by AA oxidase, becomes reduced during storage (Suryawanshi 2008).

Scrutiny of the literature did not reveal any study that used blanching, microwave drying and MAP on microwave-dried potato cubes to extend the storage period. Dried potatoes tend to be too hard and can rip and perforate the package, so one key objective of this study was to use dried potato with higher moisture using MAP with the ultimate objective of increasing storage time.

In this study, we examined the effect of the type of packaging material, namely transparent biaxially oriented polypropylene laminate (BOPP), semi-transparent BOPP and a polyethylene-polyamide (PE-PA) laminate, on the quality of dried potatoes under different MAP conditions. Potato var. ‘Baraka’ was used in this study as it is the most important product in Mojen, Iran, most likely because of three positive characteristics: high dry matter content, long storage life, good resistance to dehydration (Abbas et al. 2012). In addition, ‘Baraka’ includes, on a fresh weight basis, 10–30 % carbohydrates, 1–1.5 % protein, 1–2 % dietary fiber, 0.8–1.2 % mineral matter, and 0.1–0.2 % fats, and, on a dry weight basis (mg/100 g dry mass), 17.56 mg calcium and 84–145 mg AA (Abbas et al. 2012). In addition, ‘Baraka’ is a good source of vitamins B1, B3, B6, folate, pantothenic acid, riboflavin and minerals such as potassium, phosphorus and magnesium (Murniece et al. 2011).

Materials and methods

Plant material

Potato (var. ‘Baraka’) with a specific weight of 1.08 g/cm³, total solid content of 19 %, and 49 mg/100 g AA, was purchased from the Mojen region in the north of Shahroud, Iran. Based on the advice of Abong et al. (2010), potatoes weighing 80–100 g and with length=95.43 mm, width=60.7 mm, and diameter=41.43 mm were stored in a dark room at 10–15 °C and 95 % relative humidity for 24 h before processing and stored at 20 °C. The latter step was performed since the concentration of reducing sugars increases during low temperature storage (Sotomea et al. 2009).

Sample preparation

After sorting, whole potatoes were cleaned, washed and peeled by hand with a knife. All potatoes were cut into 1 cm×1 cm×2 cm cubes with a slicer (Nicer dicer, Model FA2009, Zhe Jiang, China), according to Arroqui et al. (2002). To stop browning, potato cubes were immersed at room temperature in water that included 5 % (w/v) AA and 0.2 % (w/v) citric acid (Arroqui et al. 2002). Two blanching conditions (hot water, steam), three atmospheric conditions (under vacuum, N₂, natural atmosphere) and three packaging materials (transparent BOPP; semi-transparent BOPP; PE-PA laminate) were tested in all permutations in this study. In total, there were 18 treatments as three repetitions with 60 g of potato cubes per treatment.

Blanching and drying

To inactivate polyphenol oxidase, to remove air, and to increase flexibility and hardness, two blanching steps were performed using a total of 13.5 kg of peeled potato. In the first step, blanching was achieved in boiling water (90 °C for 4 min), which increases the degree of gelatinization (Bondaruk et al. 2007; Blanda et al. 2010). Hereafter, these cubes are referred to as boiled cubes. In the second blanching process, potato cubes were blanched with steam at 100 °C for 6 min using a steamer (Ben Murray Lauda, Model 200-E, Lauda-Königshofen, Germany) according to Sotomea et al. (2009). Hereafter, these cubes are referred to as steamed cubes. Blanched potato cubes (boiled and steamed) were washed thoroughly for approx. 2 min in cold water to remove starch and sugar. Surface water was removed by dabbing with filter paper. Cubes were dried in a microwave oven (LG 34 L stainless steel light wave oven (10AMP) Model MP-9483SLA, South Korea) at 600 W for 5 min until the boiled and steamed cubes reached a final moisture content of about 0.2195 and 0.333 kg water/kg dry weight, respectively (Gonzalez-Martínez et al. 2004).

Modified atmosphere packaging

Controlling gas or water vapor in packaging helps to improve the quality and shelf-life of food products (Taik Lee 2010). Designing a good MAP according to the amount of product, film permeability and equilibrium atmosphere can increase the quality and extend the shelf-life of fresh produce (Oliveira et al. 2012). MAP was thus measured to assess the effect of permeability on storage period and other postharvest parameters. After potato cubes were dried (in total, an initial 13.5 kg of fresh weight (peeled) was reduced to 3.1 kg of dried potato), they were placed in two separate dishes until they attained equal moisture. Microwave-dried potato cubes (boiled and steamed) were added separately to each of three packages (60 g/package; all manufactured by Saaf Film Novin, Tabriz, Iran): 1) transparent BOPP, 0.04 mm thick (Fig. 1a); 2) semi-transparent BOPP, 0.04 mm thick (Fig. 1b); 3) PE-PA laminate, 0.09 mm thick (Fig. 1c). All three packaging types were placed under three atmospheric conditions: 99 % vacuum, N₂ (70 % N₂ and 30 % O₂), and natural atmospheric conditions (the control). Packaging was performed with a vacuum packager (Henckelman model Boxer 42, Germany). In the vacuum condition, the air inside the package was completely removed. In the N₂ condition, the vacuum packager was connected to an adjustable N₂ flash tank. In the natural atmospheric condition, room air natural atmosphere was used. The AA content and percentage rehydration and shrinkage of all samples were measured after 60 and 120 days of storage.

Ascorbic acid content

Microwave-dried potato cubes, as prepared above, were ground separately with an electric mill (Black & Decker, model CBM2, Provo, Utah, USA). The AA content of microwave-dried potato cubes (boiled and steamed) was determined by the titration method by titrating the filtrate against 2,6-dichloroindophenol (Merck Co., Darmstadt, Germany), and was expressed on a dry weight basis. Fresh, untreated potato was used as the control. To determine AA content, 5 g of ground dried potatoes (or fresh cubes) was dissolved in 5 % (w/v) metaphosphoric acid (Merck Co.) and filtered through a single sheet of 2.5 µm filter paper (Whatman Grade 5, UK). The filtrate was titrated against 2, 6-dichloroindophenol according to Egan et al. (1981) and Arroqui et al. (2001). Results were expressed as mg AA/100 g dried potato.

Rehydration

To determine the rehydration capacity of the dried potatoes (boiled and steamed) of all treatments by microwave, a defined weight of each sample was placed in a beaker containing distilled water (20 times the weight of samples) at 25 °C. The samples were picked at 5-min intervals and after drying the surface water with a soft cloth, they were weighed again. This process was repeated for a total of 220 or 320 min for steamed and boiled cubes, respectively. The rehydration capacity, which is the percentage water gain, can be ascertained when dried food is immersed in water until it absorbs water (Cunningham et al. 2008). The amount of absorbed water (rehydration) was determined from the following equation (Russo et al. 2013):

$$\text{Water absorption (\%)} = [M_0 - M]/M_0 \times 100$$

where M₀ is the weight of dried cubes and M₁ is the weight of samples after water absorption.

Shrinkage

A predefined amount of toluene was poured into a 100-ml graduated cylinder. A fresh potato cube was placed into the cylinder and the change in volume resulting from dipping the sample into toluene was recorded (V_i). The same sample was dried by microwave (as explained above) then dipped into the toluene in a cylinder and the resulting change in volume was recorded (V_f). Sample shrinkage was calculated using the following formula (Madamba et al. 1994; Sjöholm and Gekas 1995; Arroqui et al. 2001; Taiwo and Baik 2007):

$$\text{SH (\%)} = [V_i - V_f]/V_i \times 100$$

Fig 1 (a) Transparent biaxially oriented polypropylene (BOPP) laminate; (b) semi-transparent BOPP; (c) polyethylene-polyamide laminate

where SH=shrink percentage, V_i =volume of fresh potato sample (ml) and V_f =volume of dried potato sample (ml).

Statistical analysis

This study was conducted using a completely randomized design with three replications. Analysis of variance (ANOVA) was performed on all experimental data and means were compared using Duncan's multiple range test (DMRT) with SAS software (9.1.3 Service Pack 4, SAS Institute Inc., Cary, NC, USA).

Results and discussion

The aim of this study was to evaluate the effect of the type of packaging material, namely BOPP, semi-transparent BOPP and PE-PA laminate, on the quality of dried potatoes under different MAP conditions, with for the objective of increasing storage time.

The two best results were:

- 1) PE-PA laminate preserved quantitative and qualitative factors.
- 2) Potato that was blanched with steam preserved AA. Microwave-dried potato cubes that had been blanched by steam had 14.24 mg/100 g AA and cubes blanched by water showed 3.199 % rehydration (Table 4). Samples stored for 60 days had the highest AA content (17.2 mg/100 g; Table 2). Microwave-dried potato cubes in PE-PA laminate had 14.11 mg/100 g AA, and 0.768 % shrinkage (Table 3). Microwave-dried potato cubes packed in vacuum had 13.75 mg/100 g AA and 0.769 % shrinkage while those stored under N_2 showed 3.142 % rehydration (Table 5). The best packaging is one that is impermeable to water, oxygen and light.

Char et al. (2012) studied the packaging of ready-to-eat arugula (*Eruca vesicaria* Mill.). Arugula leaves that were physically damaged dehydrated or without a characteristic yellow color were removed. Three gases (Ar, He and N_2) were injected into the bags using a gas mixer just before heat

sealing. Salads in 94–95 % N_2 +5–6 % O_2 and stored at 5 °C showed limited respiration rates and a shelf-life that was increased by 8 days.

Ascorbic acid

Effect of storage period on ascorbic acid content in microwave-dried potato cubes

The blanching treatment (boiled vs steamed), packaging type and storage period had a highly significant ($P<0.01$) effect on AA content (Table 1). An increase in the storage period of microwave-dried potato cubes from 60 to 120 days significantly decreased AA content and rehydration percentage but significantly increased shrinkage percentage (Table 2). AA decreased during cooking and storage of Latvian potato tubers and the loss of AA depended on the storage conditions and period, as well as on the cooking method (Murniece et al. 2011). The AA content of potato tubers, averaged over five Latvian cultivars (Lenora, Brasla, Imanta, Zile and Madara), decreased after the two studied storage periods: just after harvesting (2007, 2008) and after six months of storage (2008, 2009). The AA concentration of 25 Andean potato varieties grown in three environments and was used to assess the effect of cooking and storage time, both of which decreased as storage period increased after testing raw, cooked (boiled, oven baked, microwaved) or stored tubers (Burgos et al. 2009). In that study, AA concentration in fresh tubers was 6.5 to 36.9 mg/100 g on a fresh weight basis and var. Maria Cruz retained 54 and 34 % of AA after boiling and storage for 26 weeks under three farming environments. Suryawanshi (2008) indicated that the maximum reduction in AA occurred in potatoes without any chemical treatment, and that AA oxidase, in the presence of molecular oxygen, reduced vitamin C (AA) content. The amount of AA was 11.24 mg/100 g fresh weight; during storage, the AA content decreased to 5.71 and 5.11 mg in potato slices and cubes, respectively after a 24-day storage period. Potato slices and cubes treated with 0.5 % AA, 0.2 % KMS (potassium metabisulphite) and 2 % NaCl, and packed in polyethylene bags of 200 gauge, had 5.88 and 5.99 mg of AA in slices and cubes, respectively. The maximum retention of AA was due to

Table 1 Analysis of variance for quantitative indicators of potato cubes in storage for 60 and 120 days

Source of variation	Degrees of freedom	Mean square		
		AA (mg/100 g microwave-dried potato cubes)	Rehydration (%)	Shrinkage (%)
Storage period (t)	1	1393.38**	3.909**	0.09**
Packaging material (p)	2	11.926**	0.012 ^{ns}	0.015**
Packaging condition (c)	2	4.549*	0.129**	0.014**
Pre-treatment (k)	1	55.216**	1.594**	0.000003 ^{ns}
t×p	2	4.788*	0.001 ^{ns}	0.003*
t×c	2	1.985 ^{ns}	0.002 ^{ns}	0.005**
t×k	1	15.788**	0.042 ^{ns}	0.009**
p×c	4	0.828 ^{ns}	0.012 ^{ns}	0.001 ^{ns}
t×p×c	4	1.298 ^{ns}	0.01 ^{ns}	0.001 ^{ns}
p×k	2	0.972 ^{ns}	0.01 ^{ns}	0.002 ^{ns}
c×k	2	3.16 ^{ns}	0.018 ^{ns}	0.005**
t×p×k	2	0.609 ^{ns}	0.007 ^{ns}	0.002 ^{ns}
p×c×k	4	0.405 ^{ns}	0.006 ^{ns}	0.002*
t×p×c×k	6	0.88 ^{ns}	0.004 ^{ns}	0.003**
Error	72	1.177017	0.016796	0.0008326

ns, *, **: Not significant, significant at $P<0.05$ and $P<0.01$, respectively (DMRT). AA=ascorbic acid (equiv. vitamin C)

a decrease in its oxidative reduction in the presence of molecular oxygen by AA oxidase. The total AA content of potato products (slices and cubes) decreased as storage period increased. According to Lešková et al. (2006), storage period and cooking methods affect the destruction of AA content and as the quantity of AA during cooking and storage of potato tubers takes place, the amount of AA content decreases by about 30 %. After cooking at 55–60 °C for 1 h, this decrease is also attributed to the amount of oxygen present. Ilow et al. (1995) compared the effect of cooking vegetables (cauliflower, white cabbage, Brussel sprouts, French bean, and potatoes) by microwave, pressure-cooking or conventional cooking (i.e., boiling in cold water) with uncooked controls; average losses of AA were 13.9, 32.8, 37.8 and 53.3 %, respectively. Warthesen et al. (1984) reported that 67.8 and 78.6 % of AA was retained in spinach and green beans, respectively that had been cooked in a microwave but after boiling, these levels dropped to 33.9 and 63.7 %, respectively. Thus, boiling in water leads to a decrease in AA content. The amount of AA can be used as a quality attribute of dried products (Arroqui et al. 2001). In potatoes, blanching causes the loss of AA,

which is used as an indicator of the intensity of the thermal treatment applied; although these losses can be caused by enzymatic oxidation, thermic degradation and diffusion; the main mechanism during potato blanching is diffusion (Arroqui et al. 2001).

Effect of packaging materials on ascorbic acid content in microwave-dried potato cubes

The changes in atmosphere and permeability of packaged microwave-dried potato cubes were significantly ($P<0.01$) affected by the packaging material used (Table 1). In packaging film, oxygen transmission rate (OTR) is a factor that can influence the package atmosphere of products (Xiao et al. 2014). AA is sensitive to air, heat, water and storage period (Burgos et al. 2009). The presence of oxygen in packages decreased the AA content in microwave-dried potato cubes that were blanched with boiling water and packed in natural atmospheric conditions in BOPP (Table 3). The presence of oxygen can destroy AA in cooked potato cubes (Lešková et al. 2006). PE-PA laminate preserved AA significantly better than

Table 2 Effects of storage period on vitamin C (mg/100 g microwave-dried potato cubes), rehydration (%) and shrinkage (%) of microwave-dried potato cubes

		AA (mg/100 g microwave-dried potato cubes)	Rehydration (%)	Shrinkage (%)
Storage period	60 days	17.12 a	3.268 a	76.3 b
	120 days	9.93 b	2.887 b	82.1 a

Means followed by the same letter(s) for each treatment (i.e., within a column) are not significantly different at $P<0.05$ (DMRT). AA=ascorbic acid (equiv. vitamin C). $n=3$

Table 3 Effects of packaging materials on vitamin C content, rehydration and shrinkage of microwave-dried potato cubes

		AA (mg/100 g microwave-dried potato cubes)	Rehydration (%)	Shrinkage (%)
Packaging materials	Transparent BOPP	12.95 c	3.073 a	80.6 a
	Polyethylene-polyamide laminate	14.11 a	3.062 a	76.8 b
	Semi-transparent BOPP	13.52 b	3.097 a	80.1 a

Means followed by the same letter(s) for each treatment (i.e., within a column) are not significantly different at $P < 0.05$ (DMRT). AA=ascorbic acid (equiv. vitamin C). $n=3$

BOPP (Table 3): 14.11 mg/100 g and 12.95 mg/100 g of microwave-dried potato cubes, respectively. Suryawanshi (2008) indicated that the loss of AA might be due to its oxidation in air. Increasing film thickness increased the retention of AA in higher gauge polyethylene due to less permeability to the atmosphere which is essential for the retention of AA during storage: 300 gauge polyethylene packages had longer storage ability and maximum retention of AA in potato products (slices and cubes). Film thickness of packaging material has an important role in gas permeability: as thickness increases, permeability to moisture and air decreases, leading to an increase in the storage period of the product, and thus also having a positive effect on the quality of the product (Ornelas-Paz et al. 2012). The permeability of packaging in MAP has an effect on product quality and can extend the shelf-life (Oliveira et al. 2012). For example, Ornelas-Paz et al. (2012) packed Jalapeño peppers under MAP conditions (O_2 , CO_2 and N_2 , all with 99.99 % purity) at 7 °C and unpacked peppers at 7 °C and 23 °C for 4 weeks. The 23 °C condition and film thickness were the two factors that decreased the CO_2 and O_2 transmission rates. Whereas O_2 permeability (PO_2) increased in permeated packages, as measured by an O_2/CO_2 analyzer, storage time and film thickness increased CO_2 levels inside the packages. Packaging thickness was an important factor for the preservation of pepper quality, and the AA content in the peppers was $444.5 \mu\text{g g}^{-1}$, which increased continuously in the control group that had been stored at 23 °C. Ornelas-Paz et al. (2012) also noted that a decrease in O_2 could preserve the AA content in peppers because CO_2 levels inside the packages increased.

Effect of atmospheric conditions on ascorbic acid content in microwave-dried potato cubes

The AA content decreased in the presence of O_2 in natural atmospheric conditions but a significant difference was observed between microwave-dried potato cubes at different conditions ($P < 0.01$). According to Table 5, vacuum and N_2 atmosphere effectively preserved AA. In vacuum packaging, films are non-permeable or poorly permeable and the air is sucked out (Thompson 2010). The amount of AA under vacuum and N_2 atmosphere was 13.745 mg/100 g and 13.721 mg/100 g respectively, for microwave-dried potato

cubes. Ramesh et al. (1999) noted that cutting, blanching, drying and storing led to a decrease in AA content and quality of paprika, potato and carrot. For example, the loss of AA content in dried processed potatoes (cultivar ‘Bintje’) placed in an inert atmosphere was about 2 %. Ramesh et al. (1999) also used inert atmosphere under low O_2 conditions to help decrease oxidative damage and retain nutritional value and were able to retain AA content in the processed vegetables because N_2 provides a protective atmosphere, preventing oxidation. N_2 is an inert component and in the presence of only N_2 , it almost completely delayed ripening in plums and potatoes by preventing the accumulation of sugars at low temperature although it had an undesirable side effect, namely retarded ripening of tomatoes (Thompson 2010). Thus, a vacuum, due to the lack of O_2 , retains AA. The reduction of O_2 content in MAP is an important principle of MAP packages. Packaged meat under vacuum maintained its quality better than MAP (80 % $CO_2/20$ % N_2); in this case, at least 40 % CO_2 helped to maintain meat without off-odours while the use of N_2 prevented package collapse (Karabagias et al. 2011). Ooraikul and Stilies (2002) reported that for all dried products packaged by MAP, a concentration difference is created between intercellular gases and the atmosphere around the product. In vacuum packages, these gases diffuse into the packages and then into the product flesh. The rate of transmission of O_2 into the cell depends on the partial pressure difference, diffusion coefficient of the packaging material, resistance of the product cells to gas diffusion, temperature of the air around the package, temperature of the product and the packaging method (Ooraikul and Stilies 2002). The activity of AA oxidase, which decomposes AA, decreases as O_2 concentration decreases (Ooraikul and Stilies 2002). Atmospheric conditions increase the loss of AA content because air inside packages can absorb moisture from dried potatoes and AA oxidase in the vicinity of moisture and O_2 destroys AA (Lešková et al. 2006; Suryawanshi 2008; Munyaka et al. 2010).

Golaszewska and Zalewski (2001) reported that select temperature and moisture contents and O_2 availability decreased AA content: higher water activity had an important effect on the loss of AA; in the dry method (using a microwave, pressure cooker, or acuthermal potatoes), losses of AA in potatoes were 8–17 %, while in wet methods, losses of AA were higher (20–40 %).

Effect of type of blanching on ascorbic acid content in microwave-dried potato cubes

AA is used as an indicator of the quality of potatoes, and blanching causes losses to AA content. Blanching is used to prepare raw vegetables for long-term storage (canning and freezing). Blanching also inactivates enzymes and enzymatic oxidation, and is thus responsible for undesirable changes, including losses to AA content (Arroqui et al. 2001).

Table 1 shows significant differences in AA content between different treatments. The initial AA concentration in microwave-dried potatoes cubes that were blanched with steam was 14.243 mg/100 g microwave-dried potato cubes, and those blanched with boiling water had 12.813 mg/100 g initial mass (Table 4). Water solubility and mass transfer, heat sensitivity and enzymatic oxidation are important reasons for the decrease in AA content; thus, processing under low O₂ conditions and in an inert atmosphere can effectively retain AA. Ramesh et al. (1999) cut paprika fruits into slices of 1 cm³, and carrots and potatoes into 30-mm and 4-mm discs, sliced under a N₂ atmosphere; processed vegetables were steam-blanching for 3 min at 100 °C under atmospheric conditions. After blanching, the vegetables were dried in hot air, or using N₂ gas. The dried material was stored at −18 °C and products processed under N₂ were stored in an N₂ atmosphere. Drying in hot air and N₂ gas had no effect on the AA content of carrot blanched and dried in hot air and inert gas, but losses of AA during inert gas processing of blanched paprika were reduced by 13 %; in potatoes, there was only a 2 % reduction in the loss of AA (Ramesh et al. 1999). Vishwanathan et al. (2013) used infrared (IR) blanching and IR-assisted hot air drying of carrot slices. Carrot slices (10 mm thick) were blanched in hot water at 90±2 °C for 5 min, steamed for 3 min and exposed to IR radiation for 15 min. The amount of AA retained in IR-blanching, water-blanching and steam-blanching carrot was 62 %, 43 % and 49 %, respectively. For carrot slice 5 mm thick, 37 % of AA was preserved after hot water blanching and 41 % after steam blanching. AA retention in IR blanching–hybrid dried slices was 39 % higher than following the water blanching–hot air dried method.

Arroqui et al. (2001) used slices of potatoes (var. ‘Mona Lisa’) 70 mm in length and 12 mm in diameter, blanching them in different water-based solutes (distilled water; water with 2.6 kg/m³ soluble solids; water with 0.5 kg/m³ glucose)

at 80 °C for 10, 30, 45, 60 min. In all cases, as time and temperature increased, AA content decreased. Zheng and Lu (2011) noted that AA is sensitive to high temperature and is very soluble in water, thus AA content is destroyed during blanching; they thus evaluated the effect of blanching using microwave heating (900 W, 30 s) followed by water blanching and water blanching on AA degradation in different parts (bud, upper, middle, and butt) of green asparagus; AA content in all parts of asparagus during microwave pre-treatment were higher than those during water blanching at 70, 80 and 90 °C.

In this study, the reduction in AA following blanching with boiling water was greater than by steam blanching. O₂ plays an important role in destroying AA, thus all processes that use blanching (microwave, boiling, steam, and oven) lead to the removal of air from tissue (Gonzalez-Martinez et al. Gonzalez Martinez et al. 2004). As shown in Table 4, the highest content of AA (14.243 mg/g) was observed in steamed blanched potatoes. Mazzeo et al. (2011) evaluated the influence of boiling and steaming on AA content in carrot, cauliflower and spinach; both cooking treatments had a negative effect on AA content, on average (across all three vegetables) decreasing AA content by 18 % and 10 %, while steaming had the greatest negative effect on AA content in cauliflower.

Shrinkage

During drying, heat and water transfer occur simultaneously, and removal of water from food improves the quality of fruits and vegetables and increases the storage period. In addition, this moisture evaporation creates stresses in cellular structures that lead to changes in volume (reduction) and surface of fruit and vegetables, and also causes chemical changes and changes in physical appearance, shape, thickness, decreasing product diameter (Taiwo and Baik 2007; Madiouli et al. 2012; Curcio and Aversa 2014; Kumar et al. 2014). This process is called shrinkage, which is one major physical change that takes place during the drying process, and involves a decrease in volume when water is removed and increases the hardness of fruit with high moisture content, such as papaya (Senadeera 2008; Karabagias et al. 2011; Brasiello et al. 2013; Kurozawa et al. 2012; Liu et al. 2012).

Table 4 Effects of blanching on vitamin C content, rehydration and shrinkage of microwave-dried potato cubes

		AA (mg/100 g microwave-dried potato cubes)	Rehydration (%)	Shrinkage (%)
Blanching	Blanched with hot water	12.81 b	3.199 a	79.2 a
	Blanched with steam	14.24 a	2.956 b	79.2 a

Means followed by the same letter(s) for each treatment (i.e., within a column) are not significantly different at $P < 0.05$ (DMRT). AA=ascorbic acid (equiv. vitamin C). $n=3$

Effect of storage period on the shrinkage of microwave-dried potato cubes

The results of ANOVA show that storage time, packaging material and packaging conditions caused highly significant effects on the shrinkage of microwave-dried potato cubes (Table 1). Storing microwave-dried potato cubes for 120 days caused them to shrink by about 7.89 % (Table 2). Yadollahinia et al. (2009) studied the shrinkage of potato (var. 'Santana') slices 10 mm thick after drying at 60 °C, 70 °C and 80 °C and after exposure to air velocities of 0.5 and 1.0 m/s. They showed that shrinkage was linearly related to moisture content, and airflow direction had a significant effect on shrinkage of the samples dried at 60 °C and 70 °C but no significant effect at 80 °C.

The loss of water during the storage period causes changes in cellular structures, which would then lead to changes in shape and decreased cellular dimensions, thus developing shrinkage (Russo et al. 2013). Moisture has an influence on storage ability of potato, and higher gauge polyethylene bags absorb less moisture than lower gauge polyethylene bags (Suryawanshi 2008). Table 2 shows that in our study, the moisture content of samples were reduced during the storage period.

Effect of packaging material on shrinkage of microwave-dried potato cubes

Packaging is one of the most important factors in the acceptance of products. Unsuitable packaging may decrease product acceptability, increase oxidation and off-flavors, increase waste, and result in lowering overall product quality and shelf life (Meiron and Saguy 2007).

Evaluating the shrinkage of a product as a function of moisture content showed that significant shrinkage of the microwave-dried potato cubes occurred in transparent and semi-transparent BOPP packages. Table 3 shows that the potato cubes that were packed in PE-PA laminate had the least shrinkage. Permeability of packaging limits the storage period (Galić et al. 2011). Removal of moisture has a high impact on shrinkage (Karabagias et al. 2011; Kurozawa et al. 2012); therefore, the shrinkage of samples in permeable packages is significant. In our study, as shown in Table 3, weight loss and shrinkage were observed for samples packaged in PE-PA laminate. Polymer materials are not absolute barriers against water vapor, gases and organic substances and film structure, thickness and temperature influence gas diffusion and permeability (Siracusa 2012). The permeability and thickness of packaging deteriorated the quality of stored strawberries (Xanthopoulos et al. 2012). Suitable permeability to water vapor and gases (O₂, CO₂, etc.) can increase the shelf life of food (Galić et al. 2011). Drying due to removal of water may lead to changes in volume and shape, and these changes are

not only described by the evaluation of volumetric shrinkage (Mayor et al. 2011), so increased shrinkage was observed in microwave-dried potato cubes due to the removal of water from the permeable packaging materials. In this study, PE-PA laminate had positive effects on reducing shrinkage due to greater thickness and non-permeability to water vapor and O₂. The attributes of packaging material thus have an important effect on the quality of food. Lower air-drying temperatures lead to products with suitable quality; at 45 °C, shrinkage is limited (Karathanos et al. 1993). Temperature and relative humidity influence the barrier properties of a packaging material.

Effect of packaging conditions on shrinkage of microwave-dried potato cubes

MAP reduces the deterioration of quality-related parameters and improves the shelf-life of packaged produce by reducing water loss, as well as metabolic and microbial activity (Martínez and Artès 1999).

Different packaging conditions significantly affected the shrinkage of microwave-dried potato cubes (Table 5): 0.77 %, 0.804 % and 0.802 % for packaging under vacuum, atmospheric and N₂ packaging, respectively. Martínez and Artès (1999) reported that iceberg lettuce packed in perforated (22 mm thickness) or unperforated (25, 30 or 40 mm thickness) polypropylene films could be stored up to 2 weeks at 2 °C (storage period) and then held for 2.5 days at 12 °C (shelf-life period). In their study, passive MAP in 40 mm polypropylene and active (initial 5 % O₂ and 0 % CO₂) MAP in 30 mm polypropylene were the best treatments for overall visual quality, and modifying the atmosphere around the product created a saturated or near-saturated atmosphere around it which decreased water loss and shrinkage and increased the quality by reducing metabolic changes. The application of a suitable packaging film and storage at low temperature minimizes water loss and prevents shrinkage (Martínez and Artès 1999).

Rehydration

Water transport in foods is an important physical process during drying, storage and rewetting, and significantly affects the quality of food products and the transport of water within porous foods (Marabi and Saguy 2004). A porous microstructure and porosity are two important factors in the mechanism of rehydration since capillary imbibition plays an important role in the uptake of water while a reduction in the number and size of pores decreases rehydration properties and higher bulk porosity increases rehydration values (Marabi and Saguy 2004).

Table 5 Effects of packaging conditions on vitamin C content, rehydration and shrinkage of microwave-dried potato cubes

		AA (mg/100 g microwave-dried potato cubes)	Rehydration (%)	Shrinkage (%)
Packaging conditions	Natural atmosphere	13.12 b	3.066 b	80.4 a
	Vacuum	13.75 a	3.024 b	76.9 b
	N ₂	13.72 a	3.142 a	80.2a

Means followed by the same letter(s) for each treatment (i.e., within a column) are not significantly different at $P < 0.05$ (DMRT). AA=ascorbic acid (equiv. vitamin C). $n=3$

The first stage of rehydration is quick, and then the rate of water absorption gradually decreases (Marabi and Saguy 2004). Moreover, during rehydration, vitamins, sugars, amino acids, and minerals decrease (Maldonado et al. 2010). Rehydration as a quality factor and the capacity of water absorption can assist in the selection of the best product (Cunningham et al. 2008; Maldonado et al. 2010; Ramallo and Mascheroni 2012). Maté et al. (1999) noted that a good quality dried product can be obtained from cooked potatoes of suitable texture with a high rehydration rate. In their study, potatoes were cut into 4 cm long and 0.8 cm thick slices and blanched two ways: short period (2 min, 90 °C) and long period (30 min, 90 °C). Blanched potatoes were dried in a convective air drier and rehydration properties were compared. In the first 2 min of blanching with hot water at 90 °C, gelatinization occurred and changed structures and affected the properties of the dried product. Rehydration was performed at 70 °C and at 100 °C. At 100 °C, the rehydration ratios of unblanched, short- and long-period blanched potato slices were 4.16, 4.18 and 5.44, respectively, whereas at 70 °C the rehydration ratios were 3.50, 4.00 and 4.35, respectively. Potatoes blanched for 30 min increased the rehydration ratios.

Effect of storage period on rehydration of microwave-dried potato cubes

During rehydration, volume increases since water absorption equals the volume of imbibed water (Maldonado et al. 2010). This initial period of high water uptake can be attributed to capillaries and cavities near the surface, and as water absorption proceeds, rehydration rate declines due to an increase in the extraction rate of soluble materials (Cunningham et al. 2008).

Storage time significantly affected the water absorption capacity (Table 1). After rehydration for 120 days, storage was 11.658 % more than rehydration after 60 days. Pre-treatments, drying method, physical structure and chemical composition affected the rate of water absorption. Shrinkage and porosity affect rehydration capacity and high shrinkage and low porosity reduce rehydration capacity (Mayor et al. 2011; Russo et al. 2013). Russo et al. (2013) investigated the effect air drying at four different temperatures (40, 50, 60 and 70 °C) on rehydration of eggplant slices with a diameter of

30 mm and a thickness of 6 mm: as drying air temperature increased, drying period became shorter. The drying temperature strongly influenced the microstructure of dried samples: porosity increases with air temperature, but the structure was better preserved at an intermediate temperature (60 °C). In particular, at 70 °C, the structure of dehydrated samples had broken and water uptake was faster during rehydration. Optimum drying conditions led to little change in the microstructure of capillary tubes, so rehydration increased rapidly. The shrinkage of capillary tubes increased as storage time increased, thus water absorption was reduced. In fact, the reduction in the volume and shape of cellular structures is one of the most important physical changes that happened during drying (Russo et al. 2013). However, an increase in the storage period due to changes in physical structures and porous microstructures, as well as increased shrinkage, led to a decrease in rehydration. Some reduction in water absorption was due to an increase in retrogradation and changes to the structure of starch as storage period increased.

Effect of package conditions on rehydration of microwave-dried potato cubes

When polymers are used in food packaging, solution, diffusion and permeation are important characteristics that can alter the shelf life of food controlled by the use of MAP (Siracusa 2012).

N₂ is an inert gas and its solubility in oil and water is low, thus its inclusion in dried food packages can create vacuum conditions and extend the product's shelf life (Ooraikul and Stilies 2002). Thompson (2010) and Ramesh et al. (1999) confirmed the positive effect of N₂ in preserving the quality of a fresh product. In this study, packaging conditions showed significant differences in rehydration of the products (Table 5): the highest rehydration (3.142 %) was observed in samples packaged under N₂ atmosphere but there were no significant differences between the rehydration of samples packaged under atmospheric and vacuum conditions. Durance (1999) also showed that dried potatoes were better preserved under N₂ conditions because capillary tubes were damaged less than in package under vacuum.

Effect of blanching on rehydration of microwave-dried potato cubes

In our study, the highest and the lowest amount of rehydration were 3.199 and 2.956 % for water-blanching and steam-blanching potatoes, respectively (Table 4).

Marabi and Saguy (2004) studied the effect of blanching in deionized water at 90 °C for 5 min and drying in air on fresh carrots (cv. ‘Concerto’) that had been cut into 0.4 cm thick slices, before drying was completed using freeze-drying to a final moisture content of 30 g/kg (wet basis): air-dried period increased, causing bulk and open porosity to decrease, and rehydration to decrease. Maldonado et al. (2010) investigated the amount of water absorbed by mango (var. ‘Tomy Atkins’). The fruit was cut into 4×4×0.4 cm slabs with a thickness: side ratio of 1:10. They reported that by increasing the temperature from 25 to 40 °C caused more water and fewer solids to be absorbed. At 60 °C, rehydration decreased because high temperature damaged cellular structure. Finally, water absorption capacity was acceptable at 40 °C and temperatures that exceeded 40 °C decreased rehydration.

There were significant differences between the rehydration of water-blanching and steam-blanching samples (Table 4). Cunningham et al. (2008) showed that the final rehydration ratio value of potatoes blanching in boiling water (100 °C) for 5 min and then dried by convective oven or microwave methods was 5.97 and 5.93, respectively.

Sotomea et al. (2009) stated that the amount of rehydration of whole potatoes and potato cylinders 8 mm in diameter and 40 mm in length blanching with superheated steam and a spray of hot water micro-droplets and hot water depends on the physicochemical changes during the drying process. Steam blanching not only destroys the structural arrangement of cells, but also creates a dried and firm layer on top of the product during evaporation which hinders the absorption of water. Superheated steam caused weight loss and the evaporation of water formed a dried layer on the surface of the products. Boiling water or saturated steam as a way to blanch potato (sliced to a thickness of 15 mm) causes softening of the tissue and unexpected quality changes since some solids are dissolved in hot water (Huang et al. 2011).

Severin et al. (2005) reported that potatoes (cut into 1 cm³ cubes) blanching by microwave in a sodium chloride solution and dehydrated on a belt drier had the highest rehydration percentage. Dried potato cubes absorbed 100 % liquid during the first minute of immersion and the end of rehydration, they had absorbed the highest quantity of liquid compared to potato cubes dehydrated in an air cabinet or by microwaves. Potato cubes dehydrated on a belt drier and blanching in sodium-chloride absorbed about 200 % of liquid whereas samples dehydrated in an air cabinet or by microwaves absorbed 50 and 100 % of liquid amounting to their dry weight, respectively.

Kouadio et al. (2011) reported that cassava boiled in water for 20 min and dried at 103 °C for 3 h in a vacuum oven had a low water absorption capacity (21.2 %). Amylopectin is responsible for the swelling of starch granules and thus for an increase in water absorption capacity (Kouadio et al. 2011) and during cooking, mealy cooking, and hard cooking, cassava absorbed at least 12.4 % of water. The hard-cooking cultivars absorbed less water and showed lower water absorption capacity (21.2 %).

Conclusion

PE-PA laminate packaging under vacuum conditions maintained a higher concentration of AA in microwave-dried potato cubes. Pretreatment of microwave-dried potato cubes with boiling water negatively influenced AA content. The AA content and the percentage rehydration decreased and the percentage of shrinkage increased during storage. The percentage of rehydration in dried potato cubes was higher in hot water-blanching potato cubes than in steam-blanching cubes. PE-PA laminate packaging had lower permeability than transparent BOPP and semi-transparent BOPP. BOPP laminate packages in natural atmosphere are not suitable for packaging dried potato cubes. Under N₂, the high rate of water absorption of potato cubes could be related to less destruction of capillary tubes.

Conflicts of interest The authors declare no financial or other conflicts of interest.

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