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Valorisation of Vegetables from the Northern Portugal through Drying: Study of the Effect of Different Drying Methods on Texture, Colour and Physicochemical Properties

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Vegetables are often overproduced and discarded, generating large amounts of waste (vegetable surpluses that are not used for distribution and marketing). Vegetables have high moisture content and deteriorate over a short period. One possibility to take advantage of these products is through the drying process. The final vegetable quality is highly dependent upon the drying method, as well as their composition and physical properties. The aim of this study was to produce dehydrated vegetables from the Northern Portugal, tomato (Solanum lycopersicum), Turnip (Brassica rapa L.), Courgette (Cucurbita pepo L.) and Cucumber (Cucumis sativus L.), using two different drying methods: convective air-drying (T=60°C; 8h-tomato; 4h-turnip and cucumber, 6h-courgette) and freeze-drying (P/t=0.7Pa/48h).
In this work moisture, ash, protein, carbohydrates and fibre content, water activity (aw), texture and color were determined. The analysis of variance (ANOVA) and the Tukey test were used to determine statistically different values at a significant level of $p<0.05$. Results showed that carbohydrate content was higher in CD than in FD vegetables (except for cucumber). On the contrary, it was found a slight decrease on protein content between fresh and dried vegetables. It was also found that FD scored higher protein content compared to CD, for all vegetables, with the exception of cucumber. Concerning the crude fibre and ash contents there were no differences between CD and FD vegetables.
In conclusion it was demonstrated that both dehydration methods are efficient in relation to the maintenance of nutritional properties, being a useful alternative to extend the vegetables shelf-life and consequently to reduce food waste in the primary sector, fresh vegetable industry. However, the freeze-drying process showed to be a better process because it provides vegetables that are more similar to the fresh product in terms of colour and texture.

1. Introduction

Several organizations such as European Food Safety Authority (EFSA), Food and Agriculture Organization (FAO), United States Department of Agriculture (USDA), World Health Organization (WHO) recommend increased fruit and vegetable consumption because of the protection they offer against diseases, such as, cardiovascular disease, cancer and cataract and macular degeneration (Del Caro et al., 2004; Murcia et al., 2009; Mamelona et al., 2007). The knowledge of the nutritive value of food, particularly fruits and vegetables, is necessary in order to encourage the increase in their consumption, and their use for nutritional and technological applications. Fresh vegetables contain nutritive constituents including minerals, vitamins (C, E to A) and phytochemicals (folates, glycosinlates, carotenoids, flavonoids, phenolic acids, selenium, lycopene and dietary fibers) (Zapotoczny et al., 2018). Fruits and vegetables are the most used commodities among horticultural crops, but their processing residues are still generally infra-utilized and considered a low value material. Fresh and processing industries generate significant losses and wastes which are becoming a serious economic and environmental problem (Sagar et al., 2018). The need for reducing the generation of

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food wastes and developing processes that allow their reuse by re-introducing the wastes or their components in the productive cycle has been discussed during years, but it still challenges all the agents involved. The sustainable development goals defined by the Food and Agricultural Organization of the United Nations especially focus on sustainability of food systems, as “sustainable consumption and production patterns” must be ensured, and especially mentions the coordination of global initiatives, activities, and projects on food losses and waste reduction (Bas-Bellver et al., 2020). In the case of fruits and vegetables the percentage of wastes is 45%, the United Nations Food and Agriculture Organization (FAO) having suggested values as high as 60%.

Present food transformation processes need not only to focus on proper waste management, but they also need to be rethought to contribute to circular economy through the valorization of by-products, which are reintroduced in the economic cycle (Conesa et al, 2019).

Fruit and vegetable residues are perishable and have a very short shelf life. They are easily fermented while accumulated in the fresh processing plant facilities. For this reason, the preliminary treatment of the residues in the place where they are produced is expected to improve their durability as well as enable a better use and, additionally, help preserve the bioactive compounds it contains. The pretreatment (e.g., drying) of fresh residues immediately after processing to extend their durability could eliminate wastes and reduce environmental pollution. Fresh-cut vegetables, have emerged to fulfil consumer demands for healthy, palatable and easy to prepare plant foods (Allende et al., 2006). Fresh fruits and vegetables are highly perishable commodities (due to their high moisture content around 80%) that deteriorate over a short period of time if improperly handled (Orsat et al., 2006).The market for dehydrated vegetables is important for most countries worldwide. Dehydration offers a means of preserving foods in a stable and safe condition as it reduces water activity and extends shelf-life much beyond that of fresh vegetables (Murcia et al., 2009). Drying constitutes an alternative to the consumption of fresh fruits and vegetables, and allows their use during the off-season. It is one of the most widely used methods for food preservation, and its objective is to remove water from the food to a level in which microbial spoilage and deterioration reactions are greatly minimized. Moreover, besides providing longer shelf-life, it also originates smaller space needs for storage and lighter weight for transportation. The drying of agricultural products can be undertaken in closed equipment’s (solar or industrial dryers) to guarantee the quality of the final product (Guiné et al., 2011).

Different drying methods are used in the drying of fruits and vegetables: solar drying, air drying, microwave drying, vacuum drying, spray drying, among others. Air drying is the most common method, despite having some important disadvantages. This drying method can have a strong impact on the quality of the dehydrated product, leading to some injuries such as the worsening of the taste, colour and nutritional value, decline in the density and water absorbance capacity and shifting of the solutes from the internal part of the drying material to the surface, due to the long drying period and high temperature. Moreover, it is long-lasting and involves a high energy consumption (Guiné et al., 2011; Karam et al., 2016).

The aim of the project is the valorization of vegetables from the Northern Portugal using different drying methods. The specific aim was to study of the effect of different drying methods on colour, texture and physicochemical properties of several vegetables that are waste generated (vegetable surpluses that are not used for distribution and marketing) in the manufacturing lines of four selected vegetables in order to obtain nutritional products.

The present approach is a clear example of collaboration between primary sector, fresh vegetable industry and university to address the concept of global sustainability of food systems, focused not only on the environment, but also on food access and the development of technologies that increase bioavailability of nutritional products. Both functional food development and circular economy and sustainability of the food system meet at this point.

2. Materials and Methods

2.1. Raw materials

The following raw materials were kindly provided by the company PAM (Produção Distribuição Hortícola Litoral, Lda.). In this work four vegetables were studied: tomato (Lycopersicon esculentum) of the variety *Vinícius*, Turnip (Brassica rapa var rapifera) of the variety *Pelésis*, Courgette (Cucurbita pepo L.) of the variety *Brilhante* and Cucumber (Cucumis sativus L.) of the variety *Carman*. All of vegetables that are traded by the company (primary sector, fresh vegetable industry), the products were selected based on those who have a higher break throughout the year and become waste generated. The company PAM has a large amount of vegetable surpluses that are not used for distribution and sale.

2.2. Vegetables drying process production

The vegetables were washed with potable water, disinfected with stabilized chlorine (Glow, Portugal) in a 150 ppm chlorine concentration (1 pellet/20L of water) for 10 min. Then vegetables were cut with 4.5 mm thick and placed on perforated stainless steel trays. In the process of dehydration by convective air-drying, a hot air convection oven (Fagor, Visual plus model, Portugal) was used at a temperature of 60 °C during 8h for tomato, 4h for turnip and cucumber, and 6h for courgette (operation conditions optimized in previous work).
In the process of dehydration by freeze-drying, after cutting step, the vegetables were subjected to freezing process at a temperature of -80 ºC and stored. For dehydration process, the Christ Alpha1-2 LDplus Freeze-drying was used for 48 hours at 0.7 Pa. For both processes, after cooling down to room temperature, the dehydrated vegetables were properly packaged and analyses were carried out.

2.3 Sample preparation

In order to carry out analyses the convection-dried vegetable samples were ground with a mortar and the freeze-dried vegetable samples, being considerably hygroscopic, were crushed with a mincer. Then samples were packed in heat-sealed plastic bags and stored in a place protected from light and moisture.

2.4. Analytical methods

Water activity was determined using an Aqua lab Pawkit Water Activity Meter (Decagon, USA). The moisture content was determined according to the AOAC 925.10 method (AOAC, 1995). Carbohydrate content was determined using DNS colorimetric method based on Analytical Chemistry of Foods (James, 1995). Crude fibre and ash content were determined using AOAC Method 962.09:1995 and AOAC 920.115E: 1995, respectively. Protein was determined using AOAC Method 955:04, 1995. For colour determination, a Minolta Chroma Meter CR300 colorimeter (Japan) was used and 10 replicates were performed for each sample condition. The texture of cereal bars was measured using a TA-XT2i Texture Analyser (Stable Micro Systems Ltd, United Kingdom). Vegetables samples were subjected to deformation in a single compression cycle, to a depth of 1,5 mm at 0.5 mm/s, using a stainless-steel cylindrical probe (4-P) and the texture parameter hardness was calculated through the maximum force in the compression cycle. All tests were carried out with samples at room temperature (25 ºC) and at least 2 hours after the drying process. All physicochemical analyses were performed in triplicate, and for texture profile analysis, 15 replicates were performed for each formulation.

2.5.Statistical analysis

All data were analysed statistically using an ANOVA procedure (IBM SPSS Statistics 25). The Tukey HSD test was used to investigate significant differences in physicochemical, texture, color parameters. Significant differences were set at $p<0.05$.

3. Results and Discussion

In this work, evaluation of different drying methods on texture and physicochemical properties of vegetables from the Northern Portugal was performed. Table 1 summarizes the physicochemical parameters obtained after exposing the fresh vegetables to the respective drying methods: freeze-drying and convective-drying process. It is possible to notice that, after the dehydration process, the moisture content decreases sharply. The final moisture content obtained for tomato, turnip, courgette and cucumber dehydrated by CD was 6.50 ± 1.42 %, 7.57 ± 1.56 %, 7.51 ± 0.47 % and 6.29 ± 1.25 %, respectively (Table 1).
In the case of the freeze-drying process, after 48 hours, for tomato, turnip, courgette and cucumber, the following values were obtained: 7.64 ± 0.71 %, 5.40 ± 0.19 %, 6.82 ± 0.09 % and 7.22 ± 0.15 %, respectively.
The results showed that there were no statistically significant differences in the moisture content obtained, for each of the vegetables, between the two drying processes, SC and LF ($p>0.05$). According to Amezquita et al. (2018) in their study with orange peels, mango and prickly pear obtained similar results of moisture content less than 10% (between 1.3 to 3.5%), after the freeze-drying process and the convective-drying process. Concerning water activity (a_w) by comparing both drying processes (Table 1), it is possible to observe that the courgette and the cucumber dehydrated by FD present lower values than the CD process ($p<0.05$). On the contrary, in the case of tomato and cucumber, it appears that the values of aw, for both methods, do not present significant differences ($p>0.05$). According to Muñoz-lópez et al. (2018), food products with aw below 0.6 and a moisture content of approximately 0.18-0.20 g/g can be considered safe and stable in relation to microbial, enzymatic, physicochemical variations, which can lead to food deterioration during storage.
The values obtained in this work, for both drying methods, assure the microbiological stability of dried vegetables.

Table 1: Results for moisture, aw, carbohydrates, fibre, protein and ashes of vegetables: (FR) - Fresh; (CD) - Convective air-drying; (FD) - Freeze-drying. Mean values ± standard deviation for n=3. Values with different letters are statistically different by the Tukey test (p<0.05).

Vegetable	Dry method	% Moisture	a_W	% carbohydrates	% Fibre	% Protein	% Ashes
Tomato	FR	94,42±0.18b	0.94±0.03a	24.41±0.07a	13.74±0.17a	17.62±0.02a	7.36±0.57a
	CD	6.50±1.42a	0.61±0.01b	32.14±0.15a	13.98±0.78a	10.43±0.39b	8.40±0.55a
	FD	7.64±0.71a	0.63±0.11b	26.37±1.76a	14.29±0.27a	13.72±0.74c	9.06±0.28a
Turnip	FR	94.18±0.28b	0.86±0.02a	35.58±0.21ac	8.43±0.41a	9.05±0.01a	14.05±0.17b
	CD	7.57±1.56a	0.46±0.02b	42.27±0.21b	9.71±0.55a	11.37±0.18b	11.65±0.28a
	FD	5.40±0.19a	0.50±0.02b	31.88±0.80c	10.29±0.12a	12.81±0.20c	11.74±0.40a
Courgette	FR	93.73±0.19b	0.91±0.01a	34.88±0.39ac	5.48±0.13a	19.51±0.03a	11.11±0.78b
	CD	7.51±0.47a	0.54±0.01b	52.21±2.68b	5.85±0.38a	16.67±0.27b	8.56±0.15a
	FD	6.82±0.09a	0.45±0.03c	44.45±1.26c	6.14±0.12a	17.09±0.87b	9.03±0.35a
Cucumber	FR	95.48±0.11b	0.88±0.02a	48.64±0.28a	7.92±0.21a	13.37±0.02b	10.56±0.78a
	CD	6.29±1.25a	0.60±0.04b	43.77±0.03a	8.57±0.11a	13.47±0.28b	9.00±0.56a
	FD	7.22±0.15a	0.43±0.01c	36.02±2.37a	9.70±0.39a	11.19±0.30c	9.36±0.25a

The ash content is an important parameter, as it shows the presence of several minerals. It is known that the quality of many food depends on the concentration and type of mineral: calcium, phosphorus, iron, magnesium. Table 1 shows that there are no statistical differences between the ash content obtained for both drying methods (p>0.05). The turnip has the highest ash content compared to the other vegetables, in its fresh state 14.05±0.17 %, after drying by convection, 11.65±0.28 %, and after freeze-drying 11.11±0.78 %. Results show that drying process slightly decreased the final ash content of the vegetables, except for the tomato. Amezquita et al. (2018) obtained the same result in the prickly pear shell, obtaining values between 18% and 22%. Regarding carbohydrates (Table 1), it is possible to confirm that, in the case of turnip and courgette, the CD process presented a higher carbohydrates content when compared with FD (p<0.05). On the contrary, in the case of cucumber and tomato, there were no differences between the two drying processes (p>0.05). Same results were found by Amezquita et al. (2018) in the mango peel and pear peel. It was also found that there are no statistical differences (p>0.05), between the carbohydrate content of fresh and FD vegetables. On the contrary, courgette and turnip CD scored the highest carbohydrates content, 52.21±2.68 % and 42.27±0.21 %, respectively These results indicate greater nutritional values at the level of these dried vegetables.

According to Table 1, tomato and turnip scored a higher fibre content than other vegetables. It is also found that, for all vegetables, there are no statistical differences between the results obtained for the two drying methods. Through the results obtained it was also found that there are no statistical differences between fresh and dehydrated vegetables. Which means that drying did not influence the fibre content of vegetables.

According to Regulation (EC) Nº 1924/2006 and with the results obtained it is possible to claim "source of fibre" and "rich in fibre" for dried vegetables, except for courgette CD, once it presents less than 6g of fibre/100g of product. The protein content per 100 g of product for each fresh and dried vegetable is shown in Table 1. Results show that fresh tomato and courgette have the highest protein values. It was also found that FD scored higher protein content compared to CD, for all vegetables, with the exception of cucumber. In the case of courgette, there were no differences between both dehydration techniques. These results are in line with those obtained by Amezquita et al. (2018) with FD pear. After dehydration process, in the case of tomato and courgette, the protein content decreased, possibly due to the denaturation of proteins in the skin (p<0.05). Among the dehydration processes, there were significant differences (p<0.05), with the exception of the courgette (p>0.05). The same was obtained by Amezquita et al. (2018) with orange peel and prickly pear peel. The results obtained for the protein content may allow certain claims, for all dehydrated vegetables, with the exception of tomato, according to the Regulation (EU) Nº 432/2012, such as "source of fibre".

Results in Figure 1 showed that the vegetables hardness decreased after dehydration processes, with the exception of turnip. Although the fresh turnip has a very uniform and hard texture, the force required to penetrate the fresh vegetable is smaller than dried vegetable, since it has a very spongy and hard texture. The other fresh vegetables have a more cohesive and firm texture, requiring high penetration force. Tomato CD and FD scored the lowest hardness values.

It was also found that there were no statistical differences between the hardness of both dehydration processes (*p*>0.05). In Table 2 it is possible to observe the variation of colour parameters for the vegetables studied before and after drying processes. Concerning luminosity parameter (L *), it can be seen that for tomato and courgette there were no statistical differences between the fresh and dried, regardless of the method (*p*>0.05). Regarding turnip and cucumber, there are significant differences between fresh and FD, with a higher luminosity in the FD vegetable (*p*<0.05). In the latter case, FD made it possible to obtain clearer and more luminous cucumber and turnip samples. These results are in accordance with Zhang et al. (2018), who also obtained higher L * values after FD of Ashitaba leaves.
Concerning a* parameter (green/red) there were no differences (*p*>0.05) between fresh, CD and FD tomatoes, courgettes and cucumbers. It is still possible to conclude that FD vegetables have lower a* values than fresh ones. These values are in agreement with the work of Zhang et al. (2018), who also concluded that FD was a better method to obtain dehydrated samples with lower a* (green tendency).
Results showed no differences in b* parameter (yellow/blue) for tomato and courgette between fresh and two dehydration methods. It was also concluded that freeze-drying was the method with the lowest b* values (blue tendency).

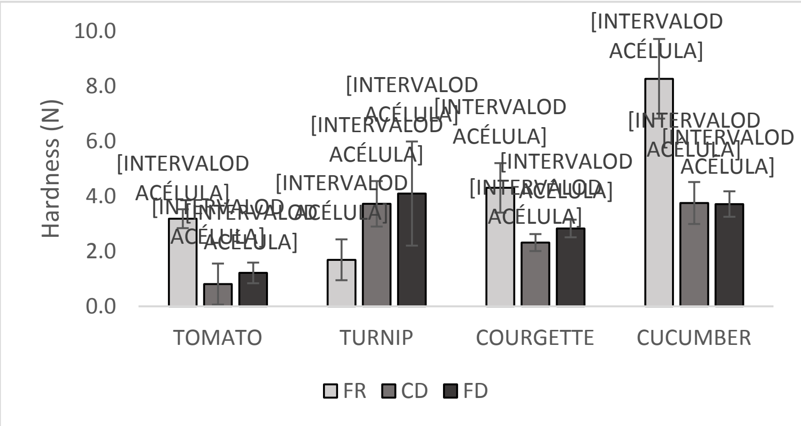

Figure 1 – Variation of the hardness of vegetables: (FR) - Fresh; (CD) - Convective air-drying; (FD) - Freeze-drying. Mean values ± standard deviation for n=15. Values with different letters are statistically different by the Tukey test (p<0.05).

Table 2: Results for colour parameters: L, a*, b* of vegetables: (FR) - Fresh; (CD) - Convective air-drying; (FD) - Freeze-drying. Mean values ± standard deviation for n=15. Values with different letters are statistically different by the Tukey test (p<0.05).*

Vegetable	Dry method	L*	a*	b*
	FR	55.84±6.59a	20.82±2.60a	25.50±3.36a
Tomato	CD	65.76±6.32a	23.01±4.24a	38.21±14.11a
	FD	68.15±7.64a	16.90±3.00a	24.52±4.16a
	FR	81.30±3.17a	-3.65±0.40a	3.05±1.22a
Turnip	CD	85.25±2.32ab	4.07±0.08ab	6.33±1.49b
	FD	89.30±1.01b	-4.48±0.31b	2.89±1.04a
	FR	86.95±1.11a	-3.27±1.14a	19.82±2.58a
Courgette	CD	85.31±2.66a	-2.18±0.48a	27.55±4.32a
	FD	88.51±2.18a	-3.2±1.95a	20.15±3.13a
	FR	69.99±3.37a	-8.88±0.80a	21.35±2.06a
Cucumber	CD	68.61±2.07a	-7.93±1.19a	29.56±1.23b
	FD	84.52±2.28b	-8.17±0.45a	17.72±2.79a

4. Conclusions

From the physicochemical, colour and texture results it was concluded that both dehydration methods were effective in the dehydration of vegetables, tomato, turnip, courgette and cucumber, when compared with fresh

vegetables.The dried vegetables obtained with FD and CD showed water activity values and a moisture content low enough to guarantee the non-development of microorganisms and undesirable chemical and enzymatic reactions.Regarding the physicochemical characteristics, carbohydrate content was higher in CD than in FD vegetables, except for cucumber. Concerning the crude fibre and ash contents, there were no differences between CD and FD vegetables. As for the protein content, it was found a slight decrease on protein content between fresh and dried vegetables. It was also found that FD scored higher protein content when compared to CD, for all vegetables, with the exception of cucumber.
In conclusion it was demonstrated that both dehydration methods are efficient in relation to the maintenance of nutritional properties, being a useful alternative to extend the vegetables shelf-life and consequently to reduce food waste in the primary sector, fresh vegetable industry. However, the freeze-drying process showed to be a better process because it provides vegetables that are more similar to the fresh product in terms of colour and texture.vegetable surpluses, that are not used for distribution and marketing, have been successfully transformed into functional products by a series of processes involving pre-treatment and dehydration processes allowing obtaining stable products with rich nutritional values, allowing their re-use, thus contributing to the circular economy.

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