# Physicochemical, Functional and Bioactive Properties of Pea (Pisum sativum L.) Pods Microwave and Convective Dried Powders

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**Research Article**

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# Physicochemical, functional and bioactive properties of pea (*Pisum sativum* L.) pods microwave and convective dried powders

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**Conflict of interest term form**

The present work has no known conflicts of interest associated and there has been no significant financial support that could have influenced its outcome.

**Data availability statement**

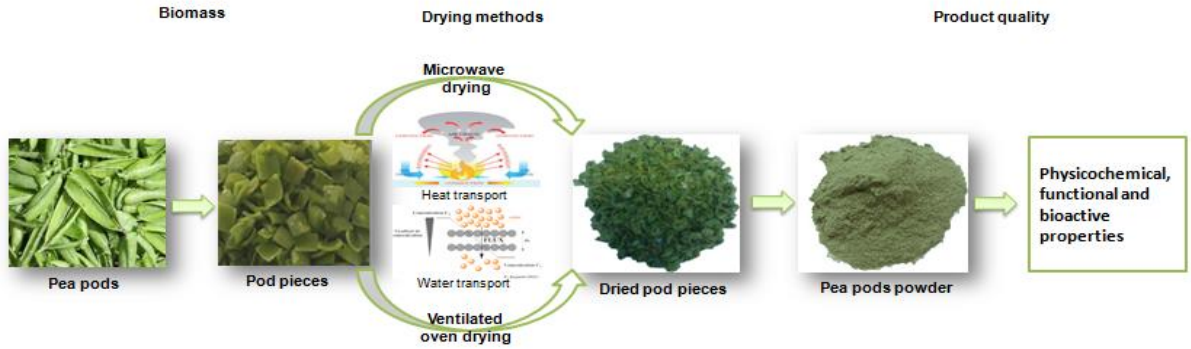
Authors can confirm that all data generated during the study are included in the article and/or its supplementary information files.

**Keywords**: Pea pods powders; microwave drying; Convective drying; color; functional properties; bioactive compounds.

**Abstract**

As the primary by-product of pea processing industry, pea pods represent a rich source of various high-value molecules. The aim of this work is to investigate the effect of nine different microwave output powers (200 to 1000 W) and five different ventilated oven temperatures (40, 60, 80, 100 and 120 °C) on the quality of pea pod such as physical-chemical (water activity, total color change), functional properties (water retention capacities and swelling capacity) and bioactive properties (total phenolic content, total flavonoid content and antioxidant capacity). The results show that microwave drying reduced significantly the drying time. Convective drying led to a greater color change than microwave drying. Convective drying at 80 °C for 135.33 min appeared the best process in terms of functional properties giving the highest values of water retention capacity and swelling capacity. Both microwave and convective drying methods could increase phenolic and antioxidant compounds content of pea pods. It was suggested that the microwave method can be a promising technology for drying the pea pods due to the shorter drying time, and higher product quality.

**Graphical Abstract**




**Statement of Novelty**

Drying of by-products from pea processing industry was investigated as a critical step prior to their valorization for energy and fuel production as well as chemicals recovery. The drying of pea pods has never been investigated before which is the case of the present study. Our research work reported that microwave drying technique can be used for conservation of this valuable product by preserving quality of fresh materials and to economizing energy and time.

## 1. Introduction

Currently, about 1300 million tons of food wastes are produced per year due to a lack of proper processing and preservation technique [1]. On the other hand, according to the United Nations (UN) food agency, everyday 18,000 children die of hunger and malnutrition [2]. Therefore, proper food processing must be emphasized to reduce this massive loss.

Peas are marketed after a simple industrial process in which the pod is removed to prepare the seed as frozen, tinned or fresh [3]. The industrial process generates abundant residues which represent an inexpensive material that has been undervalued until now, used mainly as fertilizer or for animal feeds [4]. The pea by-products pose an economic and environmental problem due to their high volumes, organic load and disposal costs [5], but they can also be a promising source of functional compounds [6]

Pea pods are by-products emanating from pea processing industry. These pods represent a rich source of various high-value molecules. They are very rich in dietary fiber (more than 50% content, mainly insoluble in water dietary fiber), proteins, potassium and iron[7] and phenolic compounds. The latter, if derived from a low-cost resource, such as green pea pods, have great potential, may find an application in the food, feed, cosmetic and pharmaceutical industries.

Recent applications of pea pods include bioethanol and bio-char production [8], polysaccharide and carbohydrate recovery [9], in addition to their use as a source of dietary fibers [5]. The presence of dietary fiber and other nutritive compounds provides an important added value to pea by-products and the possibility to balance food according to nutritional requirements and consequently an advantage against the use of isolate functional ingredients[10].

There is a continuous demand to develop innovative approaches for the valorization of pea pod by-products by applying environmentally and economically sustainable processes. One of the critical steps for by-products stabilization is the drying operation since, due to their high moisture content, they are highly perishable and need to be stabilized for further processing.

In the drying industry, one of the goals is to minimize the energy consumption, both for environmental and cost reasons [11], preserving at the same time the product quality[12], with the quality of dried biomaterial being one of the fundamental indicators in the assessment of the drying process effectiveness[13]. In addition to the nutritional quality, which should be ideally preserved, sensory properties are to be considered and evaluated, either directly through a tasting, or indirectly through objective analyses, such as color, water retention and swelling capacity, content in antioxidant compounds [14].

Conventional drying techniques are still extensively employed due to unquestionable advantages such as simple apparatus and a very well-known drying mechanism [15], with satisfactory efficiency in the initial period of drying caused by relatively high drying rates and large capacity [16]. But, on the other hand, a long-lasting hot air drying has a detrimental effect on quality of the obtained product and a higher cost of operation [17].

Freeze and vacuum drying have been considered as an most effective drying methods to obtain superior quality products, however, it is too time-consuming and high cost make those unpopular [18, 19]. For instance, freeze drying requires a longer drying time, and the cost is about 200–500% higher than that of hot air drying [20].

Whereas, vacuum drying needs higher initial and operating cost to maintain low pressure throughout the drying process [21]. Consequently, novel drying methods are emerging to deal with the weakness of conventional, freeze and vacuum drying and create high-quality products.

Microwave drying, a relatively new technology, has been recommended as a fast and effective alternative drying technique [22]. Microwave-assisted thermal conversion of biomass has received significant attention in recent years as it is capable of improving the process efficiency and product quality through rapid volumetric heating [23].

In the literature several vegetables were dried using the microwave drying methods. Some of them are; Green Bean Slices [24], asparagus [25], mushroom [26], eggplant [27] green peas [28]. As it seen from the literature the drying effect on the quality of pea pods has never been investigated before which is the case of the present study whose objectives were: (i) to determine and evaluate quality of pea pods powders obtained by convective and microwave drying methods, (ii) to compare two processes: convection drying and microwave drying of pea pods, and finally (iii) to find the most suitable drying conditions among the applied ones for achieving high-quality pea pods powders.

## 2.Materials and methods

### 2.1 Raw material

Good quality fresh and matured fruits of green peas (*Pisum sativum* L.) were purchased from the local market (Bejaia, Algeria). The fruits were sorted, washed with tap water followed by distilled water to remove the dust, shelled and the two recovered half-pods cut into approximately equal parts with dimension of about 1 cm2 and 0.3 cm thickness.

### 2.2 Drying procedures

For microwave drying (MWD), a domestic microwave (Maxipower, Model MASMO23S, China) with 2450 kHz working frequency was used. The microwave was equipped with cavity dimensions of 22.5 cm × 37.5 cm × 38.6 cm and a digital control system for microwave power (the latter linearly adjustable from 100 to 1000 W) and irradiation time. Approximately, 100 g of pea pods pieces were spread uniformly in a monolayer on the plate and dried at nine different microwave powers (200, 300, 400, 500, 600,700, 800, 900 and 1000 W) until constant weight. Conventional drying (CD) experiments were performed in a ventilated oven (Memmert, ULE-600, Germany). Approximately100 g of pea pods pieces were spread uniformly in a monolayer on the oven tray (38.5 cm × 27 cm) and dried at five different temperatures (40, 60, 80, 100 and 120 °C) and air velocities of 1.0 m/s until constant weight. Three repetitions were performed for each temperature and power, and the data provided were an average of these results.

The dried pod pieces were crushed using an electric grinder (IKA model A11 basic), and sieved using an automatic sieve shaker (Rheinische Str.36 model D-42781 Haan) in order to obtain a fine and homogeneous powder. The resulting powders were stored in glass jars, hermetically sealed, protected from light, until use.

The moisture content (MC) of the fresh and dried pea pods samples was evaluated according to the Schulze, Hubbermann [29]. The results were expressed as a percentage of the wet base.

### *2.1 Physicochemical properties*

*Determination of water activity (aw)*

Water activity (aw) was measured at 25 °C using an AquaLab Series 4TEV water activity meter (Decagon Devices, Inc., Pullman, Washington, United States).

*Color measurement*

The surface color of fresh and dried samples was determined by a colorimeter (Minolta CR-400, Konica Minolta, Japan) in five different points on the sample surface. The CIE *Lab* color parameters were used to describe the color of samples, where $L^*$ indicates lightness, $a^*$ indicates chromaticity on a green (−) to red (+) axis and $b^*$ indicates chromaticity on a blue (−) to yellow (+) axis. The total color change $\Delta E$ between fresh and dried product was calculated with Eq. (1)[30]:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

### *2.4 Functional properties*

*Swelling Capacity (SC)*

The Swelling Capacity *(SC)*was analyzed by the method described by Robertson, de Monredon [31]. One hundred milligrams of dry weight of sample were hydrated in a measuring cylinder with 10mLdistilled water at room temperature. After 18 h, the final volume (mL) was recorded, and SC was expressed as volume (mL)/g of original substrate dry weight.

*Water-Holding Capacity (WHC)*

The Water-Holding Capacity (WHC) was according to the method described byLv, Liu [32]: distilled water (15 mL) was transferred into centrifuge tubes containing 250 mg of sample. The mixture was agitated and kept at room temperature for 24 h. After centrifugation at 3641rpm for 1 h, the mixture was filtrated using quantitative filter paper and residue fresh weight was recorded. WHC was expressed as grams of water per gram of dry weight, respectively.

### *2.5 Bioactive properties*

#### *2.5.1 Total Phenolic Content (TPC)*

To evaluate the total phenolic content, dried pea pods powders were extracted using an ultrasonic processor (SonicsVCX 500, Connecticut, USA) according to the protocol proposed by Dahmoune, Boulekbache [33]. Briefly, one gram of dried pea pods powder was extracted with 40 mL (w/v) of 64%ethanol (v/v) at 77.79% of amplitude during 15.05 min of holding time. The extracts were filtered using filter paper Whatman n°3 and transferred to 100 mL volumetric flask.

Total phenolic content was determined spectrophotometrically using the Folin–Ciocalteu colorimetric method. A 2.5 mL sample of distilled water-diluted Folin-Ciolcateu reagent (1/10) was added with 1 mL of the extract. After incubation for 2 min at room temperature, 2 mL of sodium carbonate ($75 g \cdot L^{-1}$) were added.the mixture was incubated for 15 min at 50 °C and finally cooled in a water-ice bath. The absorbance at 760 nm (SHIMADZU UV-1800, Japan) was immediately measured [34] against the blank (obtained with the same protocol but with ethanol instead of the extract). Results were expressed as gallic acid equivalents content of pea pods ($mg_{GAE}/g_{DW}$) by means of a calibration curve obtained with a standard of gallic acid dissolved in ethanol in the 0.02 to 0.12 mg/mL concentration range. The same extract was used to evaluate the content of flavonoids and antioxidant activity.

### *2.5.2 Flavonoid content*

Flavonoid content was estimated by the $AlCl_3$ (Aluminium chloride) method [35]: 1 mL of the extract solution was added to 1 ml of 2% methanolic $AlCl_3 \cdot 6H_2O$. The absorbance was read 10 min later at 430 nm against a blank. The flavonoid contents were expressed as equivalents (mg quercetin/gDW) by means of a calibration curve obtained with standard quercetin (dissolved in ethanol concentration range 0.01to 0.06 mg/mL) treated in the same conditions.

### *2.5.3 DPPH° Radical-scavenging activity assay*

The free radical scavenging activity was determined according to the method described by Mishra, Ojha [36] and Sharma and Bhat [37]. Briefly, 0.1 mL of the extract were mixed with 3.9 mL of a $6 \times 10^{-5}$ M methanol DPPH solution. The mixtures were vigorously shaken and left standing at room temperature in the dark for 30 min, and the final absorbance was measured at 517 nm. The results were expressed as a percentage effect (I%) of control absorbance reduction (Eq. 2)

$$\text{Percentage effect (I\%)} = \left(\frac{\text{Abs}_{\text{Control}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{Control}}}\right) \times 100 \quad \textbf{(2)}$$

Different sample dilutions in methanol were used in order to obtain anti radical curves and calculate the IC50 values, which is the extract concentration for a 50% percentage effect. The I% was plotted versus pea pods powder concentration.

### *2.5.4 Ferric reducing power assay (FRAP)*

The reducing power was performed according to the method reported byFerreira, Baptista [38]. Various concentrations of pea pod ethanolic extracts (2.5 mL) were added to 2.5 mL of phosphate buffer (200 mM, pH

6.6) followed by 2.5 mL of 1% potassium ferricyanide. The reacting mixture was then incubated in a water bath at 50 °Cfor 20 minutes. The reaction was stopped by adding2.5 mL of 10% (w/v) trichloroacetic acid and the content was centrifuged at 650 rpm for 10 min. To 5 mL of the supernatant was added 5 mL of distilled water and 1 mL of 0.1% ferric chloride and the resulting mixture was vortexed and finally the absorbance was read at 700 nm. The reductive potential was expressed as EC50 (µg/mL) related to the pea pods powder corresponding to 50% absorbance intensity.

### *2.6 Parameter estimation and statistical methods*

Three replications of each drying experiment were carried out and triplicate samples of each experiment were analyzed. All assays were carried out in triplicate and the results are expressed as mean values ± standard deviations. The effect of microwave drying power and oven drying temperature on the estimated parameters of the best fitted model was statistically evaluated using analysis of variance (ANOVA). ANOVA was performed using JMP7 Statistics Software. Tukey's multiple range test (HSD) was used to compare means of the estimated kinetic parameters. Evaluations were based on the $\alpha$=0.05 level Move

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## 3. Results and discussion

### *3.1 Physicochemical properties*

Drying of the pea pods started with an initial moisture content around 87.79 ± 0.195% and continued until no further changes in their mass were observed, e.g., to a final moisture content of about 10% which was then taken as the equilibrium moisture content in the next computations. The changes in MR with time during drying of the pea pods are shown in Figure 1.

Drying temperature and microwave power have a significant effect on drying time with drying time decreasing considerably with increasing oven temperature or microwave power. The required drying time to equilibrium moisture in conventional drying at 40, 60, 80, 100 and 120°C was about 850 ± 22.91, 206.33 ± 4.61, 135.33 ± 6.42, 86.33 ± 5.68 and 50.16 ± 1.25 min, respectively. At higher drying temperatures, the heat transfer rate and mass transfer rate increase leading to faster moisture evaporation and shorter drying duration[39]. In microwave drying, time to reach equilibrium moisture at 200, 300, 400, 500, 600, 700, 800, 900 and 1000 W was about 217.11 ± 0.67, 99.05 ± 2.04, 72.91 ± 0.79, 53.88 ± 0.29, 44 ± 0.94, 37.55 ± 0.34, 32.16± 0.36, 27.38 ± 0.39 and 22.36 ± 0.42 min, respectively, suggesting higher mass and heat transfer rates. In fact, in MWD there is a rapid MW penetration in the product volume with fast heat generation, followed by a great vapor pressure difference between the center and the surface of the products, resulting in forced expulsion of gases and fast water vapor diffusion[40].

#### *3.1.1 Water activity*

Water activity ($a_w$) is a critical parameter that allows determining the product stability and safety. it is worth mentioning that above the value of 0.4 the relative speed of hydrolysis, lipid oxidation, enzymatic, microbiological and Maillard reactions increases considerably [41].The overall dry products obtained by different drying conditions were characterized by the $a_w$ lower than 0.4 (Table 1). The lowest $a_w$ value was

reached after microwave drying at 1000 W for 22min and the highest $a_w$ value was reached for sample dried in conventional oven at 40 °C for 850 min.

### *3.1.2 Color*

The color parameters of fresh and dried pea pods including the *L*, a*, b** and ΔE, under different drying conditions, are shown in Table 2.

The *L** value increases with drying indicating formation of a darker color. A reduction in drying time reduced the lightness variation. The darker color may be due to exposure to oxygen and to enzymatic browning reaction [42]. The statistical analysis showed differences between fresh and dried pea pods at different drying conditions ($p < 0.05$) for the two drying methods. Also the relatively high content of sugars, proteins, and chlorophyll may favor color changes in dried pea pods [28].

The initial sample showed a negative *a** value indicating greenness, while it increased towards positive (red) values together with the drying treatment severity in terms of high temperatures or microwave powers. The statistical analysis showed significant differences between fresh and dried pea pods at different drying conditions ($p < 0.05$) for both drying methods, except for CD at 40 °C. Temperatures above 120 °C expediting molecular changes towards the creation of brown compounds as the result of diverse reactions, such as for example decomposition of chlorophyll and other pigments such as carotenoid, polyphenols polymerization and Maillard reaction[43]or even pigment concentration due to water reduction [44]. However, the *b** values slightly changed and in conventional drying it increased more the longer the treatment revealing in this case decomposition of different compounds probably more sensitive to oxygen exposition, rather than heat (such as carotenoids). In microwave drying *b** variation was not so correlated with drying time.

The total color change of dried pea pods (ΔE), showed the same trend as *b** and lower values for MD confirming that a long-lasting hot air drying causes a meaningful color alteration and application of microwave can shorten the drying time limiting color change [13].

## *3.2 Functional properties*

In order to evaluate possible modifications affecting the structural arrangement of cell wall polysaccharides from pea pods samples, hydration-related properties such as swelling and water retention capacity were measured on fresh and dried samples (Table3).

### *3.2.1 Swelling capacity (SC).*

Convective drying decreased this property showing anyway an increase from the treatment at 40°C to that at 80°C (with a value close to that of fresh sample) and then a decrease with increasing temperature. The statistical analysis showed significant differences between fresh and dried pea pods for both microwave and convective drying methods ($p < 0.05$), except for CD at 80°C. At lower temperatures, the drying time necessary to decrease moisture content is considerably high affecting functional properties. On the flip side, high temperatures cause some structural changes in final products, such as changes to carbohydrate granules, in particular starch, protein denaturation. So, the optimal conditions for functional properties are a compromise betwixt temperature and drying time [14]. For microwave drying, SC values were on average lower and the increase in microwave power led to the decrease of SC until 400 W and then an increase from 500 to 1000 W .It is reported that MD affects the fibrous matrix modifying the structural characteristics and the chemical

composition of the fiber (water affinity components) due to the high internal pressure produced by microwave heating which can cause expansion and *SW* of the sample structure [45].

#### 3.2.2 *Water retention capacity (WRC).*

In general, dehydration promoted a decrease of the WRC for all the tested conditions, with a correlation with temperature / microwave power similar to that commented for SC which is expected due to the same compounds involved in SC and WRC. Statistical analysis showed significant differences between fresh and dried pea pods for both microwave and convective drying methods ($p < 0.05$).Similar investigations reported that drying temperature is the main factor affecting the WRC [46]. The results for MD showed that volumetric heating during microwave caused higher internal pressure at the start of the drying stage and faster evaporation, resulting in cell swelling, but with the reduction of moisture content, the volume shrinkage is increased which decreases the rehydration capacity[47].According to Hodge and Osman [48], flours with high WRC have more hydrophilic constituents such as fibers. Apple, wheat, pea, and carrot fibers have a WRC ranging from 2.5 to 10 g/g dry weight. From a technological point of view, fibers are used as texturing agent or additive to increase volume, essentially due to their capacity to absorb water [49]. Thanks to the high value of WRC, pea byproduct could be utilized as a functional ingredient: to reduce calories intake, avoid syneresis, modify the viscosity and texture of formulated foods.

### *3.3 Total polyphenolic, total flavonoids compounds and antioxidant activity*

The content in antioxidant compounds and antioxidant activity of plant materials was generally lower in the fresh material in agreement with some recent studies that have demonstrated that dehydrated plant materials contain larger amounts of antioxidants when compared to fresh plant materials [50].

#### *3.3.1 Antioxidant compounds*

In the present study, the total polyphenols content (TPC) and total flavonoids (TFC) in ethanol extracts of pea pods increased significantly after both conventional and microwave drying and with decreasing drying time. The statistical analysis showed significant differences between fresh and dried pea pods at different drying conditions ($p < 0.05$) using both drying methods, except for CD at 40 and 60 °C and MD at 200 W. This increase was probably due to changes in their extractability due to the disruption of the plant cell wall(as already commented for MD) enhancing the release of bound polyphenolic and flavonoid compounds [51]. Additionally, the formation of Maillard reaction products may add antioxidant activity and interfere with the Folin-Ciocalteu, DPPH and FRAP test. A decrease in total phenolics and flavonoids was observed only for CD at 40 and 60 °C and MD at 200 W for which overexposure to atmospheric oxygen for long times might have brought to compounds oxidation [52]. Another possibility concerning the low level of phenolic compounds in the fresh sample could be the presence of active enzyme polyphenol oxidase which is faster inactivated at higher temperatures [53].

#### *3.3.2 Antioxidant activity*

The effect of drying method on the antioxidant capacity of ethanol extracts from pea by-product was assessed by the DPPH° radical scavenging assay and the ferric-reducing power estimation. In agreement with what observed for antioxidant compounds, results showed that drying significantly enhanced the overall antioxidant activities of samples, except for the samples dried at 40 °C in CD. The maximum radical scavenging activity values were found after microwave treatment at 1000W. The ferric reducing ability of the extract showed a similar trend to

the results observed from the DPPH° assay. Firstly, this can be atributable to the increased amount of antioxidant compounds in the extracts. High correlations were found between DPPH° and total flavonoids and total phenolics. Secondly, there might also be the formation of novel compounds having antioxidant activity during drying, as Maillard compounds[54].

## 4. Conclusion

In this study, the effects of microwave output powers and oven temperatures on the different factors including color, functional and bioactive properties of pea pods were investigated to find suitable drying conditions among the applied ones for this valuable product. The main findings of this study can be summarized as:

- ✓ Increasing the microwave power level or drying temperature resulted in a reduction in drying time and that this reduction is more significant when applying microwave drying.
- ✓ The lowest water activity $a_w$ value was reached after microwave drying at 1000 W for 22min.
- ✓ The convective dried pea pods samples exhibited a greater color change than microwave dried pea pods samples.
- ✓ Conventional drying at 80 °C during 135.33 min was the most efficient combination that provided the highest swelling and water retention capacity.
- ✓ Drying could increase functional compounds, in terms of extractable phenolic and antioxidant compounds, with microwave drying at 1000 W for 22.36 min appearing the best process from this point of view.

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## References

1. Gustavsson, J., et al., *Global food losses and food waste*, 2011, FAO Rome.
2. UN, *18,000 children die every day of hunger.* 2007.
3. Belghith-Fendri, L., et al., *Pea and Broad Bean Pods as a Natural Source of Dietary Fiber: The Impact on Texture and Sensory Properties of Cake.* J Food Sci, 2016. **81**(10): p. C2360-C2366.

4. Mateos-Aparicio, I., A. Redondo-Cuenca, and M.J. Villanueva-Suárez, *Isolation and characterisation of cell wall polysaccharides from legume by-products: Okara (soymilk residue), pea pod and broad bean pod.* Food Chemistry, 2010. **122**(1): p. 339-345.

5. Mateos-Aparicio, I., A. Redondo-Cuenca, and M.J. Villanueva-Suarez, *Broad bean and pea by-products as sources of fibre-rich ingredients: potential antioxidant activity measured in vitro.* J Sci Food Agric, 2012. **92**(3): p. 697-703.

6. Carle, R., et al., *Method for obtaining useful materials from the by-products of fruit and vegetable processing.* Patent application, WO, 2001. **1**(78859): p. A1.

7. Mateos-Aparicio, I., et al., *Pea pod, broad bean pod and okara, potential sources of functional compounds.* LWT - Food Science and Technology, 2010. **43**(9): p. 1467-1470.

8. Stella Mary, G., et al., *Production, characterization and evaluation of biochar from pod (Pisum sativum), leaf (Brassica oleracea) and peel (Citrus sinensis) wastes.* International Journal of Recycling of Organic Waste in Agriculture, 2016. **5**(1): p. 43-53.

9. Vojvodic, A., et al., *Compositional evaluation of selected agro-industrial wastes as valuable sources for the recovery of complex carbohydrates.* Food Res Int, 2016. **89**(Pt 1): p. 565-573.

10. Tiwari, B.K., A. Gowen, and B. McKenna, *Pulse foods: processing, quality and nutraceutical applications*2011: Academic Press.

11. Talens, C., M. Castro-Giraldez, and P.J. Fito, *A thermodynamic model for hot air microwave drying of orange peel.* Journal of Food Engineering, 2016. **175**: p. 33-42.

12. Sabarez, H.T., *Modelling of drying processes for food materials.* 2015: p. 95-127.

13. Szadzinska, J., et al., *The effect of high power airborne ultrasound and microwaves on convective drying effectiveness and quality of green pepper.* Ultrason Sonochem, 2017. **34**: p. 531-539.

14. Dehnad, D., S.M. Jafari, and M. Afrasiabi, *Influence of drying on functional properties of food biopolymers: From traditional to novel dehydration techniques.* Trends in Food Science & Technology, 2016. **57**: p. 116-131.

15. Szadzińska, J., S.J. Kowalski, and M. Stasiak, *Microwave and ultrasound enhancement of convective drying of strawberries: Experimental and modeling efficiency.* International Journal of Heat and Mass Transfer, 2016. **103**: p. 1065-1074.

16. Figiel, A., *Drying kinetics and quality of beetroots dehydrated by combination of convective and vacuum-microwave methods.* Journal of Food Engineering, 2010. **98**(4): p. 461-470.

17. Mujumdar, A. and S. Jangam, *Some Innovative Drying Technologies for Dehydration of Foods*2018.

18. Pan, Y.K., L.J. Zhao, and W.B. Hu, *The Effect of Tempering-Intermittent Drying on Quality and Energy of Plant Materials.* Drying Technology, 1998. **17**(9): p. 1795-1812.

19. Xu, Y., et al., *A comparative evaluation of nutritional properties, antioxidant capacity and physical characteristics of cabbage (Brassica oleracea var. Capitate var L.) subjected to different drying methods.* Food Chem, 2020. **309**: p. 124935.

20. Zhang, M., H. Jiang, and R.-X. Lim, *Recent Developments in Microwave-Assisted Drying of Vegetables, Fruits, and Aquatic Products—Drying Kinetics and Quality Considerations.* Drying Technology, 2010. **28**(11): p. 1307-1316.

21. Gunasekaran, S., *Pulsed microwave-vacuum drying of food materials.* Drying Technology, 1999. **17**(3): p. 395-412.

22. Horuz, E., et al., *Effects of hybrid (microwave-convectional) and convectional drying on drying kinetics, total phenolics, antioxidant capacity, vitamin C, color and rehydration capacity of sour cherries.* Food Chem, 2017. **230**: p. 295-305.

23. Asomaning, J., et al., *Recent developments in microwave-assisted thermal conversion of biomass for fuels and chemicals.* Renewable and Sustainable Energy Reviews, 2018. **92**: p. 642-657.

24. Doymaz, I., A.S. Kipcak, and S. Piskin, *Microwave drying of green bean slices: drying kinetics and physical quality.* Czech Journal of Food Sciences, 2016. **33**(No. 4): p. 367-376.

25. Kipcak, A.S. and O. Ismail, *< b> Comparison of the microwave drying kinetics of culture and natural asparagus.* Acta Scientiarum. Technology, 2018. **40**: p. e39922-e39922.

26. Lombraña, J.I., R. Rodríguez, and U. Ruiz, *Microwave-drying of sliced mushroom. Analysis of temperature control and pressure.* Innovative Food Science & Emerging Technologies, 2010. **11**(4): p. 652-660.

27. Chouaibi, M., et al., *Influence of drying processes on bioactive compounds profiles, hydroxymethylfurfural, color parameters, and antioxidant activities of Tunisian eggplant (Solanum melongena L.).* Journal of Food Processing and Preservation, 2021: p. e15460.

28. Chahbani, A., et al., *Microwave drying effects on drying kinetics, bioactive compounds and antioxidant activity of green peas (Pisum sativum L.).* Food Bioscience, 2018. **25**: p. 32-38.

29. Schulze, B., E.M. Hubbermann, and K. Schwarz, *Stability of quercetin derivatives in vacuum impregnated apple slices after drying (microwave vacuum drying, air drying, freeze drying) and storage.* LWT - Food Science and Technology, 2014. **57**(1): p. 426-433.

30. Garau, M.C., et al., *Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange (Citrus aurantium v. Canoneta) by-products.* Food Chem, 2007. **104**(3): p. 1014-1024.

31. Robertson, J.A., et al., *Hydration Properties of Dietary Fibre and Resistant Starch: a European Collaborative Study.* LWT - Food Science and Technology, 2000. **33**(2): p. 72-79.

32. Lv, J.S., et al., *Chemical composition and functional characteristics of dietary fiber-rich powder obtained from core of maize straw.* Food Chem, 2017. **227**: p. 383-389.

33. Dahmoune, F., et al., *Valorization of Citrus limon residues for the recovery of antioxidants: Evaluation and optimization of microwave and ultrasound application to solvent extraction.* Industrial Crops and Products, 2013. **50**: p. 77-87.

34. Georgé, S., et al., *Rapid Determination of Polyphenols and Vitamin C in Plant-Derived Products.* Journal of Agricultural and Food Chemistry, 2005. **53**(5): p. 1370-1373.

35. Quettier-Deleu, C., et al., *Phenolic compounds and antioxidant activities of buckwheat (Fagopyrum esculentum Moench) hulls and flour.* Journal of Ethnopharmacology, 2000. **72**(1): p. 35-42.

36. Mishra, K., H. Ojha, and N.K. Chaudhury, *Estimation of antiradical properties of antioxidants using DPPH assay: A critical review and results.* Food Chem, 2012. **130**(4): p. 1036-1043.

37. Sharma, O.P. and T.K. Bhat, *DPPH antioxidant assay revisited.* Food Chem, 2009. **113**(4): p. 1202-1205.

38. Ferreira, I.C.F.R., et al., *Free-radical scavenging capacity and reducing power of wild edible mushrooms from northeast Portugal: Individual cap and stipe activity.* Food Chem, 2007. **100**(4): p. 1511-1516.

39. Torki-Harchegani, M., et al., *Dehydration characteristics and mathematical modelling of lemon slices drying undergoing oven treatment.* Heat and Mass Transfer, 2015. **52**(2): p. 281-289.

40. Sadeghi, M., O. Mirzabeigi Kesbi, and S.A. Mireei, *Mass transfer characteristics during convective, microwave and combined microwave-convective drying of lemon slices.* J Sci Food Agric, 2013. **93**(3): p. 471-8.

41. Labuza, T.P., *Water content and stability of low moisture and intermediate moisture foods.* Food Technol, 1970. **24**: p. 543-550.

42. Maurya, V.K., et al., *Effect of drying methods (microwave vacuum, freeze, hot air and sun drying) on physical, chemical and nutritional attributes of five pepper (Capsicum annuum var. annuum) cultivars.* J Sci Food Agric, 2018. **98**(9): p. 3492-3500.

43. Michalska, A., et al., *Physicochemical properties of whole fruit plum powders obtained using different drying technologies.* Food Chem, 2016. **207**: p. 223-32.

44. Wojdyło, A., A. Figiel, and J. Oszmiański, *Effect of drying methods with the application of vacuum microwaves on the bioactive compounds, color, and antioxidant activity of strawberry fruits.* Journal of Agricultural and Food Chemistry, 2009. **57**(4): p. 1337-1343.

45. Sumnu, G., E. Turabi, and M. Oztop, *Drying of carrots in microwave and halogen lamp–microwave combination ovens.* LWT - Food Science and Technology, 2005. **38**(5): p. 549-553.

46. Vega-Gálvez, A., et al., *Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo).* Journal of Food Engineering, 2008. **85**(1): p. 42-50.

47. Wang, H., M. Zhang, and A.S. Mujumdar, *Comparison of Three New Drying Methods for Drying Characteristics and Quality of Shiitake Mushroom (Lentinus edodes).* Drying Technology, 2014. **32**(15): p. 1791-1802.

48. Hodge, J. and E. Osman, *Principles of Food Science Part 1. Food Chemistry.* by 0. R. Fennema, Marcel Dekker Inc., New York, Basel, 1976.

49. Oakenfull, D., *Physicochemical properties of dietary fiber: Overview.* FOOD SCIENCE AND TECHNOLOGY-NEW YORK-MARCEL DEKKER-, 2001: p. 195-206.

50. Pinela, J., et al., *Antioxidant activity, ascorbic acid, phenolic compounds and sugars of wild and commercial Tuberaria lignosa samples: effects of drying and oral preparation methods.* Food Chem, 2012. **135**(3): p. 1028-35.

51. Choi, Y., et al., *Influence of heat treatment on the antioxidant activities and polyphenolic compounds of Shiitake (Lentinus edodes) mushroom.* Food Chem, 2006. **99**(2): p. 381-387.

52. Sousa, A.D., et al., *Drying kinetics and effect of air-drying temperature on chemical composition of Phyllanthus amarus and Phyllanthus niruri.* Drying Technology, 2018. **36**(5): p. 609-616.

53. Roshanak, S., M. Rahimmalek, and S.A. Goli, *Evaluation of seven different drying treatments in respect to total flavonoid, phenolic, vitamin C content, chlorophyll, antioxidant activity and color of green tea (Camellia sinensis or C. assamica) leaves.* J Food Sci Technol, 2016. **53**(1): p. 721-9.

54. Hayta, M., M. Alpaslan, and A. Baysar, *Effect of drying methods on functional properties of tarhana: A wheat flour-yogurt mixture.* Journal of Food Science, 2002. **67**(2): p. 740-744.

**Figure Legends**

**Fig. 1–** Experimental (symbols) and simulated (solid lines) decrease in moisture ratio (MR) of pea pods during microwave drying (**A**) at different powers (□ 200, ▽ 300,Δ 400, ◇ 500, ● 600, ■ 700, ▼ 800, ▲ 900 and □ 1000 W) and oven drying (**B**) at different temperatures (● 40, ■ 60, ▼ 80, ▲ 100 and □ 120 °C). Solid lines are calculated MR using the Midilli *et al.* model.

# Figures

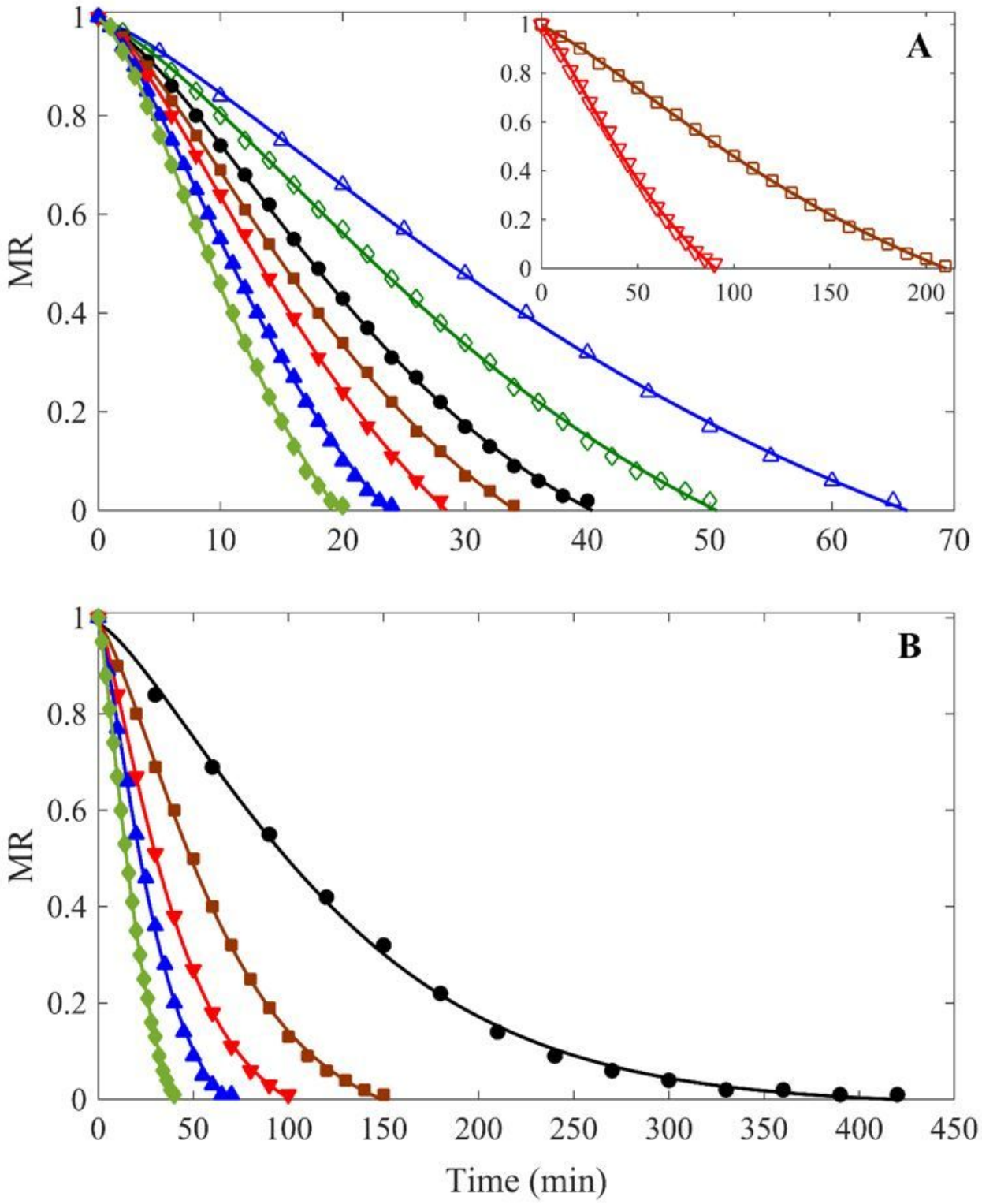


**Figure 1**

Experimental (symbols) and simulated (solid lines) decrease in moisture ratio (MR) of pea pods during microwave drying (A) at different powers (□ 200, □ 300,Δ 400, □ 500, □ 600, □ 700, □ 800, Δ 900 and □ 1000

W) and oven drying (B) at different temperatures (□ 40, □ 60, □ 80, Δ 100 and □ 120 °C). Solid lines are calculated MR using the Midilli et al. model.

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