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Effects of hot air, microwave and vacuum drying on drying characteristics and in vitro bioaccessibility of medlar fruit leather (pestil)

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Abstract The effects of microwave (90 W and 180 W), hot air (60 and 70 °C) and vacuum (60 and 70 °C with 200 and 300 mbar) drying methods on drying characteristics, total phenolic content, antioxidant capacity, color and in vitro gastrointestinal digestion of medlar pestil were investigated. Medlar showed a good potential for pestil production while being the most applicable in microwave treatments. For drying kinetics, five thin-layer drying models were applied and the Page and Modified Page were the best fitted models. L*, b*, chroma and hue angle decreased while a* generally increased in dried pestils. Dried samples showed a general decrement in phenolics and antioxidant capacity. According to in vitro gastrointestinal digestion, intestinal phase of all the samples resulted with an increment in phenolics, FRAP and DPPH compared to undigested extracts. In conclusion, different drying methods may affect the release of phenolics and antioxidant capacity, while leading to increased bioaccessibility during intestinal digestion.

Keywords Medlar · Pestil · Drying kinetics · In vitro gastro intestinal digestion

Introduction

Mespilus germanica L., which is a member of Rosaceae family, is commonly known as medlar. It is indigenous in southeastern Europe, Anatolia, Crimea, Caucasia and the northern parts of Iraq and Iran. In Turkey, 4352 tons of medlar were harvested in 2017 according to Turkish Statistical Institute (Akbulut et al., 2016, TUIK, 2018). Medlar is a potential source of ascorbic acid and natural antioxidants as well as including phenolics like chlorogenic acid, rutin and p-coumaric acid. Medlar fruits could be eaten raw or consumed in the form of jam, jelly, marmalade, wine, liquer and pickle. Fruits are likewise utilized in the therapy of constipation and evacuation of kidney and bladder stones. Fruit leather (pestil) is a traditional product formed by the addition of sucrose and starch into the pulp and the dehydration of fruit pulp into leathery sheets. As a result of the increasing awareness of consumers in healthy food consumption, demand for value-added products has raised and pestil gained importance as being an economic source of natural fruits with several nutrients (Chen and Martynenko, 2018; Jaturonglumlert and Kiatsiriroat, 2010; Lee and Hsieh, 2008; Ruiz et al., 2014; Tontul and Topuz, 2017). Polyphenols are of great importance being in this group not only with health beneficial effects but also their intake and bioaccessibility. Bioaccessibility is defined as the quantity of nutrient delivered from food matrix. In this topic, the bioaccessibility of polyphenols are affected from molecular interactions between phenolics and other components, release from the food matrix and the chemical state of the compound as they are ingested as complex mixtures. Besides, mechanical and thermal treatments may result with the enhancement in digestibility and bioaccessibility of nutrients (Lemmens et al., 2010).

Drying of food is a complex thermal process including simultaneous heat and mass transfer in the product. Advantages of thermal processing incorporate enzyme and microbial inactivation, shelf life prolongation, enhanced digestibility and bioavailability of nutrients and antioxidants as well as the negative effects like loss of desirable

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nutrients. To obtain a high quality dried product, drying method and time comes as the most important factors. In this shed of light, thin layer drying models are used for the development of the system performance as well as allowing the determination of the best operational conditions specific to different food or products (Sampaio et al., 2017).

Evaluation of drying methods used in food industry displays that, hot air drying is the quite common and effective method, even though it has some disadvantages such as the drying time continuation and low energy effectiveness (Arslan and Ozcan, 2010). As an elective technique, vacuum drying is utilized at decreased pressures, empowering food to be dried at lower temperatures. With this strategy, less oxidation responses happen because of the nonappearance of air, while the sensorial properties of the dried foods are kept up. Microwave drying is another option with different focal points, such as a higher drying rate, homogeneous energy conveyance on the material and preferable process control. On the contrary, it may lead to unequal warming and conceivable textural harm besides its high installation costs (Arslan and Ozcan, 2010; Maskan, 2001).

There are so many literature about pestil production studied with diverse kinds of fruits, however, medlar has been evaluated with using advanced drying techniques for the first time. Besides, there are several scientific reports about mathematical modelling of drying of several fruit and vegetables and revealing the phenolic content and antioxidant capacity. To the best of the knowledge, this research was the first in which drying kinetics of medlar fruit leather were studied with thin layer models and both the bioaccessibility of phenolic content and antioxidants were reported via an in vitro digestion model. The first aim of this research was to produce a natural high quality medlar pestil and reveal the best drying parameters via mathematical modelling of drying kinetics. The second aim was to determine the effects of different drying processes on total phenolic content and antioxidant capacity and monitore their changes in the in vitro gastrointestinal track.

Materials and methods

Materials

Mature medlar fruits were harvested on January 15, 2018 in Bursa Turkey and left to storage at 4 ± °C for a week to get ripened and softened. Width and length of the fruits were measured respectively as 3.10 ± 0.23 and 3.58 ± 0.19 cm with a vernier caliper.

Preparation of pestil

Medlar fruits were washed, peeled, pitted and homogenized with a domestic blender (Beko, Turkey). Soluble solid content (°Brix) of the puree was 23 °Bx. Freshly prepared puree (51%), distilled water (37%) and sucrose (10%) were boiled in an open kettle at constant stirring then wheat starch (1.6%) and ascorbic acid (0.4%) were added to the paste to obtain 42 °Bx. Boiling was carried out for 15 min on average. Final brix of the mixture was arranged according to similar studies like 40–50 °Bx and 50–55 °Bx in pomegranate (Tontul and Topuz, 2017) and mango fruit leathers (Pushpa et al., 2006) respectively. Afterwards, cooked medlar mixture (approximately 100 g) was evenly spread on a 10 × 10 cm square plastic mold stated on the greaseproof paper with a thickness of 4 mm and dried under several conditions in hot air, microwave and vacuum drying techniques. After the each treatment, pestil samples were pulled from the surface, packaged with a low density polyethylene film and stored at room temperature until analyzed.

Drying procedure

Three different methods (hot air, microwave and vacuum drying) were applied to the pestils and the drying experiments were carried out in triplicate. Hot air drying treatments were performed with a cabinet type laboratory dryer (Yucebas Machine Analytical Equipment Industry Y35, Izmir, Turkey) with the technical features of 220 V, 50–60 Hz, 200 W. The temperature and relative humidity in the dryer was measured by temperature sensor (± 2 °C) and relative humidity sensor (± 2%). Drying was performed at temperatures of 60 and 70 °C and a constant 20% relative humidity. 50 g of pestil (10 × 10 cm square) with a thickness of 4 mm was placed on the greaseproof paper as a thin layer. The temperatures were applied in accordance with previous reports (Jaturonglumlert and Kiatsiriroat, 2010; Pushpa et al., 2006; Tontul and Topuz, 2017). All along drying, the samples were removed at intervals and weighed ahead being returned to the dryer. Pestil samples were weighed at 15 min intervals for 3 h and the loss of moisture was determined by weighing the plate using a digital balance (Mettler Toledo, MS3002S) measuring to the accuracy of 0.01 g. Drying experiments were completed between 115 and 175 min depending on the temperature.

Microwave drying experiments were conducted in a domestic microwave oven (Bosch, HMT72G420, Munich, Germany) with the technical features of 230 V–50 Hz and maximum output of 800 W. The dimensions of the microwave cavity were 520 × 479 × 341 cm in size and it was consisted of a rotating glass plate of 315 mm diameter

at the base of the oven. Drying treatments were performed at 90 and 180 W microwave power levels. 50 g of pestil samples stated on greaseproof paper were put on a rotating glass plate in the microwave oven. Drying was applied between 16 and 60 min depending on the microwave power level. During drying, the rotating glass plate was removed from the microwave oven at 5 and 1 min intervals respectively at 90 and 180 W and weighed using a digital balance (Mettler Toledo, MS3002S) measuring to accuracy of 0.01 g.

The vacuum drying experiments were carried out in a vacuum dryer (Memmert VO400, Germany, 49 L volume) at 60 and 70 °C; 200 and 300 mbar. The temperature and vacuum levels were determined according to the literature then 50 g of samples stated on the greaseproof paper were used (Paul and Das, 2018). The moisture loss of samples during drying was recorded at 15 min intervals for 4 h. Duration of drying process was recorded between 85 and 230 min depending on the vacuum pressure.

Moisture analyzer (Sartorius MA150, Germany) was used for the determination of moisture content of pestils. Drying experiments were all continued until the moisture content decreased to almost 0.08 g water/g dry base (initial moisture 1.49 g water/g dry base) and during drying treatments all of the samples were weighed for a maximum duration of 10 s.

Mathematical modelling of drying curve

Five thin-layer mathematical drying models were utilized to choose the best model for portraying the drying curve of pestils. This models name and references were given respectively as Page MR = exp(−ktn) (Sarsavadiva et al., 1999), Modified Page MR = exp [(−kt)n] (Overhults et al., 1973), Logarithmic MR = a exp(−kt) + c (Arslan and Ozcan, 2010), Lewis MR = exp(−kt) (Doymaz, 2006) and Handerson and Pabis MR = a exp(−kt) (Westerman et al., 1973).

The moisture ratio (MR) and drying rate of pestils throughout drying were calculated using the consequent equations:

$$MR = \frac{M - M_e}{M_i - M_e} \quad (1)$$

where MR is moisture ratio, M is the moisture content at a specific time (g water/g dry base), M_i corresponds to initial moisture content (g water/g dry base), M_e is the equilibrium moisture content (g water/g dry base).

$$Drying\ rate = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where M_t and M_{t+dt} are the moisture contents at t and t + dt (g water/g dry base) respectively, and t is drying time (min).

Root mean square error (RMSE) gives deviation between the estimated and experimental amounts for the models. The higher correlation coefficient (R^2), and reduced RMSE, Chi square (χ^2), were used to determine the goodness of fit model in the hot air, microwave and vacuum drying curves of pestil samples. These parameters can be determined with the subsequent equations:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{1/2} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - n} \quad (4)$$

where $MR_{exp,i}$ is the experimentally dimensionless moisture ratio for test i, $MR_{est,i}$ is the estimated dimensionless moisture ratio for test i, N is the number of observation and n is the number of constants in the model (Arslan and Ozcan, 2010).

Physicochemical analyses

Color analysis

Color of medlar pestils were determined by using a chroma meter (Konica Minolta CR-5, Bench-top, Japan). L*, a*, b* values were displayed as lightness, redness and yellowness. Chroma and hue angle were calculated from these values (Mujumdar, 2000).

Extraction of polyphenols

Initial (undigested) extracts of medlar pestils were prepared according to Vitali et al. (2009).

In vitro bioaccessibility

In vitro digestion of medlar pestils was performed according to Minekus et al. (2014). Samples were passed through a two-step gastrointestinal digestion stages as stomach and intestinal phases.

Total phenolic content

Total phenolic content was determined by Folin–Ciocalteu spectrophotometric method (Spanos and Wrolstad, 1990) and the results were expressed as mg gallic acid equivalents per 100 g dry weight ($R^2 = 0.9835$).

Antioxidant capacity

Antioxidant capacity of the medlar pestils was measured with 2-diphenyl-1-picrylhydrazyl (DPPH) (Katalinic et al., 2006) Copper(II) reducing antioxidant capacity (CUPRAC) (Apak et al., 2008) and Ferric Reducing Antioxidant Power (FRAP) (Benzie and Strain, 1996) methods. Trolox was used as the calibration of the standard curves respectively as $R^2 = 0.9929$, $R^2 = 0.9987$, $R^2 = 0.9993$. The results were given as µmol Trolox equivalent (TE) per g dry weight in all assays.

Sensorial analysis

Sensorial properties like color, appearance, taste, chewiness and overall acceptability were analyzed. A 9-point hedonic scale varying from "like extremely (9)" to "dislike extremely (1)" was used for the evaluation of the samples (Lim, 2011).

Statistical analysis

JMP software package version 8.0 (SAS Institute Inc. NC, 27513) was used for statistical evaluation. When significant differences were observed ($p < 0.05$), the least significant difference (LSD) test was used to determine the differences among means in triplicate.

Results and discussion

Drying characteristics of medlar pestils

Moisture ratio of the pestil samples obtained by Page's equation as a function of drying time was shown in Fig. 1. The moisture ratio decreased considerably with increasing drying time as expected. Drying technique significantly affected total drying duration in order to obtain the final moisture content. Vacuum drying at 60 °C–300 mbar had the longest duration with 230 min while microwave of 180 W had the shortest one with 15 min. Microwave drying spared the time by causing fast dissipation of water (Arslan and Ozcan, 2010; Zheng et al., 2012). In hot air drying, the time required to reduce the moisture was found higher at 60 °C with 175 min than 70 °C with 115 min at a constant drying air with 20% relative humidity. Several authors reported that, increasing drying temperature speeds up the drying process, thus shortens the drying time such as in pomegranate (Tontul and Topuz, 2017) and rose hip leathers (Ruiz et al., 2014). Drying durations at 90 W and 180 W were recorded as 60 min and 15 min respectively (Fig. 1A). These results explained that drying duration at 180 W was 75% less than the samples dried at 90 W. Furthermore in vacuum drying, treatments at 60 °C (125 min for 200 mbar and 230 min for 300 mbar) resulted with longer durations than 70 °C (85 min for 200 mbar and 115 min for 300 mbar). In the light of these data, increment of the microwave power and temperature prompted an impressive decrease in the drying durations. In vacuum drying technique, drying time decreased as the vacuum increased (Fig. 2C). Furthermore, increase in both vacuum and temperature allowed decrease in the drying time by accelerating moisture migration from the center to the outside. Identical behaviour was reported at vacuum drying of potato slices (Song et al., 2009) and hot air drying of and apples (Vega-Gálvez et al., 2012).

The calculated drying rates of pestils were depicted in Fig. 2. Drying rates ranged from 0.01 [g water/g dry matter (min)] for experiments at 60 °C–200 mbar vacuum to 0.15 [g water/g dry matter (min)] for the experiments at a microwave power level of 180 W. The drying rate of pestils raised with increasing temperature and power for both in hot air and microwave drying. Besides, drying rate accelerated with the increasing vacuum pressure and temperature. In microwave drying, a constant-rate period was observed and constant rate varied from 0.6 to 1.4 (g water/g dry matter) for a microwave power level of 90 W. For the power of 180 W, a decrement was seen after a very short acceleration at the beginning. The rate of pestil drying with hot air and vacuum methods generally decreased, and the

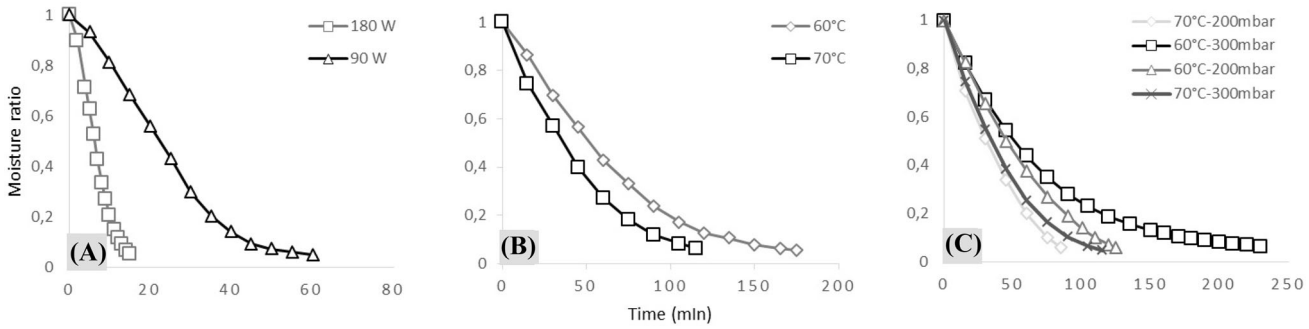

Fig. 1 Moisture ratio of pestil samples versus drying time at microwave (**A**), hot air drying (**B**) and vacuum drying (**C**) conditions

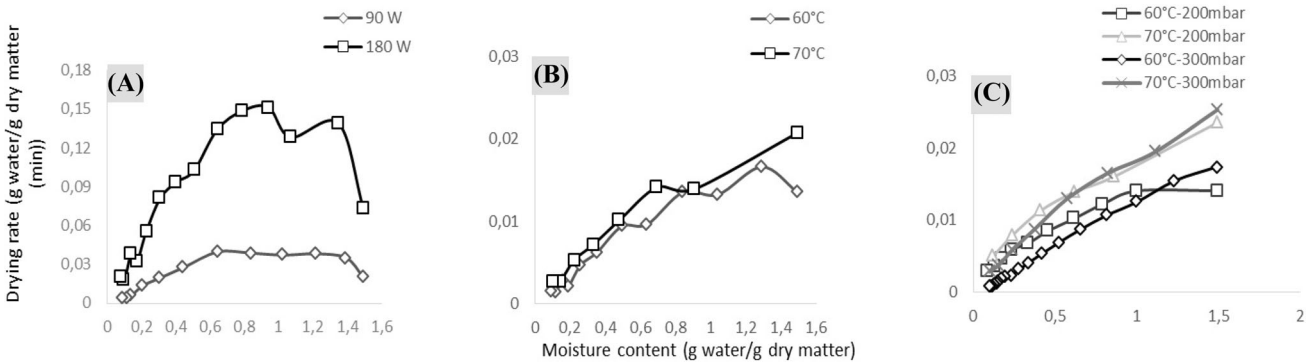

Fig. 2 Drying rate curves for pestils versus the moisture content at different microwave (**A**) hot air drying (**B**) and vacuum drying (**C**)

drying process took place in a falling rate period (Wang et al., 2007) (Fig. 2B, C). Our results were in agreement with the study of strawberry fruit leather (Lee and Hsieh, 2008).

Modelling of drying curves

The statistical results of dried pestils obtained from different models including drying model coefficients, R^2, RMSE and χ^2, were illustrated in Table 1. The R^2, RMSE and χ^2 values varied from 0.8820 to 0.9995, 0.001676 to 0.111869 and 0.000048 to 0.155179, respectively. The suitable drying methods with the highest value of R^2 and the lowest values of RMSE and χ^2 were determined from Page and Modified page models in all cases.

Color properties

General color of pestils was depicted as yellowish orange and L* was found statistically significant ($p < 0.05$) (Table 2). Non-dried mixture showed the highest L* and stated in the same group with 200 mbar vacuum treatments at 70 °C and 60 °C. When compared to non-dried mixture, L* value was significantly affected by different drying treatments ($p < 0.05$) and resulted with a 1.51–30.83 77% decrease. Additionally, L* of pestils were raised with increasing microwave power resulting with a lighter color. At the point when high powers were utilized, drying was performed in a shorter time so color was more substantially saved (Pushpa et al., 2006). Furthermore, pestils dried with hot air presented darker color as a result of the exposure to high temperature all along the time of drying.

The highest a* values were found to be significantly the same in vacuum drying (300 mbar) at 70 and 60 °C with 20.71 ± 0.17 and 20.38 ± 0.36 respectively. Compared to the fresh sample, a* increased with vacuum 300 mbar treatments at 60 and 70 °C whereas this value reduced in hot air (60 °C) and vacuum 60 °C–200 mbar treatments. b* value was significantly the highest in non-dried mixture (Table 2). While vacuum-70 °C–200 mbar treated pestils had the nearest yellow color compared to non-dried sample (30.49 ± 0.22), hot air-60 °C dried pestils were determined as the least yellow samples (16.11 ± 0.98). Microwave dried samples showed lighter and yellower color when compared to hot air, as a result of short drying period. Besides, in microwave drying, samples showed higher lightness and yellowness value with higher power, because of the lesser exposure to maillard and nonenzymatic browning reactions amid drying. The red and yellow color of pestils is ascribed to the nearness of carotenes. In addition to maillard reaction, the expansion of a value may be because of the decomposition of pigments (Maskan, 2001).

Chroma value, which was used to perceive the color intensity, was significantly ($p < 0.05$) the highest in non-dried sample. Vacuum 70 °C–200 mbar treatment showed the second highest result (35.82 ± 0.45) while the lowest value (24.48 ± 1.19) was determined from hot air-60 °C. In compliance with chroma, non-dried mixture resulted with the highest amount, and the second highest and the lowest values of hue angle were calculated from the same treatments (Table 2). Consequently, vacuum drying had the best color properties. This was associated with vacuum conditions, in which the damp material is dried under sub-atmospheric pressures, counteracted color damages and permitted to be in higher quality than conventional air process at atmospheric pressure (Krokida and Maroulis, 1999).

Effects of different drying methods on total polyphenolic content and antioxidant capacity in the in vitro gastrointestinal tract

The initial total phenolic content of the mixture before drying was determined as being the highest with 396.62 mg GAE/100 g dw ($p < 0.05$). Phenolic content after drying was affected by the method ($p < 0.05$) with a decrease ranging from 50.59% (hot air-60 °C) to 60.65%

Table 1 Statistical results obtained from the modeling of medlar pestils

Model name	Applications	Model coefficients	R^2	RMSE	χ^2
Page	Hot air 60 °C	n = 1.2299, k = 0.0054	0.9918	0.002510	0.000968
	Hot air 70 °C	n = 1.1233, k = 0.0132	0.9970	0.003635	0.000152
	Vacuum 60 °C–200 mbar	n = 1.2667, k = 0.0058	0.9968	0.003588	0.000173
	Vacuum 70 °C–200 mbar	n = 1.2124, k = 0.0117	0.9887	0.007801	0.000596
	Vacuum 60 °C–300 mbar	n = 0.793, k = 0.0215	0.9953	0.035260	0.026401
	Vacuum 70 °C–300 mbar	n = 1.1606, k = 0.0120	0.9983	0.002785	0.000089
	Microwave-90 W	n = 1.5652, k = 0.0056	0.9967	0.004170	0.000267
	Microwave-180 W	n = 1.7027, k = 0.031	0.9995	0.001775	0.000054
Modified page	Hot air 60 °C	n = 1.2299, k = 0.0143	0.9981	0.002510	0.000096
	Hot air 70 °C	n = 1.1233, k = 0.0212	0.9970	0.003635	0.000152
	Vacuum 60 °C–200 mbar	n = 1.2667, k = 0.0171	0.9968	0.003588	0.000173
	Vacuum 70 °C–200 mbar	n = 1.2124, k = 0.0256	0.9887	0.007801	0.000596
	Vacuum 60 °C–300 mbar	n = 0.7930, k = 0.0079	0.9952	0.035260	0.026401
	Vacuum 70 °C–300 mbar	n = 1.1606, k = 0.0638	0.9983	0.081725	0.077285
	Microwave-90 W	n = 1.5652. k = 0.0364	0.9967	0.004170	0.000267
	Microwave-180 W	n = 1.6930, k = 0.1296	0.9994	0.001676	0.000048
Logarithmic	Hot air 60 °C	k = 0.0265, a = 1.4861	0.9541	0.045217	0.034554
	Hot air 70 °C	k = 0.0347, a = 1.2778	0.9581	0.040614	0.022268
	Vacuum 60 °C–200 mbar	k = 0.0321, a = 1.5084	0.8927	0.055795	0.047086
	Vacuum 70 °C–200 mbar	k = 0.0394, a = 1.213	0.9365	0.042717	0.022354
	Vacuum 60 °C–300 mbar	k = 0.0220, a = 1.3341	0.9662	0.024239	0.013257
	Vacuum 70 °C–300 mbar	k = 0.0355, a = 1.3150	0.9536	0.042756	0.024679
	Microwave-90 W	k = 0.0803, a = 1.7878	0.9303	0.071605	0.086652
	Microwave-180 W	k = 0.3085, a = 2.2436	0.8820	0.090909	0.155179
Lewis	Hot air 60 °C	k = 0.0165	0.9909	0.012723	0.002279
	Hot air 70 °C	k = 0.0233	0.9922	0.111869	0.001267
	Vacuum 60 °C–200 mbar	k = 0.0202	0.9643	0.017957	0.003901
	Vacuum 70 °C–200 mbar	k = 0.0297	0.9619	0.021268	0.003694
	Vacuum 60 °C–300 mbar	k = 0.0072	0.9858	0.041929	0.035259
	Vacuum 70 °C–300 mbar	k = 0.0251	0.9875	0.013446	0.001830
	Microwave-90 W	k = 0.0480	0.9528	0.030132	0.012787
	Microwave-180 W	k = 0.1730	0.9259	0.028986	0.013503
Henderson and Pabis	Hot air 60 °C	k = 0.0176, a = 1.1388	0.9958	0.011970	0.002201
	Hot air 70 °C	k = 0.0245, a = 1.1100	0.9957	0.013836	0.002215
	Vacuum 60 °C–200 mbar	k = 0.0220, a = 1.2462	0.9784	0.024603	0.008138
	Vacuum 70 °C–200 mbar	k = 0.0327, a = 1.2045	0.9732	0.032325	0.010240
	Vacuum 60 °C–300 mbar	k = 0.0059, a = 1.2278	0.9893	0.081752	0.141925
	Vacuum 70 °C–300 mbar	k = 0.0268, a = 1.1539	0.9932	0.018471	0.003948
	Microwave-90 W	k = 0.0555, a = 1.3710	0.9781	0.032637	0.016365
	Microwave-180 W	k = 0.2127, a = 1.5595	0.9691	0.039872	0.027515

RMSE root mean square error, R^2 correlation coefficient

(microwave-90 W) (Table 3). The lowering effect of drying on phenolics can be ascribed to the degradation and oxidation during heat treatment (Qu et al., 2010). Similar decrement was reported in blueberry and rose hip leathers (Chen and Martynenko, 2018; Ruiz et al., 2014). According to the results of total antioxidant capacity, a general decrement both in CUPRAC (0.31–57.34%), DPPH (53.39–57.32%) and FRAP (54.37–56.83%) assays was determined in undigested extracts. Microwave-180 W (125.77 ± 6.00) was found significantly ($p < 0.05$) higher

Table 2 Color values of medlar pestil samples

Drying processes	L*	a*	b*	Chroma	Hue angle
Non-dried mixture	49.52 ± 0.00[a]	18.52 ± 0.01[de]	34.14 ± 0.01[a]	38.84 ± 0.02[a]	61.52 ± 0.02[a]
Hot air-60 °C	34.25 ± 1.27[c]	18.42 ± 0.73[e]	16.11 ± 0.98[f]	24.48 ± 1.19[f]	41.15 ± 0.61[e]
Hot air-70 °C	35.36 ± 0.25[c]	19.34 ± 0.25[cd]	18.92 ± 0.27[f]	27.06 ± 0.36[e]	44.37 ± 0.20[d]
Microwave-90 W	35.51 ± 0.96[c]	18.94 ± 0.60[cde]	19.01 ± 0.51[f]	26.84 ± 0.47[e]	45.12 ± 1.35[d]
Microwave-180 W	42.03 ± 0.36[b]	19.61 ± 0.72[bc]	24.54 ± 0.78[g]	31.42 ± 1.06[d]	51.38 ± 0.15[c]
Vacuum 60 °C–200 mbar	48.28 ± 1.28[a]	18.27 ± 0.47[e]	28.87 ± 0.19[c]	34.12 ± 0.29[c]	57.76 ± 0.51[b]
Vacuum 70 °C–200 mbar	48.77 ± 0.63[a]	18.80 ± 0.49[cde]	30.49 ± 0.22[b]	35.82 ± 0.45[b]	58.34 ± 0.48[b]
Vacuum 60 °C–300 mbar	42.75 ± 0.44[b]	20.38 ± 0.36[ab]	26.07 ± 0.28[d]	33.10 ± 0.19[c]	51.98 ± 0.72[c]
Vacuum 70 °C–300 mbar	41.93 ± 0.05[b]	20.71 ± 0.17[a]	26.18 ± 0.16[d]	33.38 ± 0.21[c]	51.65 ± 0.19[c]

[a–g]Different letters in the same column display significant difference ($p < 0.05$)

than other samples in CUPRAC assay with the nearest result to non-dried mixture. DPPH analysis of the pestils were found statistically significant ($p < 0.05$). Microwave-90 W (6.87 ± 0.01), vacuum 70 °C 300 mbar (6.81 ± 0.07) and vacuum 60 °C 300 mbar (6.78 ± 0.01) revealed the highest results as well as showing no significant differences ($p > 0.05$). In FRAP analysis, microwave-90 W (23.19 ± 0.54) was significantly ($p < 0.05$) higher than those of the other samples with the lowest decrement (54.37%) compared to non-dried mixture.

Ruiz et al. (2014) reported trolox equivalent antioxidant capacity (TEAC) of hot-air dried rose hip leathers in average as 24 and 17 µmol TE/g dm (dry matter) respectively in 60 °C and 70 °C treatments. Additionally TEAC of rose hip leathers were presented as 33 and 21 µmol TE/g dry matter in vacuum drying at 60 °C and 70 °C. These results were in accordance with CUPRAC analysis being higher in hot air drying at 60 °C than 70 °C (Table 3) and the mean interval of current data. Chen and Martynenko (2018) reported DPPH results of dried blueberry leather between 59.19 and 71.92 µmol TE/g dm in freeze and forced-air dried samples.

The effect of in vitro digestion on total phenolic content and total antioxidant capacity of the pestils was presented in Table 3. During stomach phase, changes in phenolics of all the samples were statistically significant ($p < 0.05$). Generally for all the treatments except for microwave (90 W and 180 W) and vacuum 200 mbar (60 °C and 70 °C), results were decreased in stomach phase compared to initial values. Additionally a declining trend was observed after simulated gastric digestion in CUPRAC, DPPH and FRAP ($p < 0.05$) in accordance with Tomas et al. (2018) both in these three assays. Remarkably, total phenolic content from intestinal phase was higher than stomach phase and initial extracts in all of the samples. Intestinal phase of all the samples resulted with an increment in total phenolic content (49.42–97.15%) FRAP (65.15–85.24%) and DPPH (10.19–18.71%) compared to undigested extracts. In agreement with current data, greater total phenolic content from intestinal phase than stomach phase and initial extracts in tomato sauce using the same in vitro digestion method was reported (Tomas et al., 2018). Moreover, Oliveira and Pintado (2015) determined an increase in antioxidant capacity of strawberry and peach yoghurt in the intestinal phase compared to non-digested extracts, which is consistent with current DPPH analysis. This study supported that the bioaccessible phenolics increased during intestinal digestion. This situation was explained previously that, by the entrance in the colon phenolics could be catabolized by human gut microbiata into low molecular compounds allowing them to be absorbed throughly (González-Sarrías et al., 2017). In general, current data showed that applied drying methods and treatments (microwave: 90 W and 180 W, hot air: 60 and 70 °C, vacuum: 60 and 70 °C with 200 and 300 mbar) may have an influence on the release of total phenols and antioxidant capacity, therefore, on the bioaccessible fraction. Moreover, both undigested (initial) and in vitro digested pestil samples measured by CUPRAC and FRAP methods were found to be higher than DPPH assay. Results of CUPRAC could be attributed to the properties of the reagent being selective and stable as well as the Cu(I) ion emerging as a product of the CUPRAC cannot then act as a prooxidant (Apak et al., 2008). Besides, lower results of DPPH can be explained with the method's characteristics, which targets sterically hindered radicals than biologically active short-lived ones (Schaich et al., 2015).

Sensorial properties

Pestils dried at 70 °C with a vacuum of 200 mbar had the highest color scores (Table 4). 60 °C–200 mbar resulted with the highest values of appearance and taste criterias. While the chewiness of pestils were found the highest in

Table 3 Changes in the total phenolic content and total antioxidant capacity of pestil samples during simulated in vitro digestion

Analysis	Initial	Stomach phase	Intestinal phase
TPC			
Non-dried mixture	396.62 ± 3.84^{a}	366.83 ± 4.53^{a}	672.79 ± 21.03^{a}
Hot air-60 °C	195.94 ± 1.07^{b}	168.38 ± 4.56^{d}	292.78 ± 7.50^{d}
Hot air-70 °C	186.73 ± 7.61^{bc}	172.81 ± 6.16^{cd}	318.35 ± 7.98^{bc}
Microwave-90 W	156.06 ± 9.31^{g}	167.26 ± 6.15^{d}	307.68 ± 5.25^{bcd}
Microwave-180 W	159.25 ± 2.07^{fg}	174.96 ± 4.78^{cd}	309.84 ± 4.43^{bc}
Vacuum 60 °C–200 mbar	168.11 ± 2.93^{ef}	180.30 ± 6.64^{bc}	293.27 ± 7.49^{d}
Vacuum 70 °C–200 mbar	181.37 ± 9.42^{cf}	188.23 ± 6.48^{b}	304.46 ± 7.26^{cd}
Vacuum 60 °C–300 mbar	187.74 ± 7.39^{bc}	166.19 ± 8.30^{d}	305.15 ± 7.69^{cd}
Vacuum 70 °C–300 mbar	173.86 ± 1.27^{de}	170.92 ± 5.68^{cd}	323.52 ± 3.00^{b}
CUPRAC			
Non-dried mixture	126.16 ± 24.11^{a}	46.55 ± 9.99^{f}	57.73 ± 8.34^{c}
Hot air-60 °C	96.10 ± 9.72^{b}	93.41 ± 5.24^{ab}	64.85 ± 7.18^{c}
Hot air-70 °C	70.22 ± 8.58^{b}	89.42±5.83^{bc}	95.55 ± 4.84^{a}
Microwave-90 W	69.14 ± 8.13^{c}	48.80 ± 5.65^{ef}	35.50 ± 3.69^{d}
Microwave-180 W	125.77 ± 6.00^{a}	101.93 ± 6.20^{a}	82.28 ± 9.60^{b}
Vacuum 60 °C–200 mbar	98.19 ± 7.40^{b}	62.77 ± 6.42^{d}	84.19 ± 8.38^{ab}
Vacuum 70 °C–200 mbar	98.40 ± 8.30^{b}	80.96 ± 6.87^{c}	69.28 ± 9.98^{c}
Vacuum 60 °C–300 mbar	55.49 ± 9.19^{c}	37.48 ± 7.55^{f}	25.80 ± 6.68^{d}
Vacuum 70 °C–300 mbar	53.81 ± 5.94^{c}	60.59 ± 6.36^{de}	33.23 ± 3.75^{d}
DPPH			
Non-dried mixture	14.74 ± 0.03^{a}	12.95 ± 0.11^{a}	15.47 ± 0.23^{a}
Hot air-60 °C	6.51 ± 0.12^{d}	5.82 ± 0.10^{c}	7.43 ± 0.12^{bcde}
Hot air-70 °C	6.67 ± 0.07^{c}	5.75 ± 0.06^{c}	7.35 ± 0.15^{cde}
Microwave-90 W	6.87 ± 0.01^{b}	5.88 ± 0.11^{bc}	7.76 ± 0.43^{b}
Microwave-180 W	6.29 ± 0.01^{e}	5.86 ± 0.13^{bc}	7.27 ± 0.18^{de}
Vacuum 60 °C–200 mbar	6.30 ± 0.06^{e}	5.55 ± 0.02^{d}	7.18 ± 0.09^{e}
Vacuum 70 °C–200 mbar	6.47 ± 0.01^{d}	6.04 ± 0.09^{b}	7.68 ± 0.15^{bc}
Vacuum 60 °C–300 mbar	6.78 ± 0.01^{b}	5.91 ± 0.20^{bc}	7.56 ± 0.18^{bcd}
Vacuum 70 °C–300 mbar	6.81 ± 0.07^{b}	5.85 ± 0.09^{bc}	7.51 ± 0.09^{bcde}
FRAP			
Non-dried mixture	50.83 ± 0.40^{a}	46.00 ± 0.65^{a}	80.41 ± 0.85^{a}
Hot air-60 °C	22.93 ± 0.22^{bc}	20.25 ± 0.04^{b}	39.39 ± 0.52^{cde}
Hot air-70 °C	22.79 ± 0.50^{bcd}	20.18 ± 0.57^{b}	39.94 ± 1.13^{bcd}
Microwave-90 W	23.19 ± 0.54^{b}	20.44 ± 0.26^{b}	38.30 ± 0.18^{e}
Microwave-180 W	22.29 ± 0.46^{cd}	20.92 ± 0.28^{b}	41.29 ± 0.92^{b}
Vacuum 60 °C–200 mbar	21.94 ± 0.62^{d}	20.14 ± 0.40^{b}	39.23 ± 1.49^{de}
Vacuum 70 °C–200 mbar	22.31 ± 0.28^{bcd}	20.92 ± 0.48^{b}	40.71 ± 0.72^{bc}
Vacuum 60 °C–300 mbar	22.92 ± 0.85^{bc}	19.95 ± 0.47^{b}	39.76 ± 0.35^{cd}
Vacuum 70 °C–300 mbar	22.94 ± 0.45^{bc}	20.30 ± 0.29^{b}	39.41 ± 0.19^{cde}

TPC (total phenolic content) and total antioxidant capacity (CUPRAC, DPPH, FRAP) is expressed as mg of GAE (gallic acid equivalent) per 100 g dw and μmol of TE (Trolox equivalent) per g dw respectively

Different letters in the same column display significant difference ($p < 0.05$)

hot air-60 °C, the second highest scores were obtained from vacuum (200 mbar) treatments at 60 °C and 70 °C. Similarly, overall acceptances of pestils were found as the best in vacuum (200 mbar) treatments at 60 °C and 70 °C. Additionally, drying at microwave with a power of 180 W had the lowest scores of all the criterias and the increased microwave power resulted with lower sensorial scores (Pushpa et al., 2006). The results of sensorial analysis showed that, although microwave-180 W had the lowest

Table 4 Sensorial properties of medlar pestils

Drying processes	Color	Appearance	Taste	Chewiness	Overall acceptability
Hot air-60 °C	6.50 ± 1.76^{b}	7.50 ± 1.22^{a}	7.83 ± 1.47^{a}	8.33 ± 0.51^{a}	7.66 ± 1.21^{a}
Hot air-70 °C	7.66 ± 0.51^{ab}	7.33 ± 0.81^{a}	7.00 ± 1.54^{ab}	7.66 ± 0.51^{abc}	7.50 ± 0.83^{a}
Microwave-90 W	4.00 ± 2.00^{c}	4.16 ± 1.83^{b}	6.16 ± 0.98^{bc}	7.00 ± 0.63^{cd}	5.66 ± 0.81^{b}
Microwave-180 W	3.66 ± 1.86^{c}	3.33 ± 2.16^{b}	4.66 ± 1.50^{c}	6.50 ± 0.83^{d}	5.16 ± 0.75^{b}
Vacuum 60 °C–200 mbar	8.00 ± 1.54^{ab}	8.66 ± 0.81^{a}	8.16 ± 0.98^{a}	8.16 ± 1.16^{ab}	8.16 ± 0.98^{a}
Vacuum 70 °C–200 mbar	8.50 ± 1.22^{a}	8.00 ± 1.54^{a}	8.00 ± 1.26^{a}	8.16 ± 1.16^{ab}	8.16 ± 1.32^{a}
Vacuum 60 °C–300 mbar	7.00 ± 0.89^{ab}	7.33 ± 0.81^{a}	7.00 ± 1.26^{ab}	7.33 ± 0.81^{bcd}	7.50 ± 0.54^{a}
Vacuum 70 °C–300 mbar	6.66 ± 1.03^{b}	7.33 ± 0.81^{a}	7.50 ± 1.51^{ab}	7.66 ± 0.81^{abc}	7.66 ± 1.03^{a}

[a–d]Different letters in the same column display significant difference ($p < 0.05$)

scores, all of the samples resulted in acceptable properties in the light of "overall acceptability".

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Compliance with ethical standards

Conflict of interest The author declare no conflict of interest.

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