Effect of a physical pre-treatment on drying kinetics and phenolic compounds in goji berries (*Lycium barbarum* L.)

Paola Russo[a], Giuseppina Adiletta[*b], Marisa Di Matteo[b], Luciano Cinquanta[c]

[b] *Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 84084 Fisciano (SA), Italy.*

[a] *Department of Chemical Engineering Materials Environment, University of Rome ''La Sapienza'', Via Eudossiana 18, 00184 Roma, Italy*

[c] *Department of Agricultural, Food and Forest Sciences, University of Palermo, Viale delle Scienze 4, 90128 Palermo, Italy*

Corresponding author. Tel.: +39 089964334 E-mail: gadiletta@unisa.it

Abstract

This work investigated the effect of a physical pretreatment on the Goji properties (drying kinetics, phenols) after drying. The pretreatment is based on the peel abrasion for the removal of the wax outer peel layer, which creates a barrier to the movement of moisture across the membrane. The drying kinetics were modeled by a Fick's diffusion model in cylindrical coordinates. Model results showed the pretreatment is able to increase the effective diffusion coefficient of 2-3 times with respect to untreated gojis by decreasing the resistance to the moisture transport.

Moreover the shorter exposure time to high temperatures and to oxygen better preserve the phenolic content of the fruits, especially at 50 and 60 C.

Keywords

goji berry, drying, pretreatment, phenols, mathematical model

1. INTRODUCTION

Goji berries, also known as wolfberries, are orange-red ovoid fruits of Lycium barbarum or L. chinense and belong to the solanaceae family (Kosin´ska-Cagnazzo et al., 2017a). These fruits have long been used in traditional Chinese medicine as anti-hypertension and anti-fatigue agents; moreover, they are believed to protect hepatic function and to be an effective remedy for the treatment of eye problems, skin rashes and diabetes (Kosin´ska-Cagnazzo et al., 2017b).

Since 2005, goji consumption have increased rapidly because these berries are viewed as functional food (Potterat, 2010; Rosa et al., 2017), or as an 'exotic superfood' by nutritionists (Rosa et al., 2017; Hummer et al., 2012). Through specialized health product stores, L. barbarum has entered the health food market with a total export of US$ 120 million from China (Donno et al., 2016)

Researchers, consumers and food companies are taking more of an interest in goji berries because they are rich antioxidant components such as carotenoids and polyphenols, (Ignat et al., 2011), recognized as beneficial to prevent and treat several diseases (Szajdek & Borowska, 2008). In goji berries, the main phenols are phenolic acids and flavonoids (Szajdek & Borowska, 2008).

In recent years the cultivation of goji berries in Europe was due to the growing interest of the consumers for these berries, as well as alarming reports on the content of pesticides in fruits originating from China (Kosin´ska-Cagnazzo et al., 2017b; Hacker et al., 2010). The cultivation of goji berries in Romania (Mocan et al., 2014), Bulgaria (Dzhugalov et al., 2015), Spain and Italy (Donno et al. 2016; Fratianni et al., 2018) is reported in literature.

Since fresh goji berries have short shelf life, owing essentially to fungal decay (Mocan et al., 2014), they are mainly present on the European market as dry berries, especially originating from Ningxia province in China (Kosin´ska-Cagnazzo et al., 2017a). Dried berries are consumed as a snack or can be used for the production of functional food: in confectionary goods or in bakery products and soups (Hummer at al., 2012; Gao et al., 2008). To reduce water activity of fresh berries and prolong their shelf life, the most common preservation is the drying (Brasiello et al, 2011).

Traditionally, goji berries are harvested in late summer to autumn. After this operation, firstly, the berries are dried without sunlight until the skin shrinks, and then they are dried in the sun until the outer skin becomes hard but the pulp is still soft (Adiletta et al., 2015).

Goji drying is difficult because this berry contains a wax outer peel layer, which creates a barrier to the movement of moisture across the membrane. For this reason, the long exposure to high temperatures may reduce the nutritional value of the fruit (Adiletta et al., 2015). Different dipping techniques were applied to overcome this problem.

Wu et al. (2015) investigated the drying characteristics and quality of Lycium barbarum with a pre-treatment using 3% alkali. Li et al. (2014) evaluated the effect of dipping with sodium carbonate and sodium sulfite solution on the content of total flavonoid in sun-dried, hot-air-dried and freeze-dried goji. However, the chemical additive residue in the samples gives rise to food safety problems. Beside chemical pretreatment, some physical pre-treatments have also been developed for grapes (Adiletta et al., 2016) and plums (Cinquanta et al., 2002) to reduce drying time and preserve the quality of final products. In a previous paper, the effect of a physical pre-treatment on colour and carotenoids changes in dried goji, were studied (Fratianni et al., 2018).

The aim of this work is to study the effect of a peel abrasion, to remove the waxy layer from the fruit before drying, on drying kinetics at different temperatures and on phenolic compounds of dried goji berry (Lycium barbarum L.).

2. MATERIALS AND METHODS

2.1 Raw material

Italian fresh organic goji berries (Lycium Barbarum L.) were kindly provided by South Italy farmers joined in the "LYKION" organization. In order to use uniform samples, goji berries with the same size (length h=14.85 $\pm$ 0.56 mm and average radius r=8.07 $\pm$ 1.10 and weight 0.91 $\pm$ 0.07 g) and without surface damage were chosen. The initial water content of samples was: 3.36 $\pm$ 0.10 g /g (db), measured according to AOAC standards (1990).

Two different types of samples were compared in this study: untreated goji (UTR) and abraded goji (TR). Before drying, some of the samples (TR) were subjected to a physical abrasive pretreatment. A motorized rotating drum was used for the goji peel abrasion, as reported elsewhere (Adiletta et al., 2015).

2.2 Drying experiments

In a convective dryer (B80 FCV/E6L3, Termaks, Norway) the drying experiments on UTR and TR samples were carried out at 50, 60 and 70 °C with an air velocity at 2.1 m/s.

The weight of nine samples was continuously recorded using a weight sensor (Phidgets INC., Canada): a transducer that converts mechanical force into electrical signals. Moisture ratio (M_t/M_0) was calculated as the ratio between the actual (M_t) and the initial (M_0) moisture content on dry basis. Goji samples were dried up to a final moisture value of 0.03 $\pm$ 0.02 g /g (db) using different air temperatures (50, 60 and 70 °C). All drying experiments were carried out in triplicate.

2.3 Mathematical model

A diffusion model is developed to describe the drying process of goji berries. A three-dimensional model of mass transfer that assumes fruits as an isotropic, homogenous and continuous solid phase was adopted. In this model, an isothermal condition was considered since in drying conditions here analyzed, the characteristic time of thermal transient was far less than that of mass transport.

Goji berries shape can be approximated to that of a cylinder, so that the equation that describes the mass diffusion phenomenon (i.e. water during drying) in cylindrical coordinates was adopted:

$$\frac{\partial M}{\partial t} = \frac{1}{r}\left\{ \frac{\partial}{\partial r}\left(rD_{eff}\frac{\partial M}{\partial r}\right) + \frac{\partial}{\partial z}\left(rD_{eff}\frac{\partial M}{\partial z}\right)\right\}$$

(1)

102   where D_{eff} is the diffusion coefficient (m²/s) and M is the moisture content on a dry basis (kg/kg$_{d.b.}$).

103   The initial condition is:

104    $$M(r,z,t=0)=M_0 \text{ for } 0<r<R_0, \ 0<z<h \tag{2}$$

105   The boundary conditions are:

106    $$\frac{\partial M(r=0,z,t)}{\partial r}=\frac{\partial M(r,z=0,t)}{\partial z}=0 \text{ for } t>0 \tag{3}$$

107   and at r=R₀, z=h and for t>0

108    $$-D_{eff}\rho_s\frac{\partial M}{\partial r}=h_m\rho_s(M_{sur}-M_e) \tag{4}$$

109    $$-D_{eff}\rho_s\frac{\partial M}{\partial z}=h_m\rho_s(M_{sur}-M_e) \tag{5}$$

110   ρ_s is the solid density (kg/m³) and it is kept constant; h_m is the moisture transfer coefficient (m/s);

111   M_{sur} is the moisture at the surface of the cylinder and M_e is the equilibrium moisture content

112   (kg/kg$_{d.b.}$) (i.e *the moisture content necessary to maintain equilibrium with the surrounding*

113   *atmosphere*).

114   Introducing the following dimensionless variables:

115    $$\bar{r}=\frac{r}{R_0}, \ \bar{z}=\frac{z}{R_0} \text{ and } \bar{M}=\frac{M}{M_0} \ \ \bar{M}_e=\frac{M_e}{M_0} \tag{6}$$

116   the equation (1) becomes:

117    $$\frac{\partial\bar{M}}{\partial\tau}=\left(\frac{\partial^2\bar{M}}{\partial\bar{r}^2}\right)+\left(\frac{\partial^2\bar{M}}{\partial\bar{z}^2}\right) \tag{7}$$

118   where τ is the dimensionless time $\tau=\dfrac{t\cdot D_{eff}}{R_1^2}$

119   Furthermore, the initial and boundary conditions become:

$$\bar{M}(\bar{r}, \bar{z}, \tau = 0) = 1 \text{ for } 0 < \bar{r} < 1, \ 0 < \bar{z} < \frac{h}{R} \tag{8}$$

$$\frac{\partial \bar{M}(\bar{r} = 0, \bar{z}, \tau)}{\partial \bar{r}} = \frac{\partial \bar{M}(\bar{r}, \bar{z} = 0, \tau)}{\partial \bar{z}} = 0 \text{ for } \tau > 0 \tag{9}$$

and at $\bar{r} = 1$, $\bar{z} = \dfrac{z}{R}$, for $\tau > 0$

$$\frac{\partial \bar{M}}{\partial \bar{r}} = -Sh\left(\bar{M}_{sur} - \bar{M}_e\right) \tag{10}$$

$$\frac{\partial \bar{M}}{\partial \bar{z}} = -Sh\left(\bar{M}_{sur} - \bar{M}_e\right) \tag{11}$$

The convective mass transfer coefficient and the effective diffusion coefficient are correlated with the dimensionless Sherwood number:

$$Sh = \frac{h_m \cdot R_0}{D_{eff}} \tag{12}$$

where R_0 is the radius of the sample (m). It represents the ratio of the convective mass transfer to the rate of diffusive mass transport.

In order to determinate the optimum value of the D_{eff}, the coefficient of determination of the fit (R^2), the reduced χ-square of the fit (χ^2) and the root mean square error of the fit (RMSE) were used as targets.

The finite element method is applied to solve the non-linear partial differential equations (Eq. 7) subjected to the initial and boundary conditions (Eq. 8-11). Simulations were run adopting 4974 cells and 7877 nodes. The convergence criterion assumed at each node of the computational domain was $|\bar{M}_k - \bar{M}_{k-1}| \ll 10^{-8}$ (where k represents the k-th iteration).

2.4 Titrable Acidity, pH, Aw

The pH measurements were obtained at 20°C using a pH meter (Model 2001, Crison, Barcelona, Spain). Total titrable acidity (g of malic acid /100g db) was determined by an alkaline solution (0.1M sodium hydroxide) to the end point at pH 8.1 (AOAC, 1990). The water activity (Aw) was determined using a water activity meter (Testo 650, Testo Inc., USA) at 25 °C.

2.5 Phenolic compounds

The separation and identification of polyphenol compounds in goji extracts was performed by HPLC, (Agilent 1100 chromatograph, Santa Clara, USA) with a RP-Amide column (5 μm × 150 mm × 4.6

mm) (Phenomenex, Torrance, USA). The mobile phase was water-acetic acid (98.6:1.4 v/v) (solvent A) and acetonitrile-acetic acid (98.6:1.4 v/v) (solvent B) with a flow rate of 1.0 ml/min. The solvent gradient was as follows: 4% B keeping isocratic condition during 10 min, reaching 63% B at 37 min, 100% B at 39 min, 4% B after 55 min. was used. The sample injection volume was 20 µl and the wavelengths used for the quantification of the goji extracts with the diode detector were 280 and 350 nm. Prior to HPLC injection samples and mobile phases were filtered through a 0.45 µm Millipore filter. Each sample was analysed in triplicate.

2.6 Antioxidant activity

The free radical scavenging capability of the extracts was determined using the stable radical 2.2-diphenyl-1-picrylhydrazyl (DPPH) assay (Albanese et al., 2014; Adiletta et al., 2017). The extracts for analysis were those used previously for quantification of polyphenols.

Goji extracts in different concentrations were added to 6×10^{-5}M methanol solution of DPPH. The mixture was shaken vigorously and, after 30 min of incubation at room temperature in the dark., the absorbance of remaining DPPH was recorded at 517 nm by a Perkin–Elmer lambda-Bio 40 (PerkinElmer Inc., Waltham, MA, USA). The absorbance of DPPH without antioxidant (control sample) was used for baseline measurements.

The free radical scavenging activity (AA) was calculated using the following equation:

$$\% \text{ inhibition of DPPH} = \left[(A_{blank} - A_{sample})/A_{blank} \right] * 100 \tag{13}$$

where A_{blank} is the absorbance of the control at t = 0 min and A_{sample} is the absorbance of sample after 30 min. The free radical scavenging activity (AA) was expressed as the EC_{50} value, which was defined as the mg of the extract sample concentration necessary to inhibit the initial DPPH radical activity by 50% during a 30-min incubation. The lower the EC_{50}, the higher the antioxidant activity.

2.7 Statistical analysis

The means and standard deviations of experimental results were calculated from three replicates.

Statistical analyses were performed by one-way ANOVA ($P < 0.05$) followed by a Tukey test.

The tests were considered as significant with p values of less than 0.05

Principal component analysis (PCA) was applied to identify the principal components contributing to the majority of the variation within the main physicochemical properties of all goji samples. All analyses were performed using the SPSS software package, Version 20.0 (SPSS Inc., Chicago, IL, USA).

3 RESULTS AND DISCUSSION

3.1 Drying kinetics and mathematical model

The same water content (about 0.03 ± 0.02 g /g (db)) was obtained by the drying process at the following times: 45, 21 and 12 h at the air drying temperatures of 50, 60 and 70 °C, respectively, for the UTR samples. Corresponding values for the TR samples were 22, 15 and 5 h at the same ~~respective~~ temperatures.

Results of the model in cylindrical coordinates (equations 7-11) were compared with experimental data in terms of moisture ratio in figure 1 for the untreated samples, and in figure 2 for treated samples at the temperatures considered in this work (50-70°C).

Figure 1

Figure 2

The results showed that developed model in cylindrical coordinates is able to describe the experimental drying kinetics at 60 and 70 °C, but not those at 50 °C, especially for the untreated samples.

This behaviour is probably due to the fact that the model did not take into account the reduction of the volume of goji berries during drying. A better description of the experimental data could be obtained including the shrinkage effect on the drying kinetic in the model.

Table 1 reports the values of the D_{eff} estimated by the model and the corresponding values of fitting parameters.

Table 1

The value of the effective diffusion coefficient estimated by the model ranged from $0.75*10^{-8}$ to $4.20*10^{-8}$ m^2/s in the range of temperature 50-70 °C for untreated samples and from $2.50*10^{-8}$ to $1.20*10^{-8}$ m^2/s for TR samples. Values were significantly higher than those estimated by Xie et al. (2017). The effective moisture diffusivity can be related to ~~with~~ temperature by Arrhenius-type relationship:

$$D_{eff} = D_0 \, \exp\left(-\frac{E_a}{RT}\right)$$

where D_0 is the effective moisture diffusivity at 273.15K, E_a is the active energy, R is the universal gas constant with 8.314J/mol·K as its value, T is the drying temperature. The ~~values~~ value of activation energy found in this work was 57.7 KJ/mol for the untreated samples and 99.4 KJ/mol for the treated samples.

211 The activation energy of goji berries was within the range 12.70-110.00 kJ/mol, which was reported

212 for most agricultural materials (Xie et al., 2017). In drying, activation energy is the threshold energy,

213 or the energy barrier must be overcome to initiate mass diffusion from the wet material. Hence, a

214 material with lower E_a value, indicates that moisture diffusion coefficient is more susceptible to

215 temperature effect during drying.

216

3.2 Chemico- physical properties of fresh and dried goji berries

218 Some chemico- physical qualitative data for fresh, dried UTR and TR samples are in Table 2 ~~1~~. Fresh

219 Italian goji berries showed a titrable acidity (TA), as malic acid, equal to 1.30% and a pH value close

220 to 3.90.

221 After drying process at different temperatures, the pH values of samples did not change except for

222 UTR samples dried at 60 and 70°C. Furthermore, all dried samples showed TA values higher than

223 that of fresh one. The highest significantly different TA value was found for the UTR samples dried

224 at 70 °C (1.93g malic acid/100 g) compared to the other ones.

<center>**Table 2**</center>

226

3.3 Phenolic compounds and AA

228 A total of eight phenolic compounds were identified from the goji fruits tested, mainly catechins (379

229 mg/kg), belonging to flavonoid class, present in similar high concentrations in green tea and apple

230 (Gadkaria et al., 2014). Even though catechins are not essential to human nutrition, they help in

231 improving human health by preventing various diseases. Catechins decreased in all dried samples

232 (Fig. 3), since they are sensitive to oxidation by polyphenol oxidase enzyme, acid and heat. The

233 cinnamic acids, mostly present in coffee (Panusa et al., 2017), represented the second class of

234 phenolic compounds present in the analyzed goji fruits. They were detected, at decreasing

235 concentration as follow: ferulic, caffeic, chlorogenic and p-coumaric acids. The radical scavenging

236 activity on DPPH decreased in the order caffeic acid > ferulic acid > p-coumaric acid, while in an

237 ethanol−buffer solution of linoleic acid, ferulic acid was most effective among the tested phenolic

238 acids (Kikuzaki et al., 2002). The drying always caused a significant reduction in the content in

239 cinnamic acids of fresh fruit of goji. However, the abrasive pre-treatment better preserved the content

240 in caffeic and chlorogenic acids due to the lower exposure times to high temperatures and oxygen

241 compared to the reference samples (Tab. 3). Rutin is a glycoside of the flavonoid quercetin with

242 beneficial role in controlling various diseases, including the ones related to lipid metabolism

243 (Ravirajsinh et al., 2014); among flavonoids, rutin was reported as the most frequent compound in

244 goji (Mikulic-Petkovsek et al., 2012; Protti L., 2017). Its content in goji fruits always reduced

245 significantly after ~~goji~~ drying. Finally, low amounts of querectin and kaempferol were found in fruits
246 (Tab. 3).

247 In addition, increasing the drying temperature resulted in a decrease in the antioxidant activity (an
248 increment in terms of EC$_{50}$ value). In details, TR samples ~~dried at 50 and 60°C~~ always showed a low
249 EC$_{50}$ value respect to all untreated samples.

250

251 **3.4 Principal component analysis**

252 Some of the co-authors of this work investigated the effects of abrasive pre-treatment on carotenoids
253 and colour in dried goji used in this trial (Fratianni et al., 2018); therefore, we added such data to the
254 PCA to better evaluate the results obtained. Fresh gojis and TR samples dried at 50°C and at 60°C
255 were located on the positive side of the PC1 that explained 50.2% of the overall variation with
256 phenolic content attribute. The groups of phenols considered (catechins, cinnamic acids and rutin)
257 and the main carotenoid (zeaxanthin dipalmitate) were very close in the positive quadrant of PC1.
258 Color parameters, in particular a* (redness index) were at the PC2 boundary.

259 It is to underline that after drying, small but significant carotenoid losses (15–20%) were observed in
260 all samples [12]. On the biplot, EC50, which comprised both samples dried at 70°C, and TPC, which
261 included TR 50°C and TR 60°C samples, segregated in opposite directions, meaning these two factors
262 were negatively correlated.

263
264
265 **CONCLUSIONS**
266

267 The developed model in cylindrical coordinates was able to describe the experimental drying kinetics
268 especially at 60 and 70 °C and a better fitting was obtained for treated samples. Phenolic compounds
269 undergone significant reductions in fresh gojis following drying, however samples pre-treated by
270 abrasion showed high antioxidant activity. In fact, they better preserved phenols content, such as
271 caffeic and chlorogenic acids, due to the lower exposure times to high temperatures and oxygen
272 compared to the reference samples.

273 By the PCA, treated and untreated samples dried at 70°C were segregate in opposite directions,
274 respect to the samples treated at 50~~°C~~ and 60°C, that were on the positive side of the PC1 that
275 explained over 50%, of the overall variation in phenolic compounds.

276

277 **REFERENCES**

278 Kosin´ska-Cagnazzo, A., Bocquel, D., Marmillod, I., Andlauer, W., 2017a. Stability of goji bioactives
279 during extrusion cooking process. Food Chemistry 230, 250–256.
280
281 Kosin´ska-Cagnazzo, A., Webera, B., Chablaisb, R., Vouillamoz, J.F., Moln´ar, B., Crovadore, J.,
282 Lefort F., Andlauer W., 2017. Bioactive compound profile and antioxidant activity of fruits from six
283 goji cultivars cultivated in Switzerland. Journal of Berry Research 7(1), 43-59.
284
285 Potterat, O., 2010. Goji (*Lycium barbarum* and *L. chinense*): phytochemistry, pharmacology and
286 safety in the perspective of traditional uses and recent popularity. Planta Medica 76, 7–19.
287
288 Rosa, A., Maxia, A., Putzu, D., Atzeri, A., Era, B., Fais, A., Sanna, C., Piras A., 2017. Chemical
289 composition of *Lycium europaeum* fruit oil obtained by supercritical CO_2 extraction and evaluation
290 of its antioxidant activity, cytotoxicity and cell absorption. Food Chemistry 230, 82–90.
291
292 Hummer, K.E., Pomper, K.W., Postman, J., Graham, C.J., Stover, E., Mercure, E. W., ... Zee, F.
293 (2012). Emerging fruit crops. In M. L. Badenes & D. H. Byrne (Eds.), Fruit breeding, handbook of
294 plant breeding (pp. 97–147). New York: Springer.
295
296 Donno, D., Mellano, M.G., Raimondo, E., Cerutti, A.K., Prgomet, Z., Beccaro, G.L., 2016. Influence
297 of applied drying methods on phytochemical composition in fresh and dried goji fruits by HPLC
298 fingerprint. Eur Food Res Technol 242, 1961–1974.
299
300 Ignat, I., Volf, I., Popa, V.I., 2011. A critical review of methods for characterisation of polyphenolic
301 compounds in fruits and vegetables. Food Chem 126, 1821–1835.
302
303 Szajdek, A., Borowska, E.J., 2008. Bioactive Compounds and Health-Promoting Properties of Berry
304 Fruits: A Review. Plant Foods Hum Nutr 63, 147–156.
305
306 Hacker, K., Bauer, N., Schu¨le, E., Wieland, M., Scherbaum, E., 2010. Goji Berries – A Natural Fruit?
307 Pesticide Residues in Dried Goji Berries. Chem. Veterina¨runtersuchungsamt Stuttg.
308
309 Mocan, A., Vlase, L., Vodnar, D., Bischin, C., Hanganu, D., Gheldiu, A.M, et al., 2014. Polyphenolic
310 Content, Antioxidant and Antimicrobial Activities of *Lycium barbarum* L. and *Lycium chinense* Mill.
311 Leaves. Molecules 19(100), 56-73.

312

313 Dzhugalov, H., Lichev, V., Yordanov, A., Kaymakaov, P., Dimitrova, V., Kutoranov, G, et al., 2015.

314 First results of testing goji berry (*Lycium barbarum* L.) in Plovdiv region, Bulgaria. Sci Pap-Ser B

315 Hortic, 47-50.

316

317 Fratianni, A., Niro, S., Alam, M.D.R., Cinquanta, L., Di Matteo, M., Adiletta, G., Panfili, G., 2018.

318 Effect of a physical pre-treatment and drying on carotenoids of goji berries (*Lycium barbarum* L.)

319 LWT - Food Science and Technology 92, 318–323.

320

321 Gao, Z., Ali, Z., Khan, I.A., 2008. Glycerogalactolipids from the fruit of *Lycium barbarum*.

322 Phytochemistry 69, 2856–2861.

323

324 Brasiello, A., Crescitelli, S., Adiletta, G., Di Matteo, M., Albanese, D., 2011. Mathematical modeling

325 with shrinkage of an eggplant drying process, Chemical Engineering Transactions 24, 451-456.

326

327 Adiletta, G., Alam, Md R., Cinquanta, L., Russo, P., Albanese, D., Di Matteo, M., 2015. Effect of

328 abrasive pretreatment on hot dried goji berry. Chemical Engineering Transactions 44, 127–132.

329

330 Wu, Z., Li, W., Zhao, L., Shi, J., Liu, Q., 2015. Drying characteristics and product quality of *Lycium*

331 *barbarum* understages-varying temperatures drying process. Trans. Chin. Soc.Agric. Eng. 31 (11),

332 287–293.

333

334 Li, P.L., Liao, R.Y., Wang, X., Gong, Y., Liu, D.H., 2014. Effect of different drying method and wax

335 removers on total flavonoid from Lycium barbarum L. Food Technol. 39 (5), 79–83.

336

337 Adiletta, G., Russo, P., Senadeera, W., & Di Matteo, M. (2016). Drying characteristics and quality of

338 grape under physical pretreatment. Journal of Food Engineering 172, 9-18.

339

340 Cinquanta, L., Di Matteo, M., Esti, M., 2002. Physical pre-treatment of plums (*Prunus domestica*).

341 Part 2. Effect on the quality characteristics of different prune cultivars, Food Chemistry 79, 233-238.

342

343 AOAC (1990) Official methods of analysis, 16th edn. Association of Official Analytical Chemists,

344 Washington, DC

345

346 Zhang, Q., Chen, W., Zhao, J., Xi, W., 2016, Functional constituents and antioxidant activities of
347 eight Chinese native goji genotypes. Food Chemistry 200, 230–236

348

349 Adiletta, G., Petriccione, M., Liguori, L., Pizzolongo, F., Romano, R., Di Matteo, M., 2018. Study of
350 pomological traits and physico-chemical quality of pomegranate (*Punica granatum* L.) genotypes
351 grown in Italy. European Food Research and Technology 244, 1427–1438.

352

353 Albanese, D., Adiletta, G., D'Acunto, M., Cinquanta, L., Di Matteo, M., 2014. Tomato peel drying
354 and carotenoids stability of the extracts. International Journal of Food Science & Technology 49 (11),
355 2458-2463.
356
357 Adiletta, G., Liguori L., Albanese, D., Russo, P., Di Matteo, M., Crescitelli, A., 2017. Soft-Seeded
358 pomegranate (*Punica granatum* L.) varieties: preliminary characterization and quality changes of
359 minimally processed arils during storage. Food Bioprocess Tech 10, 1631–1641.

360

361 Zhao, J., Li, H., Xi, W., An, W., Niu, L., Cao, Y., Wang, H., Wang, Y., Yin, Y., 2015. Changes in
362 sugars and organic acids in wolfberry (*Lycium barbarum* L.) fruit during development and
363 maturation. Food Chemistry 173, 718–724.

364

365 Zheng, G.Q., Zheng, Z.Y., Xu, X., Hu, Z.H., 2010. Variation in fruit sugar composition of *Lycium*
366 *barbarum* L. and *Lycium chinense* Mill. of different regions and varieties. Biochemical Systematics
367 and Ecology 38, 275–284.

368

369 Carranza-Concha, J., Benlloch, M.M., Camacho, M., Martínez-Navarrete, N., 2012. Effects of drying
370 and pretreatment on the nutritional and functional quality of raisins. Food and Bioproducts Processing
371 90 (2), 243-248.

372

373 Gadkaria, P.V., Balaraman, M., 2015. Catechins: Sources, extraction and encapsulation: A review.
374 Food and Bioproducts processing 93, 122–138.

375

376 Kikuzaki, H., Hisamoto, M., Kanae Hirose, K., Akiyama, K., Hisaji Taniguchi H., 2002.
377 Antioxidant Properties of Ferulic Acid and Its Related Compounds. *Journal of Agriculture and Food*
378 *Chemistry*, 2002, 50 (7), 2161–2168.

379

380

381 Ravirajsinh, N.J., Ranjitsinh, V.D., 2014. Polyphenols in Chronic Diseases and their Mechanisms of
382 Action. Polyphenols in Human Health and Disease. Edited by: Ronald Ross Watson, Victor R. Preedy
383 and Sherma Zibadi.

384

385 Mikulic-Petkovsek, M., Slatnar, A., Stampar, F., Veberic, R., 2012. HPLC–MS^n identification and
386 quantification of flavonol glycosides in 28 wild and cultivated berry species. Food Chemistry 135
387 (4), 2138-2146.

388

389 Protti, M., Gualandi, I., Mandrioli, R., Zappoli, S., Tonelli, D., Mercolini, L., 2017. Analytical
390 profiling of selected antioxidants and total antioxidant capacity of goji (Lycium spp.) berries. J.
391 Pharm. Biomed. Anal. 143, 252-260.

392

393 Xie, L., Mujumdar, A.S., Fang, X.M., Wang, J., Dai, J.-W., Du, Z.-L., Xiao, H.-W., Liu, Y., Gao, Z.-
394 J., 2017. Food and Bioproducts Processing, 102, 320–331.

395

396 A. Panusa, R. Petrucci, R. Lavecchia, A. Zuorro, "UHPLC-PDA-ESI-TOF/MS metabolic profiling
397 and antioxidant capacity of arabica and robusta coffee silverskin: antioxidants vs phytotoxins", Food
398 Research International, 99, 155-165, 2017

399

400

401

402

403

404

405

406

407

408

409

410

411

412

Figure Captions

Figure 1. Experimental and predicted moisture ratio for untreated samples (UTR).

Figure 2. Experimental and predicted moisture ratio for treated samples (TR).

Figure 3. Principal phenolic acids in fresh and dried samples.

Figure 4. 2D-principal component analysis plot of the main physicochemical and nutritional characteristics in fresh and dried goji samples.

UR: moisture; **pH**: pH; **TA**: total titratable acidity; **TS**: total sugars; **L***: lightness; **a***: red index; **b***: yellow index; **TPC**: total phenols content; **Lut**: lutein; **Zeax**: zeaxantin; **EC50**: antioxidant activity; **Cinnamic ac**: cinnamic acids; **Rutin**: rutin; **Catec**: catechin.; **Fresh**: fresh sample; **UTR50**: untreated sample dried at 50°C; **UTR60**: untreated sample dried at 60°C; **UTR70**: untreated sample dried at 70°C; **TR50**: treated sample dried at 50°C; **TR60**: treated sample dried at 60°C; **TR70**: treated sample dried at 70°C.
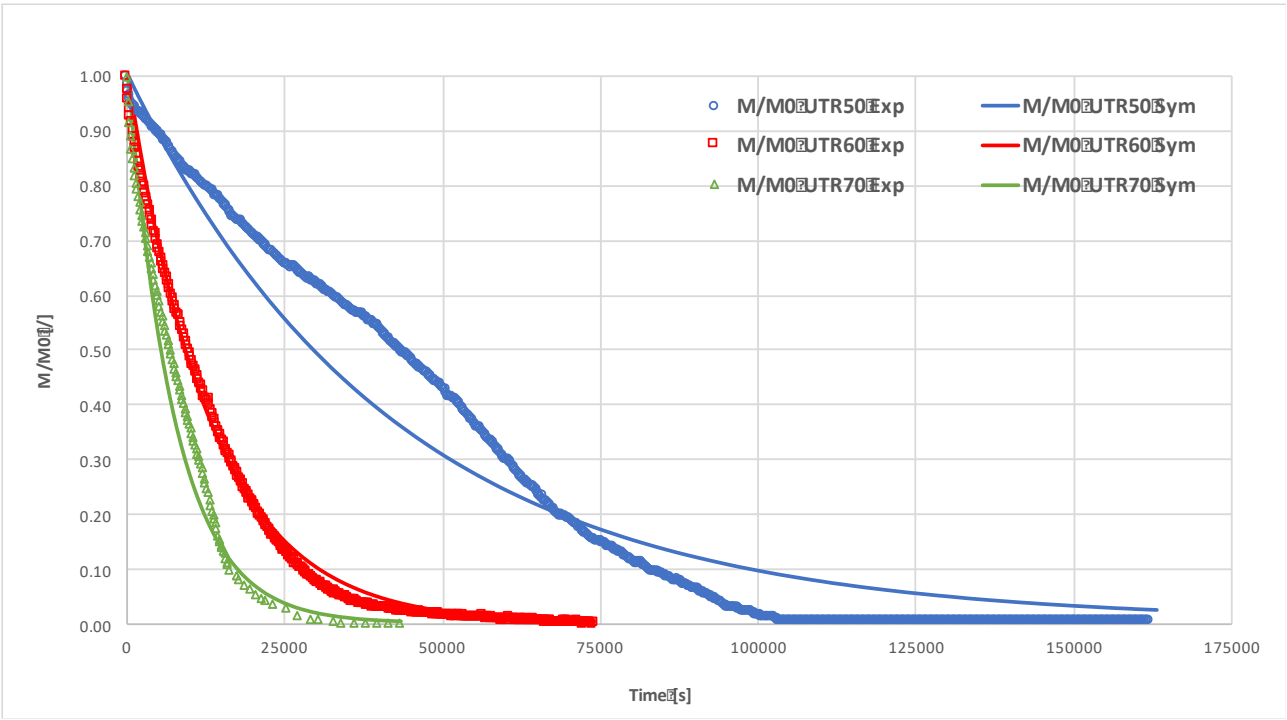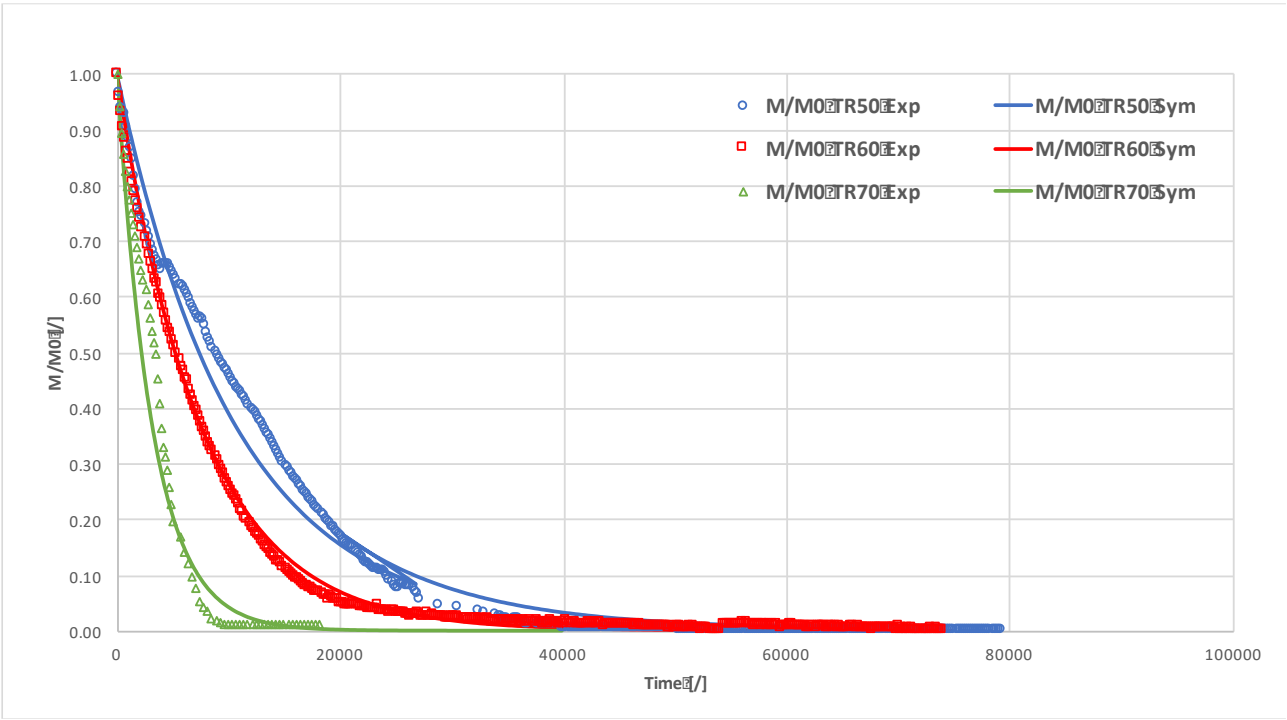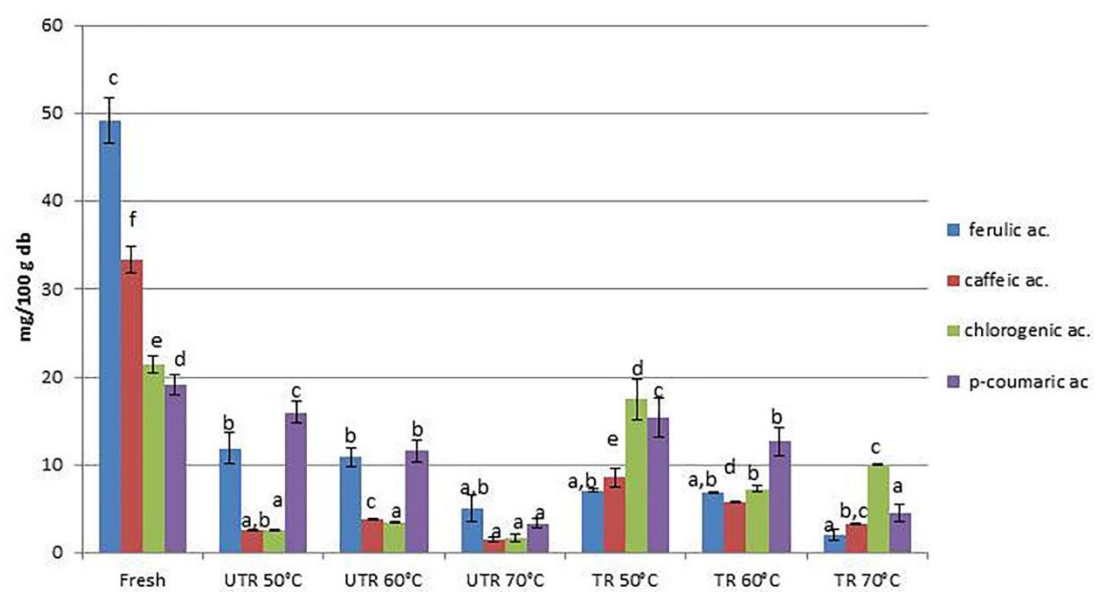
427
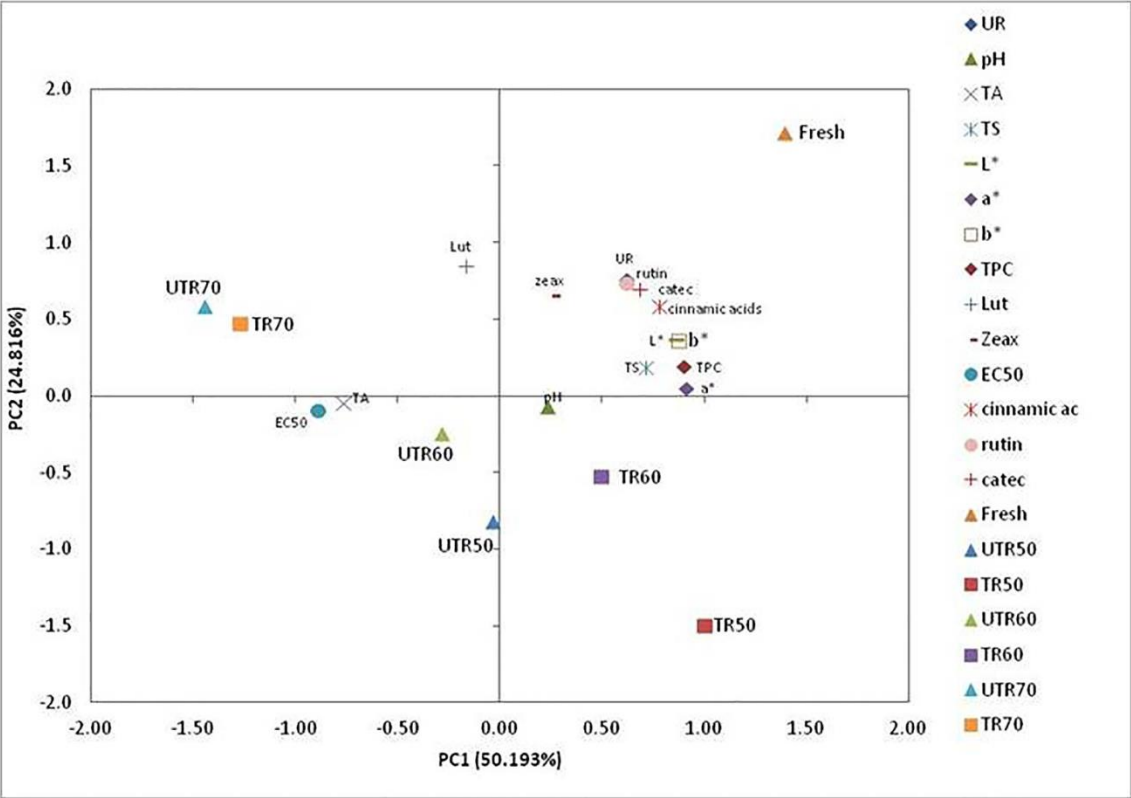
428

Figure 1

429

430

431

432

Figure 2

433

434

435

Figure 3

436

437

438

Figure 4

	Untreated		Treated	
T °C	D_{eff} (m²/s)	R^2	D_{eff} (m²/s)	R^2
50	$7.50*10^{-09}$	0.964	$2.50*10^{-08}$	0.977
60	$2.20*10^{-08}$	0.997	$4.20*10^{-08}$	0.998
70	$4.20*10^{-08}$	0.972	$1.20*10^{-07}$	0.971

Table 1 Values of the D_{eff} estimated by the model and the corresponding values of fitting parameters.

Samples	Moisture (db)	a_w	pH	Tritable Acidity (g malic acid /100g db)
Fresh	3.36 ± 0.10 [b]	0.92 ± 0.01 [d]	3.90 ± 0.01 [b]	1.30 ± 0.02 [a]
UTR 50°C	0.026 ± 0.002 [a]	0.42 ± 0.01 [c]	3.89 ± 0.01 [b]	1.47 ± 0.07 [b,c]
TR 50°C	0.026 ± 0.002 [a]	0.40 ± 0.02 [a,b,c]	3.96 ± 0.01 [b]	1.42 ± 0.01 [b]
UTR 60°C	0.025 ± 0.002 [a]	0.41 ± 0.01 [b,c]	3.78 ± 0.05 [a]	1.49 ± 0.07 [b,c]
TR 60°C	0.024 ± 0.002 [a]	0.38 ± 0.02 [a]	3.91 ± 0.02 [b]	1.52 ± 0.03 [b,c]
UTR 70°C	0.023 ± 0.002 [a]	0.39 ± 0.02 [a,b]	3.79 ± 0.05 [a]	1.93 ± 0.02 [d]
TR 70°C	0.025 ± 0.002 [a]	0.37 ± 0.02 [a]	3.95 ± 0.05 [b]	1.56 ± 0.04 [c]

495 Table 2 Physico-chemical properties of fresh and dried goji samples.

496 UTR: dried untreated berries, TR- Abr: dried abraded berries. Different letters in the same column are significantly

497 different according to Tukey test at $p<0.05$.

498

499

500

501

502

503

504

505

506

507

508

509

510

511

	Total phenols content (mg/g db)	Catechins (mg/100g db)	Rutin (mg/100g db)	Quercetin (mg/100g db)	Kaempferol (mg/100g db)	Antiox activity EC 50 (mg/ml)
Fresh	~~21.47 ±4.02[b]~~	379.15 ±24.37 [d]	29.07 ±1.43 [e]	0.66 ±0.03 d	0.70 ±0.04 c	28.59 ±0.15[a]
UTR 50°C	~~9.49 ±0.25[a]~~	46.65 ±0.73 [b,c]	4.27 ±0.47 [b,c]	0.13 ±0.01 c	0.22 ±0.06 b	85.01 ±0.35[e]
UTR 60°C	~~6.51 ±0.14[a]~~	20.46 ±1.94 [a]	3.14 ±0.58 [ab]	0.07 ±0.00 b	0.07 ±0.01 a	90.14 ±0.22[f]
UTR 70°C	~~5.55 ±0.04[a]~~	19.75 ±2.105 [a]	1.01 ±0.08 [a]	0.00 a	0.00 a	120.25 ±0.27[g]
TR 50°C	~~18.51 ±0.10[b]~~	72.51 ±1.77 [c]	6.15 ±0.6 [c,d]	0.12 ±0.02 c	0.03 ±0.00 a	32.10 ±0.20[b]
TR 60°C	~~16.97 ±1.91[b]~~	49.99 ±1.18 [b,c]	4.1 ±0.02 [b,c]	0.12 ±0.01 c	0.03 ±0.01 a	53.47 ±0.23[c]
TR 70°C	~~7.19 ±0.16[a]~~	38.14 ±1.61 [ab]	7.25 ±1.20 [d]	0.00 a	0.00 a	81.99 ±0.36[d]

512

Table 3 Total phenols content, catechin, rutin, quercetin, kaempferol and antioxidant activity in fresh and dried samples