Moisture Adsorption Characteristics of Lyophilized Algerian Arbutus unedo L. Fruit Powder

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Introduction

Strawberry tree (Arbutus unedo L.; Ericaceae family) is a typical Mediterranean wild tree, which is also cultivated in other regions of Eastern Europe [1]. Its fruit mature in autumn, at the same time as flowering [2]. It is fleshy and globular, from 1 to 1.7 cm in diameter. Its color changes from green to yellow, then to orange red and to bright red at maturity [3]. Berry fruits can be used for the fabrication of several industrialized products [4,5] since it is a rich numerous nutrinzents, especially Calcium, Phosphorus and Potassium [6]. Strawberry tree fruits are a good source of naturally occurring antioxidants [7,8]. Like other plants which are fitted with wonderful defense system assured by various biopharmaceuticals [9], the berries are also known to be used in the folk medicine as antiseptic, diuretic and laxative and against cardiovascular pathologies [10].

Establishing the relationship between equilibrium moisture content (EMC) and \( w_a \), also known as sorption isotherm (adsorption or desorption), is one of the useful measurements to the stability, microbiological and the physicochemical deterioration reactions [11] of a food’s, select formulations and storage conditions in new products and to improve drying process and equipment [12].

Water activity \( (w_a) \) is an important concept and essential parameter which describes the water availability and mobility in foods [13]. The sorption isotherms show the amount of adsorbed water as a function of steady state water activity \( (w_a) \), at constant temperature [14], it can also be used to investigate the structural features such as the specific surface area, the pore volume, the pore size distribution...

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and the crystallinity of food product [15]. Such data can be used for selecting the storage conditions and packaging systems [16] in order to prolong the shelf-life of food products. A number of equations allow the moisture content to be related to water activity [17,18].

Some studies have been carried out on the sorption isotherm of various herbs, aromatic/medicinal plants [19-21] and Wild fruits. Bag et al. [22] reported the moisture desorption isotherm of bacl (Aegle marmelos) pulp and adsorption isotherm of pulp powder while Alakali and Satimehin, [23] determined the adsorption equilibrium moisture content of Bambara groundnut (Vigna subterranea) powders. Alexandre et al. [24] showed the moisture adsorption isotherms of red Brazilian cherry powder. Vega-Galvez et al. and Alcântara et al. [25,26] determined the adsorption isotherms of Blueberry powder and Dry cashew apple, respectively.

The lyophilized powder (LP) from Algerian arbutus wild berries (Arbutus unedo L.) has been used previously in the elaboration of tablets [27,28] but for storing the raw material (LP) and keep its nutritional quality causes a problem. Consequently the study of the moisture sorption characteristics of LP under various environmental conditions is imperative. There was no research report on the moisture sorption isotherms of arbutus berry powder; we sum interested to establish the relationship between the equilibrium moisture content and water activity of LP powder at three different temperatures; (20, 30 and 40°C), to find the most and to evaluate the suitability of various models for fitting the isotherms.

Materials and Methods

Fruit and fruit powder

Fully ripe berries were randomly picked at various trees in the Kabylie region (North Algeria) during the winter 2016. The fruit was submitted to freeze drying at -64°C under vacuum (4.5 Pa) during 48 h, using lyophylizer Type (Christ Alpha1-4LD), provided with a vacuum pump (RZ 6, max pressure 0.04 Pa). The dried product is ground, sieved (sieve of type Euromatest-Sintoo, NFX11-501) to obtain powder and water was measured at 20°C (mS cm⁻¹); the lipid was determined by extracting a known weight of powdered sample with petroleum ether, using a Soxhlet apparatus. The X-ray diffraction (XRD) of LP was evaluated. The electrical conductivity of 20% LP solution in distilled water was measured at 20°C (mS cm⁻¹); the lipid was determined by extracting a known weight of powdered sample with petroleum ether, using a Soxhlet apparatus. The X-ray diffraction (XRD) of LP was investigated using diffractometer (Panalytical Xpert Pro ®).

Sorption isotherms

The sorption isotherms of LP were determined with the standard, static-gravimetric method [32] at 20, 30 and 40°C. Six saturated salt solutions were prepared corresponding to a range of water activities (0.0626-0.9200) (Table 1). These solutions were prepared in hermetic jars and maintained in a drying room regulated in desired temperature. (0.0626-0.9200) (Table 1). These solutions were prepared in hermetic jars and maintained in a drying room regulated in desired temperature.

The isotherm models used to fit the data are presented in Table 2. These equations were chosen to fit the experimental sorption data because they are most widely used for several foods.

The statistical analysis of experimental data was performed with Origin software version 8. Goodness of fit of the selected models was evaluated by means of the coefficient of determination (R²), the mean relative percentage deviation modulus (E%), the chi-squared error (χ²) and the root mean square error (RMSE) [16].

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_{exp,i} - X_{cal,i})^2} \quad \text{Eq. 2}
\]

\[
\chi^2 = \sum_{i=1}^{N} \left[ \frac{(X_{exp,i} - X_{cal,i})^2}{X_{exp,i}} \right] \quad \text{Eq. 3}
\]

\[
E\% = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{X_{exp,i} - X_{cal,i}}{X_{exp,i}} \right| \quad \text{Eq. 4}
\]

Where, \( X_{exp} \) is the experimental value, \( X_{cal} \) the value predicted by the model and \( N \) the number of experimental measurements. It is generally assumed that a good fit is obtained when \( E \% \) lower than 10% [41,42] and that is extremely good for values of \( E\% \) lower than 5% [43].

The temperature dependence of the GAB model constants was given by the Arrhenius equations [44]:

\[
C = C_0 \exp(\Delta H_c)/RT \quad \text{Eq. 5}
\]

\[
K = K_0 \exp(\Delta H_k)/RT \quad \text{Eq. 6}
\]

\[
X = X_0 \exp(-\Delta H_m/RT) \quad \text{Eq. 7}
\]

Where, \( \Delta H_c \) are pre-exponential factors, (kJmol⁻¹), \( \Delta H_k \) and \( \Delta H_m \) are respectively; the sorption enthalpy of monolayer, multilayer and the root mean square error \( (RMSE) \)

Results and Discussion

Physicochemical properties of LP

The different quality parameters of LP are summarized in Table 3.

| Solutions   | Water activity (a_w) at |
|-------------|------------------------|
|             | 20°C       | 30°C       | 40°C       |
| KOH         | 0.0932     | 0.0738     | 0.0626     |
| MgCl₂       | 0.3307     | 0.3244     | 0.3160     |
| K₂CO₃       | 0.4316     | 0.4317     | 0.4230     |
| CuCl₂       | 0.6880     | 0.6860     | 0.6800     |
| NaNO₂       | 0.7536     | 0.7314     | 0.7100     |
| KCl         | 0.8510     | 0.8360     | 0.8230     |
| BaCl₂       | 0.9200     | 0.8980     | 0.8920     |

Table 1: Selected saturated salt solutions and corresponding water activity (30.33.34).

| Model          | Mathematical expression                                      |
|----------------|-------------------------------------------------------------|
| GAB [35]       | \( X = \{X([K_a]/[1-K_a])x[1-K_a]+CK_a) \)             |
| Halsey [36]    | \( X = [a/(Lna)]^{10} \)                                   |
| Smith [37]     | \( X = A-B ln(1-a) \)                                     |
| Oswin [38]     | \( X = \{a/[1-a)]^{10} \)                                 |
| Kühn [39]      | \( X = (BLn a+1)A \)                                      |
| Caurie [40]    | \( X = \exp(A+B/A) \)                                     |

Table 2: Model equations fitted to the experimental sorption data of LP.
Crude fiber of LP is comparable to that reported by Ruiz-Rodríguez et al. [8] and is less than that reported by Özcan and Hacıseferogulları, [6] for fresh strawberry tree fruits (6.4 g/100 g of cellulose, 2.93 g/100 g soluble fibers respectively). The titratable acidity is close to that indicated in the literature 0.4% [6]. On the other hand, it is less than that given by Sulusوغlu et al. and Celikel et al. [2,45] (0.48-1.24 and 0.8-1.59% respectively) for the Turkish variety electric conductivity is greater than that calculated by Ulloa et al. [46] (0.643 mS cm\(^{-1}\)) for strawberry tree (Arbutus unedo L.) honey.

The XRD pattern of LP powder is presented in Figure 1. A broad band with very weak peaks, characteristic of amorphous forms, is observed in the pattern indicating the presence of amorphous sugar obtained by freeze-drying fruits berry. Furthermore, the amorphous characteristics are clearly reported on different dried mango powders [47] and fluidize-dried gum extracted from the fresh fruits of Abelmoschus esculentus [48]. However, Niimura et al. [49] have shown that strawberry flesh has low-crystallinity cellulose I.

### Sorption isotherms

The adsorption isotherms of LP, at different temperatures, are shown in Figure 2. As it can be observed, at a constant water activity, the equilibrium moisture contents increase with decreasing temperature; similar trends were reported by Vega-Galvez et al. and Vaquiro et al. [50,51]. This trend can be explained by considering excitation states of molecules. At increased temperatures the molecules are in an increased excitation state, thus increasing their distance apart and decreasing the attractive forces between them [52]. This leads to a decrease in the degree of water sorption at a given relative humidity with increasing temperature [53,54]. According to Catelam et al. [55] the decrease in X was due a reduction in the number of active sites due to chemical and physical changes induced by temperature and then depend on the composition of foods [15,56]. Further, examination of the figure shows that the isotherms are S-shaped (Type II). This is a typical characteristic of many biomaterials [57-59] and of fruits rich in sugars [16,60].

The average parameters related to various mathematical models, as well as the corresponding statistical data applied are recapitulated in Table 4. Graphical representation of the fit goodness of theoretical isotherms at 20, 30 and 40°C are shown in Figure 3. For all tested models, the parameters A, B and K are found to be temperature dependent and all models, with the exception of the Oswin over the used temperature range and GAB at 40°C, for values water activity greater than 71%, gave good fits to experimental data over the range of water activities employed, with E less than 10%. The Halsey and the GAB models (at T=20 and 30°C) gave the best fits (E<1%), and the lowest average values of \(\chi^2\) and RMSE.

These results are comparable to those recorded by others, Lamharrar et al. [59] have also reported that the GAB model was the best model describing the equilibrium moisture data for desorption, and the modified Halsey model was the most suitable to estimate adsorption isotherms of Artemisia herba-alba, while Lavoyer et al. [61] found very good adjustment of the GAB model to adsorption isotherms of green coconut pulp. According to Kohayakawa et al. [62], the GAB model has been extensively used for foodstuffs, mainly for fruits. Chukwu, [57] showed that the Oswin and the Bradley models gave better fits for the adsorptive mode than for the desorptive mode for the two varieties of dates (Khalas and Handal variety). In this work, the Oswin model gave a poor fit over the entire range of equilibrium moisture contents (E>10% at 30 and 40°C).

The the monolayer moisture content \(X_0\) is of particular interest; it is considered as the optimum value to assure the food stability [15] and it measures number sorbing sites [63]. Below it, the rates of deteriorative reactions, except for oxidation for unsaturated fats, are minimized [64]. Monolayer moisture contents obtained from GAB

| Parameter                | Value   |
|--------------------------|---------|
| Crude fiber (%)          | 4.440 ± 0.125 |
| Titrable acidity (%)     | 0.210 ± 0.010 |
| Pectin (%)               | 2.456 ± 0.034 |
| Total ash (%)            | 3.910 ± 0.030 |
| Acid-Insoluble Ash (%)   | 0.510   |
| Lipid (%)                | 0.801 ± 0.080 |
| Electrical conductivity (mS.cm\(^{-1}\)) | 2.550 ± 0.050 |

Table 3: Physicochemical characterization of LP.
![Figure 2: Adsorption isotherms of LP at different temperatures.](image)

| Model | Temperature (°C) | 20   | 30   | 40   |
|-------|------------------|------|------|------|
|       | R²               |      |      |      |
| GAB   |                  | 0.966| 0.976| 0.944|
|       | Xₐ (g g⁻¹)      | 0.223| 0.157| 0.143|
|       | C                | 25.417| 266.100| 262.698|
|       | K                | 0.813| 0.900| 1.065|
|       | RMSE             | 4.625 × 10⁻³| 8.118 × 10⁻³| 2.680 × 10⁻¹|
|       | χ²               | 4.556 × 10⁴| 1.040 × 10⁻³| 2.808 × 10⁻¹|
|       | E (%)            | 0.453| 0.573| 10.670|
| Smith |                  | 0.998| 0.994| 0.965|
|       | A                | 0.102| -0.064| -0.111|
|       | B                | 0.322| 0.378| 0.384|
|       | RMSE             | 1.573 × 10⁻²| 1.537 × 10⁻²| 1.714 × 10⁻²|
|       | χ²               | 1.568 × 10⁻²| 1.559 × 10⁻²| 1.610 × 10⁻²|
|       | E (%)            | 1.064| 1.898| 2.346|
| Oswin |                  | 0.996| 0.956| 0.942|
|       | A                | 0.094| 0.041| 0.028|
|       | B                | 0.694| 0.358| 0.354|
|       | RMSE             | 8.845 × 10⁻²| 1.323 × 10⁻¹| 1.253 × 10⁻¹|
|       | χ²               | 2.710 × 10⁻¹| 2.476| 3.328|
|       | E (%)            | 7.28| 12.44| 12.86|
| Caurie|                  | 0.978| 0.950| 0.939|
|       | A                | -1.989| -2.122| -2.219|
|       | B                | 1.939| 1.899| 1.914|
|       | RMSE             | 2.025 × 10⁻²| 2.806 × 10⁻²| 2.800 × 10⁻²|
|       | χ²               | 1.920 × 10⁻²| 2.00 × 10⁻²| 2.300 × 10⁻²|
|       | E (%)            | 2.23| 2.5| 2.527|
| Halsey|                  | 0.978| 0.997| 0.990|
|       | A                | 0.087| 0.070| 0.059|
|       | B                | 1.910| 1.891| 1.859|
|       | RMSE             | 1.081 × 10⁻²| 5.723 × 10⁻³| 1.063 × 10⁻²|
|       | χ²               | 1.680 × 10⁻³| 5.421 × 10⁻⁴| 1.340 × 10⁻³|
|       | E (%)            | 0.828| 0.414| 0.599|
| Khun  |                  | 0.915| 0.977| 0.990|
|       | A                | 0.231| 0.169| 0.140|
|       | B                | -0.071| -0.072| -0.073|
|       | RMSE             | 1.994 × 10⁻²| 9.750 × 10⁻³| 5.960 × 10⁻³|
|       | χ²               | 9.740 × 10⁻³| 2.810 × 10⁻³| 1.600 × 10⁻³|
|       | E (%)            | 2.20| 1.204| 0.771|

Table 4: Isotherm models used for experimental data fitting.
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There are comparable to values reported by other authors; Kaymak-Ertekin and Gedik, [69] have obtained values in the range (0.067-0.220 g g⁻¹) dry solids for grapes, apricots and apples 30, 45 and 60°C; Talla et al. [70] found values between 0.080 and 0.185 g g⁻¹ dry solids Vega-Galvez et al. [54] reported monolayer moisture contents of 0.044-0.075 g g⁻¹ dry solids for Cape Gooseberry (Physalis peruviana L.) in the temperature 20, 40 and 60°C.

The constant (C) has an enthalpic nature and is a measurement how strong the water molecules are bound to the primary sorption sites [71]. The parameter C showed no temperature dependence but is within the ranges (5.67 ≤ C ≤ ∞) as indicated by Lewicki, [72] and they is in the same extent as that reported by Alakali and Satimehin, [73] for ginger (Zingiber officinale) powders. Iglesias and Chirife, [36] studied more than 30 different foods and found that in 74% of them, C increases as temperature increases; they have explained it by irreversible changes associated with increasing temperature, such as enzymatic reactions and protein denaturation. Martínez et al. [74] showed that, the isotherms are classified as type II for C>2. According to Quirijns et al. [71] (very) high banana, mango and pine apples in the temperature range (40-60°C). For pure pineapple pulp, Gabas et al. [75] showed X₀ values in the range (14.6-16.6%) (dry basis) with a decreasing tendency of X₀ with increasing temperature from 20 to 50°C.

Values and K, approaching 1 indicate that the multilayer molecules have properties comparable with those of bulk liquid molecules. K values increase with increasing temperature. According to Cano-Higuita et al. [76] the K value provides a measure of the interactions between the molecules of vapor water in the multilayers with the adsorbent, and tends to decrease between the energy of molecules in the monolayer and those of liquid water and also observed for K close to 1.

Estimated value for K are greater than 1 at 40°C; Quirijns et al. [71] suggests that the high K values (>0.9) indicate that the monolayer and multilayer molecules are not so different and that the multilayer molecules behave more like liquid molecules. The ΔH*K values obtained in this work are not significantly affected by the temperature. The activation energy deduced in this study is in the same order of that found by Vega-Gálvez et al. (14.48 kJ mol⁻¹) [78] related to adsorption isotherms of Chilean papaya.

Table 5: Temperature Dependencies of GAB Constants.
Conclusion

The study of lyophilized powder (LP) (Arbutus unedo L.) from Algerian Arbutus berries was undertaken. The XRD pattern of LP indicates the presence of amorphous sugar obtained by freeze-drying fruits berry.

The sorption isotherms constitute an important source of information for the stability products food and its storage conditions.

For the first time, the water adsorption by LP was studied giving the following results: The moisture sorption isotherms of LP exhibited S shape described as type II which is common for many hygroscopic products. The equilibrium moisture content of LP increased with increasing water activity and decreased with increasing temperature. Among all tested models, those of Halsey and GAB (T=20 and 30°C) gave the best fits at 20 and 30°C, with the mean relative percentage deviation modulus (€) less than 1%. PI showed higher monolayer moisture content at 20°C and was found to be less shelf-stable. For LP berry, the monolayer moisture content can be used to evaluate the shelf stability and efficient use of energy in the drying process.

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References

1. Ayaz FA, Kucukislamoglu M, Reunanen M (2000) Sugar, non-volatile and phenolic acids composition of strawberry tree (Arbutus unedo L. var ellipsoides) fruits. Journal of Food Composition and Analysis 13: 171-177.

2. Celikel G, Demirsoy L, Demirsoy H (2008) The strawberry tree (Arbutus unedo L.) selection in Turkey. Scientifica Horticulturae 115: 115-119.

3. Tutin TG, Heywood VH, Burges NA, Valentine DH, Walters SM, et al. (1972) Flora Europaea. Vol. 3. Cambridge University Press, Cambridge, UK.

4. Pawlowska AM, De Leo M, Braca A (2006) Phenolics of Arbutus unedo L. (Ericaceae) fruits: Identification of anthocyanins and gallic acid derivatives. Journal of Agricultural and Food Chemistry 54: 10234-10238.

5. Simonetti MS, Damiani F, Gabrielli L, Cossignani L, Blasi F, et al. (2008) Characterization of tricglycerols in Arbutus unedo L. seeds. Italian Journal of Food Science 20: 49-56.

6. Özcan MM, Hacseferoğulları H (2010) The Strawberry (Arbutus unedo L.) fruits: Chemical composition, physical properties and mineral contents. Journal of Food Engineering 113: 1022-1028.

7. Tawaha K, Alali FQ, Gharabieh M, Mohammad M, El-Elimat T (2007) Antioxidant activity and total phenolic content of selected Jordanian plant species. Food Chemistry 105: 1372-1378.

8. Ruiz-Rodriguez BM, Morales P, Fernández-Ruíz V, Sánchez-Mata MC, Câmara M, et al. (2011) Valorization of wild-strawberry tree fruits (Arbutus unedo L.) through nutritional assessment and natural production data. Food Research International 44: 1244-1253.

9. Rahman MS (2007) Aillic and other functional active components in garlic: Health benefits and bioavailability. International Journal of Food Properties 10: 245-268.

10. Pallafu K, Rivas-Gonzalo JC, del Castillo MD, Cano MP, Pascual-Teresa S (2008) Characterization of the antioxidant composition of strawberry tree (Arbutus unedo L.) fruits. Journal of Food Composition and Analysis 21: 273-281.

11. Cherroute-Valette M, Hebert I, Hebraud M, Labodici JC, Herbert A (1998) Effects of pH on a stress on growth of Listeria monocytogenes. International Journal Food Microbiology 42: 71-77.

12. Arola A, Fernando DS, Zilda DSA, Salles A, Abraham DGZ, et al. (2006) Desorption isotherms for muci (Byrsonima sericea) and inga (Inga edulis) pulps. Journal of Food Engineering 75: 611-615.

13. Iquedjat T, Louka N, Allaf K (2006) Sorption isotherms of potato slices dried and texturized by controlled sudden decompression. Journal of Food Engineering 85: 180-190.

14. Roos YH (1995) Water and phase transitions. Phase transition in foods. London: Academic Press Inc., pp: 73-107.

15. Pedro MAM, Tellis-Romero J, Tellis VRN (2010) Effect of drying method on the adsorption isotherms and isosteric heat of passion fruit pulp powder. Ciência e Tecnologia de Alimentos, Campinas 30: 993-1000.

16. Basu S, Shivhare US, Mujumdar AS (2006) Models for sorption isotherms for foods: a review. Drying Technology 24: 917-930.

17. Vazquez G, Chenlo F, Moreira R (2001) Modeling of desorption isotherms of chestnut: influence of temperature and evaluation of isosteric heats. Drying Technology 19: 1189-1199.

18. Vuilcloud M, Marquez CA, De Michielis A (2004) Desorption isotherms for sweet and sour cherry. Journal of Food Engineering 63: 15-19.

19. Asma A, Boumediene T, Mohammed B, Brahim D, Amel S (2014) Conservation of Leaves of a Medicinal Plant of Western Algeria (Pistacia atlantica). Journal of Food Science and Engineering 4: 96-106.

20. Rosa GS, Moraes MA, Pinto LAA (2010) Moisture sorption properties of chitosan LWT. Food Science and Technology 43: 415-420.

21. Bennaceur S, Drouci B, Bennamoun L, Touati B, Saad A, et al. (2012) Experimental study and modeling of sorption isotherms of Kabar Sid EL Cheikh Capparis spinosa L. from Bechar (south west Algeria). Energy Procedia 18: 359-367.

22. Bag SK, Srivastav PP, Mishra HN (2009) Desorption and adsorption characteristics of baet (Aegle marmelos) pulp and powder. International Food Research Journal 16: 561-569.

23. Alakail JS, Salimehin AA (2007) Moisture Adsorption Characteristics of Bambara Groundnut (Vigna subterranea) Powders. Agricultural Engineering International: The CIGR E-Journal 9: 1-15.

24. Alexandre HV, Figueirêdo RMF, Queiroz AJM (2007) Moisture adsorption isotherms of red brazilian cherry powder. Revista de Biologia e Ciências da Terra 7: 11-20.

25. Vega-Galvez A, López J, Miranda M, Di Scala K, Yagynm F, et al. (2009) Mathematical modeling of moisture sorption isotherms and determination of isosteric heat of blueberry variety O’Net. International Journal of Food Science and Technology 44: 2033-2041.

26. Alcântara S, Almeida F, Silva F, Gomes J (2009) Adsorption isotherms of the dry cashew Apple. Revista Brasileira de Engenharia Agricola e Ambiental: 13: 81-87.

27. Abbas-Aksil T, Banamara S (2015) Modeling of the Dissolution Kinetics of Arbutus Wild Berries-Based Tablets as Evaluated by Electric Conductivity. Sains Malaysia 44: 301-308.

28. Abbas-Aksil T, Abbas M, Tari M, Benamara S (2016) Matrix Tablets from Algerian Lyophilized Berries (LB) (Arbutus unedo L.) Date (Phoenix dactylifera L.). Natural Products Chemistry and Research 4: 207.

29. AFNOR NFV 03 040 (1977) Méthode de détermination de la CB (Indice d’Insoluble dit Cellulosique) par la méthode de WEENDE.

30. Multon JL, Bizot H, Martin G (1991) Mesure de l'eau adsorbée dans les aliments. Techniques d'analyse et de contrôle dans les industries agro-alimentaires. 2nd edn. Lavoisier Tec and Doc, Paris, pp: 158-200.

31. Singh MP, Sharma CS (2010) Pharmacognostical Evaluation of Terminalia chebula R.M. (Eugeniaceae) fruits: Identification of anthocyanins and gallic acid derivatives. Journal of Agriculture and Food Chemistry 54: 10234-10238.

32. Alexandre HV, Figueirêdo RMF, Queiroz AJM (2007) Moisture adsorption isotherms of red brazilian cherry powder. Revista de Biologia e Ciências da Terra 7: 11-20.

33. Vega-Galvez A, López J, Miranda M, Di Scala K, Yagynm F, et al. (2009) Mathematical modeling of moisture sorption isotherms and determination of isosteric heat of blueberry variety O’Net. International Journal of Food Science and Technology 44: 2033-2041.

34. Alcântara S, Almeida F, Silva F, Gomes J (2009) Adsorption isotherms of the dry cashew Apple. Revista Brasileira de Engenharia Agricola e Ambiental: 13: 81-87.

35. Abdus Salam, Shamsel Rahman, Shamseddein Ahmed (1998) The Effect of Purification on the Antioxidant Activity of Some Alcoholic Extracts of Arbutus unedo L. Fruit. Journal of Medicinal and Poisonous Plants 7: 257-263.
