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Full Length Research Paper

Softening of dried *Vangueria infausta* (African medlar) using maltodextrin and sucrose

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Softening of dried *Vangueria infausta* using maltodextrin and sucrose was investigated experimentally. The pulp of *V. infausta* was dried in a convective dryer, the influence of drying temperature as well as relationship between water content and water activity were examined. In this study, 48 samples of *V. infausta* pulp, with and without maltodextrin or sucrose, were dried at air temperatures of 60 and 80°C, at a constant air velocity of 3 m/s, for 0-240 min, and until constant weight. The water content, water activity, hardness and toughness were evaluated throughout the drying process. Samples dried at 80°C exhibited shorter drying times than samples dried at 60°C. The water activity of fruit dried for 240 min at 80°C varied from 0.633 to 0.759, and the fruit was thus safe regarding microbiological spoilage. The hardness and toughness of the dried fruit pulp increased with the reduction in water content, and it was observed that samples of pure pulp became unacceptably hard and tough, when dried to the level needed to obtain microbiological stability. The addition of sucrose as well as maltodextrin has shown to be able to reduce the hardness as well as the toughness of the dried fruit pulp; which can be considered as a strategy to obtain dried fruit pulp with suitable consistency.

Key words: *Vangueria infausta,* drying, softener, sorption isotherm, hardness, toughness.

INTRODUCTION

In southern and eastern African regions, namely Madagascar, Tanzania, Kenya, Botswana and southern and central Mozambique, the indigenous fruit *Vangueria infausta* plays an important role in the diet of the rural population. This fruit has different names, according to different languages used in the area: *African medlar* in English (*wild medlar* is used in South Africa), *mapfilwa* in Tsonga and Shangan (South of Mozambique), *mmilo* in Sotho (South Africa), *um viyo* or *um tulwa* in Zulu (South Africa), *um vilo* in Xhosa (South Africa) and *mothwanyê* in Tswana (Botswana).

V. infausta belongs to the Rubiaceae family (Mbukwa et al., 2007; Motlhanka et al., 2008). The fruit of *V.infausta* has a diameter of about 3-6 cm, its colour varies from green to light brown when ripe, and it contains 3 to 5 seeds embedded in the soft pulp. The taste is sweet and the flavour is like that of apple (Behr, 2004) and ripens from January to May in southern

Abbreviations: a, Coeficient of equation of linear regression; **b,** coeficient of equation of linear regression; a_w, water activity; R^2, coefficient of determination; **db,** dry basis; **Eq,** equation; P_h, hardness (N); **Md,** maltodextrin; **min,** minutes; **(%),** percentage; **P,** pulp; **Suc,** sucrose; P_t, toughness (N.mm); **X,** water content (g/g dry basis); **wt,** wet basis; **α,** coefficient of GAB model; **β,** coefficient of GAB model; **ϒ,** coefficient of GAB model; **Ɛ,** standard error.

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Mozambique (Prins and Maghembe, 1994; Amarteifio and Mosase, 2006). It is consumed fresh, mixed with milk (Motlhanka et al., 2008), or made into a pulp, as a substitute for apple sauce in puddings. It is also used for making juice and alcoholic beverages. A type of vinegar can also be produced from the fruit (Wild medlar, 2011). The composition of *V. infausta* has been investigated by Magaia et al. (2013). The fruit contains large amounts of total dietary fiber (on average 62 g/100g db) of which more than half was insoluble dietary fiber; Magaia et al. (2013) also argue that the *V. infausta* pulp contains organic acid.

V. infausta deteriorates rapidly after harvest, therefore, there is a great loss of the product during the period of maximum production (January to May) due to the lack of methods of preservation. Drying is one of the methods used for industrial preservation of fruit pulps, concentrating the raw material and enabling the product to be stored for long periods (Gomes et al., 2004). With drying, the fruit is preserved as microorganisms cannot grow below a certain level of water activity. The water activity is the most important factor in controlling spoilage (Jangam and Mujumdar, 2010). The water activity of different dry matters can be expressed in sorption isotherms, and this will give a possibility to predict the shelf life of dried products (Visavale, 2012; Jangam and Mujumdar, 2010; Singh and Heldman, 2009).

Drying can be achieved by different ways: convective drying, osmotic dehydration, vacuum drying, drum drying, freeze drying, microwave drying, sun drying and spray drying (Chong and Law, 2011; Fernandes et al., 2011; Hii et al., 2011; Mujumdar and Law, 2010; Santos and Silva, 2008; Marques et al., 2006). Drying causes physicochemical changes in the product, such as the Maillard reaction, caramelization, enzymatic reactions, fat oxidation, the loss of volatile components other than water, and crystallization; the effects of these changes can be an increase in aroma, as well as changes in texture of the dried product. The degree of changes in the texture of fruits and vegetables developed during drying is strongly associated with the composition and structure of the tissue fragments and cell walls (Marzec et al., 2009; Reeve, 1970). Recently, microwave assisted vacuum drying has been investigated to predict texture parameters of dried fruits and vegetables (Huang et al., 2012). In addition, the combined drying methods also lowered the energy consumption, processing time and by that reduced the drying costs (Lee et al., 2013; Huang et al., 2012; Bonazzi and Dumoulin, 2011; Mujumdar and Law, 2010).

Many fruit materials are difficult to dry. Commonly, there are difficulties with stickiness and hygroscopicity. A common source of these difficulties is the high sugar concentrations in the fruit solids (Chong and Law, 2011). A way of understanding the material properties behind these observations is by analysing the state of the dried fruit (Roos, 1995). Products with a state above the glass transition temperature tends to be soft and sticky while products below the glass transition temperature are hard and non-sticky (Lee et al., 2013; Bonazzi and Dumoulin, 2011). Jaya and Das (2004, 2009) have shown how maltodextrin and other ingredients can be used to change the state of dried fruits and thereby optimize the properties of the final product.

The purpose of this study was to evaluate the texture properties of the dried fruit pulp of *V. infausta* and to evaluate improvements on the texture, when adding maltodextrin and sucrose to the matrix. The influence of drying temperature and the relationships between water content, water activity, hardness and toughness were investigated during convective drying.

MATERIALS AND METHODS

Raw material

The *V. infausta* fruit used in this study was obtained from the Paquete district of Maputo, Mozambique (25.5794°S, 32.6646°E) during the harvest season of 2011. After harvesting, the fruit was maintained at air temperature in plastic cooling bags and transported to the Eduardo Mondlane University laboratory within 2-3 h. The fruit was graded according to size in order to obtain samples of the same degree of homogeneity, 3-4 cm in diameter and 31.0 to 61.0 g in weight. The fruit was then packed in vacuum bags containing 10-24 units of the fruit each (around 0.5 kg), and frozen in a domestic freezer at -20°C.

Commercial samples of other various dried fruits were studied for comparison purposes, namely: dried figs, Sunny Fruit, Sunfruit k.F.C. Gida Tekstil San Ith, Izmiry, (Turkey), dried pineapple, osmotically treated with sugar, supplied by Candy King, Sverige AB, Solna, (Sweden) and dried cranberries, osmotically treated with sugar, supplied by Coop Trading, Albertslund, (Denmark).

Maltodextrin and sucrose were used for softening the dried *V. infausta;* the maltodextrin was supplied by Cargill, Charlottenlund (Denmark) and the sucrose was supplied by Nordic sugar AB, Malmo (Sweden).

Sample preparation

Preparation of pulp

Each vacuum bag containing frozen fruit was temperate in a cooling room to reach 3°C, placed at room temperature for 30 min, then placed in a vessel, containing 1.5 L water of 11°C. The coming up time to heat the water up to 97°C was 15 min and the heating was maintained for 5 min and then the sealed fruit bags were taken out from the water and allowed to cool in room temperature. The fruit was then removed from the bag, peeled using a knife, and the seeds were removed. The remaining fruit was pulped using a domestic puree sieve.

Preparation of samples and drying procedure

Three sets of experiments were performed: one with pulp, second with pulp and maltodextrin, and third with pulp and sucrose. The pulp was homogenised. The commercial maltodextrin (DE 12 - 16)

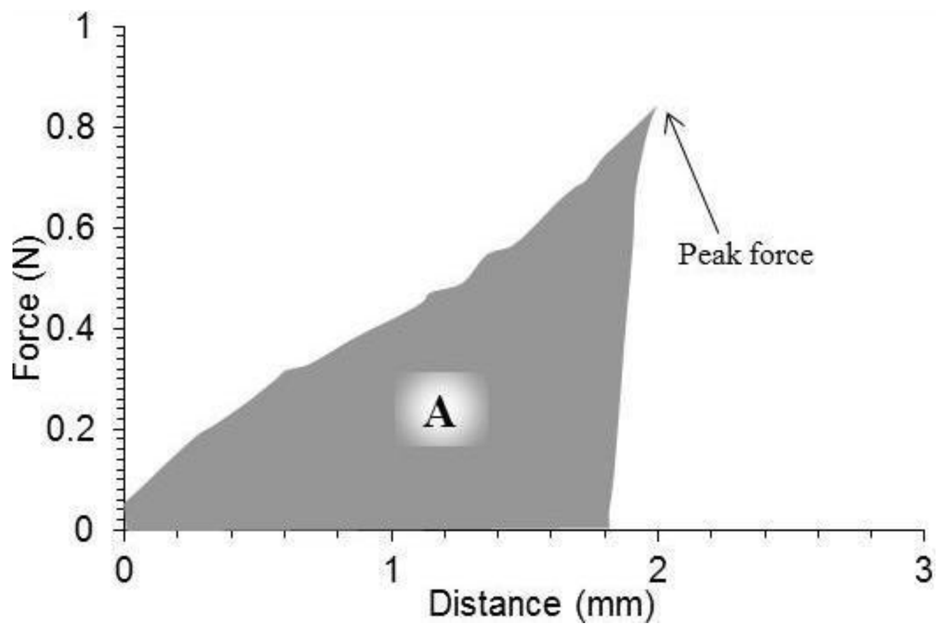

Figure 1. Hardness and toughness plot.

respectively sucrose was added to the fruit pulp at the ratio of 1:1 on weight basis, then the pulp was thoroughly mixed by spoon for 15 min. In each experiment, the pulp was distributed into eight circular samples: before drying (0 minute), six samples were placed on tray 1 (30, 60, 90, 120, 180 and 240 min) and one sample on tray 2 (dried until constant weight).

The samples were 5 mm thick, 28 mm in diameter and weight 5 g each. The samples were dried in a convective dryer as described by Skjöldebrand (1980), at air temperatures of 60 or 80°C, and air velocity of 3 m/s. During drying, the weight of the samples was recorded using a Mettler AE160 analytic weighing balance with a range of 0-162.0 g, and an accuracy of ±0.0001 g (Mettler Instrumente AG, Greifensee, Zurich, Switzerland).

The temperature of the drying air and the samples was monitored continuously using type K, 0.5 mm thermocouples. Samples were removed from the oven at time intervals and the last sample was dried up to constant weight. In addition, water content, water activity and texture were carried-out.

Analysis

pH

The pH of fresh *V. infausta* pulp was determined within 2-3 h after harvesting, using a glass electrode pH meter (Basic 20) at 25°C, standardized with buffer solutions of 4.0 and 7.0. The measurement of pH was performed in triplicate for each sample.

Water content and water activity

The water content of the initial and final samples (0.5-1.0 g) was determined by heating in a vacuum oven (Forma Scientific, Marietta, OH, USA) at 70°C for 24 h. Weighing was performed using a Mettler AE160 analytic balance. The determination was also performed in triplicate for each sample. Water activity (a_w) was measured at 20°C using an AquaLab water activity meter S 3TE, supplied by Decan Devices, Inc. (Pullman, Washington, USA), calibrated using standard salt solutions (NaCl: a_w = 0.760 M and KCl: a_w = 0.984 M), standard deviation of a_w = ±0.003.

Soluble solids

Soluble solids were determined at 20°C using a Digital Abbe WAY-S Refractometer supplied by Cometa Selecta Group, Barcelona, Spain, and expressed as °Brix (total soluble solids).

Texture analysis

The texture of *V. infausta* was determined using a texture analyser (Stable Micro Systems, version 07.13, SMS TAXT2i, Godalming, England), with stainless steel needle 2.0 mm in diameter, where the penetration force (N) was monitored. The operating conditions of the instrument were as follows: pre-test speed: 1.0 mm/s, test speed: 0.2 mm/s, post-test speed: 3.0 mm/s, 2.0 mm distance and 5.0 g trigger force. Two texture parameters (hardness and toughness) were evaluated in order to characterize the modification of the fruit resulting from drying.

In this study, hardness (N) was defined as the maximum compression force of a penetration test, while toughness (N·mm) was defined as the energy required to penetrate the sample completely (Bchir et al., 2012; Al-Said et al., 2009). Figure 1 shows an example of how the hardness and toughness were calculated. The peak force measured during the test is referred to as the hardness (Sutar and Thorat, 2011; Hii and Law, 2010; Chong et al., 2008a, b) and the area A under the curve as the toughness. Three measurements were performed on each sample obtained from each drying condition, and the final texture of the sample was recorded as the average of the three measurements.

Statistical analysis

The results were presented as mean values with the standard error. The data were analysed by analysis of variance (ANOVA) in MS Excel (Microsoft Office Excel, professional 2007).

Table 1. Properties of *Vangueria infausta* pulp.

Dry matter (%)	Experimental data			
	Water content (%)	Water activity	Soluble solid (°Brix)	pH
48.0±0.2	52.0±0.2	0.966±0.001	35.5±0.2	3.30±0.003

The values indicate mean of three measurements ± standard error. Water activity mean of two measurements ± standard error.

Table 2a. Water content (X) and water activity (a_w) of dried samples along the drying procedure at 60°C.

Drying time (min)	Pulp, 60 °C		Pulp add Md, 60 °C		Pulp add Suc, 60 °C	
	X (g/g db)	a_w	X (g/g db)	a_w	X (g/g db)	a_w
0	1.085±0.009	0.966±0.001	0.386±0.003	0.944±0.001	0.365±0.005	0.828±0.001
30	0.714±0.010	0.948±0.000	0.292±0.009	0.870±0.000	0.283±0.004	0.797±0.000
60	0.635±0.007	0.940±0.000	0.291±0.003	0.864±0.000	0.264±0.013	0.790±0.001
90	0.520±0.003	0.923±0.000	0.289±0.002	0.853±0.000	0.261±0.004	0.777±0.000
120	0.457±0.003	0.907±0.000	0.271±0.003	0.845±0.000	0.256±0.004	0.771±0.001
180	0.340±0.004	0.871±0.000	0.268±0.004	0.838±0.000	0.251±0.005	0.760±0.001
240	0.275±0.001	0.831±0.001	0.256±0.009	0.806±0.000	0.230±0.007	0.755±0.000
338 (*)	0.185±0.001	0.749±0.000				
486 (*)			0.171±0.007	0.744±0.000		
499 (*)					0.203±0.006	0.668±0.001

The values indicate mean of three measurements ± standard error, water content (X) in dry basis, drying time in minutes, a_w is water activity and (*): drying time until constant weight.

RESULTS AND DISCUSSION

Properties of *V. infausta* pulp

The characteristics of the *V. infausta* pulp used in the drying experiments is presented in Table 1. Most of the values obtained were in agreement with previous results for *V. infausta*. The dry matter of fruits in this study was high, 48%, in agreement with that reported by Magaia et al. (2013) collected in Marracuene and Manhiça, although it was higher than that previously reported by Amarteifio and Mosase (2006) (23.5%) and Saka and Msonthi (1994) (26.5%) for samples from Malawi. The dry matter varies depending on local weather conditions, and harvest time.

There is little information on fresh *V. infausta* such as on water activity, for that reason, other fruits were used for comparison purposes. The water activity of the pulp, 0.966, was comparable to values of other comparable fresh fruits such as olives, 0.96-0.97 (Fernández-Salguero et al., 1993) and figs, 0.96 (Piga et al., 2004).

Drying

Drying characteristics

The w ater content and water activity during the drying process of *V. infausta* are presented in Table 2a,b. The water content and water activity decreased with drying time for all drying processes. The final water content obtained by drying to constant weight was around 0.19 g/g db for samples dried at 60°C and 0.11 g/g db at 80°C.

The water activity of the samples dried for 240 min was between 0.633 and 0.831. The water activity of the samples dried up to constant weight was between 0.410 and 0.749. Food with water activity between 0.4 and 0.6 is considered as a dry product, whereas food with water activity between 0.65 and 0.75 is considered to be an intermediate moisture content product (Jangam et al., 2008). In addition, the water activity of 0.7 is often used as a practical limit for food of intermediate moisture content. Product deteriorating bacteria cannot grow at water activity below 0.86, however, yeasts and moulds may grow to 0.62 (Hii and Law, 2010; Barbosa-Cánovas et al., 2003).

The addition of maltodextrin or sucrose at the ratio of 1:1 to fruit pulp before drying modifies the drying characteristics. The water activity of samples to which sucrose has been added was later dried for 240 min at 80°C, 0.633. This is similar to the values of 0.61-0.63 obtained by Piga et al. (2004) for dried figs. The commercial dried fruits studied here: dried figs, pineapple and cranberry, had water activities of 0.69, 0.57 and 0.55, respectively. Fruit with water activity within this range is

Table 2b. Water content (X) and water activity (a_w) of dried samples during the drying procedure at 80°C

Drying time (min)	Pulp, 80 °C		Pulp add Md,80 °C		Pulp add Suc, 80 °C	
	X (g/g db)	a_w	X (g/g db)	a_w	X (g/g db)	a_w
0	1.085±0.009	0.966±0.001	0.386±0.003	0.944±0.001	0.365±0.005	0.828±0.001
30	0.654±0.003	0.943±0.000	0.267±0.011	0.849±0.001	0.259±0.005	0.755±0.000
60	0.521±0.005	0.926±0.000	0.241±0.008	0.819±0.001	0.234±0.005	0.729±0.000
90	0.416±0.005	0.894±0.000	0.228±0.008	0.817±0.001	0.230±0.004	0.703±0.000
120	0.320±0.001	0.852±0.000	0.222±0.006	0.798±0.001	0.211±0.001	0.692±0.001
180	0.267±0.001	0.821±0.000	0.206±0.013	0.770±0.001	0.204±0.007	0.656±0.001
240	0.176±0.002	0.738±0.000	0.200±0.004	0.759±0.001	0.196±0.006	0.633±0.001
330 (*)	0.096±0.005	0.613±0.000				
385 (*)			0.130±0.011	0.668±0.001		
480 (*)					0.102±0.001	0.410±0.000

The values indicate mean of three measurements ± standard error, water content (X) in dry basis, drying time in minutes, a_W is water activity and (*): drying time until constant weight.

Table 3. Water content (X) and water activity (a_w) of dried commercial samples.

Sample	Experimental data	
	Water content(g/g db)	Water activity
Cranberry	0.173±0.005	0.550±0.001
Pineapple	0.101±0.001	0.574±0.001
Figs	0.254±0.003	0.689±0.001

The values indicate mean of three measurements ± standard error, water content in dry basis.

safe for consumption (Hii and Law, 2010; Jangam et al., 2008; Perera, 2005).

The water content and water activity of the commercial samples are presented in Table 3. The water content (0.196 g/g db) and water activity (0.633) were in agreement with the values reported for other fruits. Azeredo et al. (2006) reported the water content of 0.208 g/g db and water activity of 0.62 for dried mango, and Díaz et al. (2009) reported the water content of 0.269 g/g db and water activity of 0.692 for dried apple.

This can be compared with dried date palm fruits (*Phoenix dactylifera L*.), that was considered as safe and with better color and texture at 24 to 25% (0.32 to 0.33 db) (Chong and Law, 2011). Thus, we may confidently considered *V. infausta* as safe at the water content of 16.4% (wet basis) (0.196 db).

Sorption isotherms

The sorption isotherms of *V. infausta* pulp dried at 60 and 80°C are shown in Figure 2a,b. Each data point on the curves represents the mean of three measurements.

Different models have been used to predict the drying behaviour of fruit. One model used to predict water sorption isotherms, the GAB model, has been described by Visavale (2012) and Toledo (2007), Equation (1):

$$\frac{\;}{X} = \alpha \quad ^{2} + \beta \quad + \gamma \qquad \text{Equation (1)}$$

where X is the water content (db), a_W is the water activity, and α, β and γ were obtained by non-linear regression of the experimental data on water activity and water content.

The coefficients of the GAB equation are presented in Table 4 and the regression lines are shown in Figure 2a,b. The high regression coefficient of determination (R^2) shows that this model accurately describes the drying characteristics of *V. infausta* in the present study.

Texture analysis

Changes in the texture of dried *V. infausta* were determined throughout the drying process (Table 5a,b). It is obvious that the hardness and toughness increased with the increase in drying time and drying temperature. The hardness of the samples dried during 240 min increased from 0.11 to 3.10 N, and those samples dried until constant weight increased from 0.10 to 14.00 N. The toughness of the samples dried for 240 min increased from 0.2 to 3.8 N·mm, and the toughness of the fully dried samples ranged from 0.2 to 15 N·mm.

The hardness of the *V. infausta* pulp, and the pulp with added maltodextrin or sucrose was before drying: 0.17, 0.34 and 0.08 N (2.0 mm needle probe), respectively. These values are in agreement with values reported for the chempedak fruit *(Artocarpus integer)* (Chong et al., 2008a, b) (0.09 N) (2.0 mm cylindrical probe) and grape

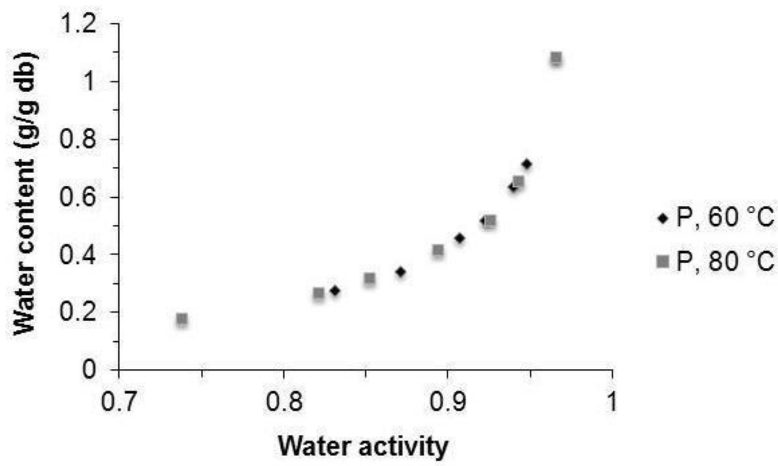

Figure 2a. Sorption isotherms of *v.A infausta* pulp dried at 60 and 80°C based on experimental data on dry basis.

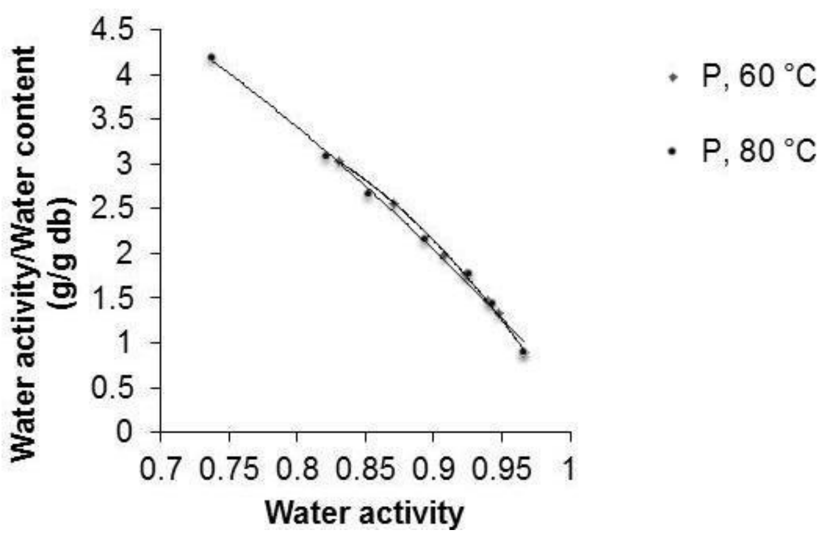

Figure 2b. Fitting GAB Equation to sorption isotherm of *V. infausta* pulp using experimental data and predicted (full line). The GAB model is described in Equation (1).

Table 4. Parameters of GAB adjustments applied to drying data

Sample (g/g db)	Drying air temperature (°C)	α	β	Ɏ	R^2
Pulp	60	-43.09	61.92	18.68	0.9983
Pulp	80	-10.96	4.96	6.48	0.9939

R^2 is coefficient of determination, α, β and Ɏ are coefficient of GAB, calculated by Equation (1), sample in dry basis, drying air temperature in degrees Celsius.

(Xiao et al., 2010) (0.62 N) (2.0 mm spherical probe). The hardness of the *V. infausta* pulp was 3 N when dried at 60°C, and 14 N when dried at 80°C (2.0 mm needle probe), which are similar to the values reported for dried

Table 5a. Toughness (P_t) and hardness (P_h) of dried samples during the drying procedure at 60°C.

Drying time (min)	**Pulp, 60 °C**		**Pulp add Md, 60 °C**		**Pulp add Suc, 60 °C**	
	P_t (N.mm)	**P_h (N)**	**P_t (N.mm)**	**P_h (N)**	**P_t (N.mm)**	**P_h (N)**
0	0.22±0.02	0.17±0.02	0.36±0.03	0.34±0.03	0.10±0.01	0.08±0.02
30	0.24±0.01	0.18±0.01	0.09±0.01	0.06±0.01	0.09±0.01	0.06±0.01
60	0.23±0.01	0.19±0.01	0.08±0.01	0.05±0.01	0.13±0.03	0.08±0.02
90	0.30±0.01	0.28±0.01	0.13±0.01	0.09±0.01	0.12±0.01	0.08±0.01
120	0.34±0.01	0.29±0.01	0.13±0.02	0.10±0.02	0.49±0.34	0.49±0.36
180	0.80±0.09	0.71±0.08	0.11±0.01	0.08±0.01	0.57±0.15	0.64±0.11
240	1.13±0.02	0.97±0.03	0.15±0.01	0.11±0.01	0.21±0.06	0.15±0.06
338 (*)	3.8±0.1	3.2±0.1				
486 (*)			1.0±0.2	1.0±0.2		
499 (*)					0.2±0.1	0.1±0.1

The values indicate mean of three measurements ± standard error, toughness (P_t) in N.mm, hardness (P_h) in N, drying time in minutes and (*): drying time until constant weight.

Table 5b. Toughness (P_t) and Hardness (P_h) of dried samples along the drying procedure at 80°C.

Drying time (min)	**Pulp, 80°C**		**Pulp add Md, 80°C**		**Pulp add Suc, 80°C**	
	P_t (N.mm)	**P_h (N)**	**P_t (N.mm)**	**P_h (N)**	**P_t (N.mm)**	**P_h (N)**
0	0.22±0.02	0.17±0.02	0.36±0.03	0.34±0.03	0.10±0.01	0.08±0.02
30	0.26±0.01	0.24±0.02	0.17±0.01	0.13±0.02	0.25±0.04	0.14±0.05
60	0.34±0.01	0.30±0.01	0.23±0.06	0.19±0.06	0.24±0.03	0.14±0.03
90	0.50±0.01	0.42±0.01	0.19±0.03	0.13±0.02	0.30±0.03	0.14±0.02
120	0.82±0.03	0.74±0.03	0.25±0.02	0.20±0.01	0.23±0.04	0.14±0.03
180	1.70±0.03	1.37±0.01	0.39±0.01	0.34±0.02	0.34±0.08	0.22±0.05
240	3.79±0.46	3.08±0.34	0.44±0.04	0.32±0.01	0.39±0.04	0.26±0.02
330 (*)	15.0±4.6	13.5±3.8				
385 (*)			8.7±1.9	8.5±2.2		
480 (*)					3.6±1.6	3.2±1.5

The values indicate mean of three measurements ± standard error, toughness (P_t) in N.mm, hardness (P_h) in N, drying time in minutes and (*): drying time until constant weight.

grapes: 10 N at 50°C, 14 N at 60°C and 17 N at 65°C (2.0 mm spherical probe) (Xiao et al., 2010) and dried chempedak fruit (Chong et al., 2008a) (3.39 N) (2.0 mm cylindrical probe). In addition to this, Chong et al. (2008a, b) reported that dried chempedak using sun drying and hot air drying has significant textural change as compared to fresh fruit. In addition, the combined drying method reported for dried mixed potato with apple chips: 7 N dried by microwave-freeze drying and 14 N dried by microwave vacuum drying (5.0 mm cylindrical probe) (Huang et al., 2011), are similar to the results reported in this study.

Adding maltodextrin or sucrose affected the hardness of the dried product. Drying at the higher temperature of 80°C resulted in a harder product: 3 N when sucrose was added and 9 N when maltodextrin was added, than drying at 60°C: 0.1 N with sucrose and 1 N with maltodextrin.

Statistical analysis using ANOVA showed that the relationship between the hardness and the toughness was linear, such that it could be expressed by the linear equation, Equation (2):

$$h \quad = + \qquad (2)$$

Where, is the hardness (N),is the toughness (N·mm), is the linear coefficient and b is the ordinate-intercept.

Table 6 presents the results of the linear regression of dried *V. infausta* pulp, and the pulp to which maltodextrin or sucrose had been added, coefficient and ordinate-intercept b, coefficient of determination (R^2), which were

Table 6. Analysis of linearity between hardness (P_h) and toughness (P_t).

Sample (g/g db)	Drying air temperature (°C)	a $(mm)^{-1}$	b (N)	R^2	Ɛ
Pulp	60	0.851	0.005	0.9997	0.006
Pulp	80	0.901	-0.076	0.9993	0.011
Pulp-Maltodextrin	60	0.972	-0.023	0.9962	0.027
Pulp-Maltodextrin	80	0.989	-0.055	0.9999	0.004
Pulp-Sucrose	60	1.189	-0.067	0.9864	0.063
Pulp-Sucrose	80	0.927	-0.094	0.9996	0.008

a is the linear coefficient and b is the intercept of linear regression, calculated by Equation (2), R^2 is coefficient of determination and Ɛ is the standard error.

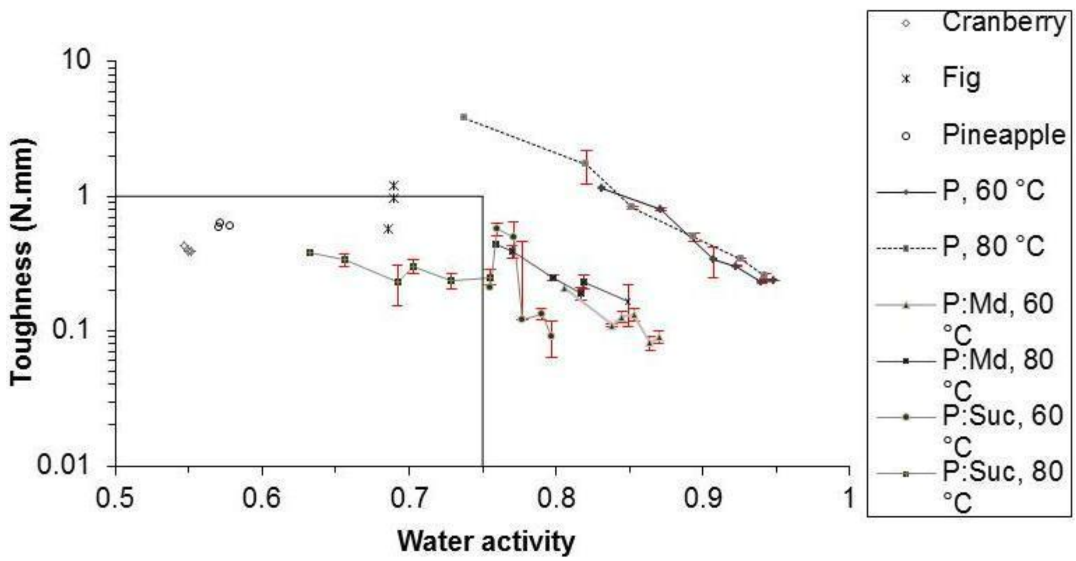

Figure 3. Toughness of dried samples as function of water activity, P - pulp, Md - Maltodextrin, Suc - Sucrose. The standard error of the commercial fruit was zero.

satisfactory and well within experimental standard errors. Kingsly et al. (2006) also reported a linear relationship between the hardness and the water content for dried pomegranate seeds (Anardana, *Punica granatum*). Thereby, it can be concluded that the critical texture can be equally well described by using either the hardness parameter or the toughness parameter.

Figure 3 shows the toughness as a function of water activity for dried *V. infausta*. We can note that each drying curve follows a trajectory with increasing tough-ness when the water activity is decreased. A possible commercial window can be defined if we consider the microbiological stability critical for the distribution and the toughness critical to the consumer perception of a dried fruit product. Possible limits of the commercial windows are for water activity values below 0.75 (Barbosa-Cánovas et al., 2003; Jangam et al., 2008) for toughness values below 1 N·mm.

The pure fruit samples form very tough structures before they reach a sufficiently low water activity to be distributed while the fruit samples with the added sucrose or maltodextrin become softer and display a drying trajectory passing through the commercial window. For comparative reasons, a few commercially dried products are included in the graph.

It should be noted that the sugars are added as dry material to the fruit pulp before drying. The solubilisation of the sucrose crystals as well as of the maltodextrin particles may be incomplete and the heterogeneity in the finally dried material may contribute to the softness.

Conclusions

The relationship between water content and water activity measured using the GAB model was found to be adequate to predict the dried *V.* infausta models for water sorption isotherms. The high coefficient of determination demonstrates that this model describes the drying characteristics in a reliable way.

The drying time is determined by the drying parameters such as temperature. Reduced water content lowers the water activity and create microbiologically stable products (aw < 0.75) at water contents below 0.2 g/g db. However, the drying also leads to an increase in hardness and toughness. An increase in drying temperatures resulted in high values of hardness and toughness. The hardness and toughness were linearly correlated making the use of both parameters to characterize the samples unnecessary. The toughness trajectory described by a fruit pulp sample never passes through the commercially possible window defined by an attractive texture and a suitable water activity. Thus, there is a need to use a softening component when drying the fruit of *V. infausta*. The use of maltodextrin and sucrose in order to soften the dried product resulted in drying trajectories passing through the commercial window.

Further work is required to investigate the level of sugar required for better softening of the dried *V. infausta* and for reducing water activity and water content.

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