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MOISTURE-DEPENDENT PHYSICAL PROPERTIES OF SEEDLESS AND SEEDED RAISIN (*VITIS VINIFERA* L.) VARIETIES

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ABSTRACT. Some physical properties of seedless and seeded raisin berries varieties were evaluated as a function of moisture content, varying from 16.12% to 35.63% (d.b.) for seedless berries and from 17.33 to 34.41% (d.b.) for seeded raisin berries. The average dimensions, shape, and mass of the both raisin berries increased as moisture content increased. The mass of 1000 berries increased linearly. Besides, in seedless berries, the bulk density increased, the true density and porosity decreased, while in seeded berries the bulk and true density decreased, but porosity increased. The Weibull distribution model statistically characterized raisins on the basis of berries dimensions for classifying and separating targets. The results indicate that classifying raisin berries by means of bivariate Weibull distribution in terms of the length and width is useful in describing the process under study and designing or calibrating the hole sizes of classifiers machinery.

Key words: Physical properties; Moisture content; Raisin berries; Weibull distribution; Classification; Dried fruits; South Azerbaijan.

INTRODUCTION

In the commercial and industrial processing of the sun-dried or field-dried raisins, the products are purchased from the rural raisin producers and transported to the plants, where they are stored in bulk, before further processing (Karimi *et al.,* 2011). Raisins contain stems, soil and some other contaminants, which are usually removed by washing with water. The raisins that are transported to the plant have initially different moisture content in range of 16 to 18%, therefore washing of the raisins at the plant increases their moisture content in range of 20 to 35% depending on initial moisture contents of them and the time of washing process (Karathanos *et al.,* 1995). In order to prepare raisins for fresh consumption and food industry, after washing process, they are conveyed to the drying house, dried (to16-17%

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moisture content), and then separated, classified and packaged. As more emphasis is placed on raisin berries quality, the need for separation and classification will become more prominent. Classification of raisins can be based on screen size. For optimizing the classification stages, it is useful to simulate the process and characterize raisin berries on the basis of dimension by statistical models (Karimi *et al.,* 2015). For example, it is possible to simultaneously classify raisin berries by means of three-parameter Weibull distribution in terms of the length and the width in order to design, calibrate and determine the hole sizes of classifiers and separating machinery.

Physical properties of agricultural crops and products as a function of moisture content are necessary for designing, improving and optimizing the equipments and analyzis of their behavior during agricultural and industrial processes such as handling, transporting, washing, drying, cleaning, grinding, malting, separating, sorting, storing and classifying (Mansouri *et al.,* 2011; Karababa and Coşkuner, 2013). Review of the literature has revealed that the physical properties of raisin at various levels of moisture content have not been studied. The aim of this study was to investigate some physical properties of two raisin varieties (seedless and seeded raisins) at moisture contents ranging from 16.12% to 35.63% (d.b.) for seedless berries and from 17.33 to 34.41% (d.b.) for seeded raisin berries, respectively. The examined properties include: characteristic dimensions, shape (geometric mean diameter and sphericity), surface area, mass, density, and porosity. The other object of this investigation was to analyze the experimental data to apply the Weibull distribution for classifying of raisin berries. The results obtained were subjected to analysis of variance (ANOVA) using SPSS 10.0 software and analysis of regression using Microsoft excel.

MATERIALS AND METHODS

The examined materials were seedless golden bleached raisins “GBR”, and seeded raisins “Faxri” produced from Thompson seedless grapes and Qizil Üzüm seeded grapes, respectively. The raisins were produced by sun drying and hanging the grape bunches outdoors at the village of Qurucan, near Tabriz in South Azerbaijan.

The initial moisture content of the sun dried raisin berries as brought from the village drying yard was determined by the vacuum oven (70°C for 48 hours under vacuum) method (Karathanos *et al.,* 1995; Karimi *et al.,* 2011). The initial moisture content of the seeded and seedless berries was found to be 16.12 and 17.33% (d.b.), respectively. Subsequently, for obtaining the desired moisture levels for the investigations, samples of sun-dried raisins were immersed in calculated quantity of tap water based on Eq. (1):

$$Q = W_i (M_f - M_i)/(100 - M_f) \quad (1),$$

where Q is the mass of water to be added in kg; W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % (d.b.), and M_f is the final moisture content in % (d.b.). The samples were sealed in plastic bags and kept in a refrigerator at 5 ºC for a week for the moisture to distribute uniformly throughout the berries (Konak *et al.,* 2002). Before conducting each test, the moisture content of samples was determined after equilibration. The required amount of samples were taken out of the refrigerator and reconditioned at room temperature (≈22ºC) before carrying out each test. All the physical properties of the raisin berries were assessed at moisture levels of 16.12, 20.36, 25.58, 31.74, and 35.63% (d.b.) for seedless raisins and 17.33, 21.24, 26.51, 30.46 and 34.41% (d.b.) for seeded raisins.

The size was determined at each moisture content by measuring the dimension of the principal axes; major (L) was defined as the length, intermediate (W) was defined as the width, and minor diameters (T) was defined as the thickness of 100 randomly selected berries. The dimensions of the berries were measured using a digital caliper with an accuracy of 0.01 mm. The mass of 1000 berries was determined by counting 100 berries at the desired moisture content and weighing on a digital electronic balance with an accuracy of 0.001 g distinctively for each berry, and then multiplying by 10 to give the mass of 1000 berries.

The geometric mean diameter (D_g) and sphericity (Φ) were calculated at each moisture content using the equations of Mohsenin, 1986. The Weibull distribution was used in this study to characterize raisin berries' size distribution. The Weibull cumulative distribution function (CDF) has the following form:

$$f_{we}(x) = 1 - \exp[-(x-\gamma/\beta)^{\alpha}] \quad (2),$$

where α, β, and γ are the shape, scale and location parameters of the Weibull distribution, respectively, and x is the independent variable corresponding to the length (L), width (W) or thickness (T) of raisin berries.

Bulk density, calculated as the ratio between the mass of a sample of raisins and the total occupied volume, was determined by pouring berries in the calibrated container from a height of 15 cm, striking off the top level and then weighing the contents. The true density is defined as the ratio of the mass of a sample berry to the solid volume occupied by the sample. The true density was determined using the water displacement method (Karimi *et al.,* 2011). The true and bulk densities were examined within five replicates. The porosity (ε) is the fraction of the space in the bulk of crops, which is not occupied by the crop. The porosity (ε) was determined using the formula of Mohesenin, 1986.

RESULTS AND DISCUSSION

Berry dimension

The length, width, and thickness of seedless raisin berries increased (*Fig. 1, a*) significantly ($p< 0.01$) from 11.94 to 13.68 mm, 8.97 to 11.28 mm and 6.27 to 8.81 mm, respectively, with the increase in moisture content from 16.12 to 35.63% (d.b.), and for seeded raisin berries these values increased (*Fig. 1, b*) significantly ($p< 0.01$) from 16.87 to 21.23 mm, 10.08 to 13.48 mm and 7.11 to 9.83 mm, as the moisture content increased from 17.33 to 34.41 (d.b.). The relationship between the principal dimensions (L, W and T) and the moisture content of seedless raisin berries are obtained as:

$$L_1 = -0.001\, M_c^2 + 0.179 M_c + 9.551 \qquad R^2 = 0.992 \qquad (3)$$
$$W_1 = -0.003\, M_c^2 + 0.285 M_c + 5.248 \qquad R^2 = 0.986 \qquad (4)$$
$$T_1 = -0.004\, M_c^2 + 0.375 M_c + 1.503 \qquad R^2 = 0.997 \qquad (5)$$

and for seeded berries:

$$L_2 = 0.26\, M_c + 12.58 \qquad R^2 = 0.975 \qquad (6)$$
$$W_2 = -0.010\, M_c^2 + 0.744\, M_c + 0.104 \qquad R^2 = 0.974 \qquad (7)$$
$$T_2 = -0.013\, M_c^2 + 0.855 M_c - 3.511 \qquad R^2 = 0.984 \qquad (8)$$

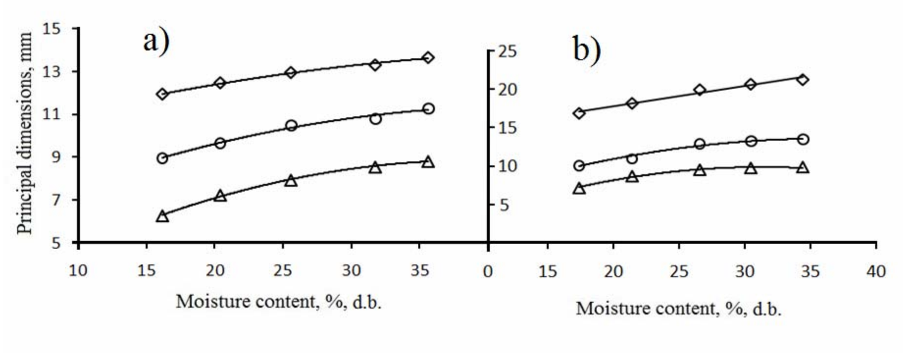

Figure 1 - Variation of the principal dimensions of seedless (a) and seeded (b) raisin berries: (□) length; (○) width; (Δ) thickness

The mean dimensions show an increase of 15%, 27% and 40% in length, width and thickness of seedless raisin berries, respectively, due to a change in moisture level from 16.12 to 35.63% (d.b.). The average expansion from 17.33 to 34.41% (d.b.) berry moisture content in length, width and thickness of seeded berries was 24%, 35% and 39%, respectively. These results indicate that during the moisture desorption process (such as drying), the raisin berries will show some decrease in width and thickness (rather than the length) with moisture. Moreover, the changes in the dimensions with increase in moisture content could be reflected in changes in the projected area of berries that influence airflow resistance and pressure drop during in-bin drying, aeration and air-cleaning operations thereby affecting the efficiency of these operations. Similarly, Işikli and Yilmaz (2011) have reported polynomial and linear relationship for the dimensions of sun-dried Berberis fruits.

Statistical modeling

Some physical properties of seedless and seeded raisin berries by mean values, ranges and standard deviations at the safe moisture contents (16.12% for seedless raisins and 17.33% d.b. the seeded raisin berries), are shown in *Table 1*.

Table 1 - Dimensional characteristics of the seedless and seeded raisin berries and their Weibull parameters

Characteristics	Raisin type	Mean value	Range of values	Standard deviation	Weibull parameters		
					α	β	γ
Length (mm)	Seedless	11.94	6.4 – 17.36	2.03	7.13	13.00	0.28
	Seeded	16.87	10.23 – 20.93	2.25	12.58	24.01	-6.17
Width (mm)	Seedless	8.97	5.36 – 14.15	1.5	3.79	5.72	4.41
	Seeded	10.08	6.72 -12.93	1.39	3.78	5.18	5.30
Thickness (mm)	Seedless	6.27	4.01 – 10.38	1.26	-	-	-
	Seeded	7.11	5.05-9.37	1.07	-	-	-

Using "easy fit" as a tool program of Kolmogorov-Smirnov testing proof for the both seedless and seeded berries depicted that the Weibull distribution has a better fit. The main parameters of the Weibull distributions for each dimension of the seeded and seedless berries to give the empirical models are presented in *Table 1*. Cumulative density function (CDF) of the Weibull distribution in terms of the length (*l*) and the width (*w*) of the seedless raisins berries by using intervals of 1 mm is:

$f_{we,1}(l_1) = 1 – \exp[– (l_1 – 0.28/13)^{7.13}]$, $\quad l_1 = [6, 7,\dots 16, 17]$ (9)

$f_{we,1}(w_1) = 1 – \exp[– (w_1 – 4.41/5.72)^{3.79}]$, $\quad w_2 =[5, 6,\dots 13, 14]$ (10)

and for the seeded raisins is:

$f_{we,2}(l_2) = 1 – \exp[– (l_2 +6.17)/24.01)^{12.58}]$, $\quad L_2=[10, 11,\dots 20, 21]$ (11)

$f_{ew,2}(w_2) = 1 – \exp[– (w_2 – 5.3)/5.18)^{3.78}]$, $\quad w_2 =[6, 7, \dots 12, 13]$ (12)

By using equations Eq. 9, 10, 11 and 12, utilizing the information from *Table 1*, and applying Matlab R2011a as a tool program it is possible to write the empirical model with nonlinear equations including both of the variables (the length and width) as a cumulative distribution function (CDF) for raisins berries:

$F(l, w) = f(l) \times f(w)$ (13)

$F(l, w) = (1– e^b) \times (1– e^c)$ (14),

for seedless berries:

$F_1(l_1, w_1) = 6.103 \times (m.n.e^b.e^c)$ (15),

where $b = – (l_1 – 0.28/13)^{7.13}$,

$c = – (w_1 – 4.41/5.72)^{3.79}$,

$m = – (l_1 – 0.28/13)^{6.13}$ and

$n = – (w_1 – 4.41/5.72)^{2.79}$

and for seeded berries:

$F_2(l_2, w_2) = 8.015 \times (m.n.e^b.e^c)$ (16),

where $b = – (l_2 + 6.17)/24.01)^{12.58}$,

$c = – (w_2 – 5.3)/5.18)^{3.78}$,

$m = – (l_2 + 6.17)/24.01)^{11.58}$ and

$n = – (w_2 – 5.3)/5.18)^{2.78}$.

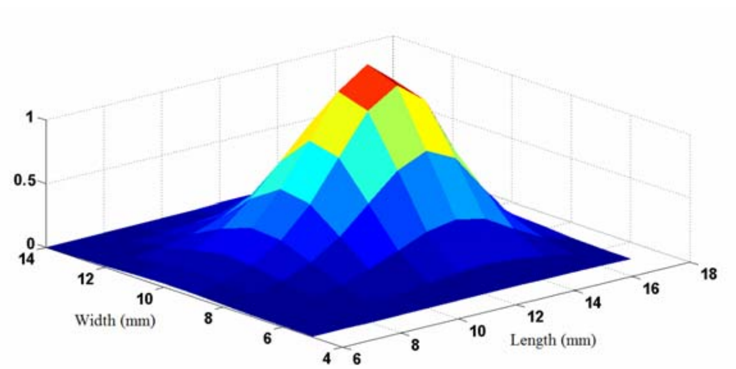

Figure 2 - Bivariate cumulative distribution function of Weibull for seedless raisin berries

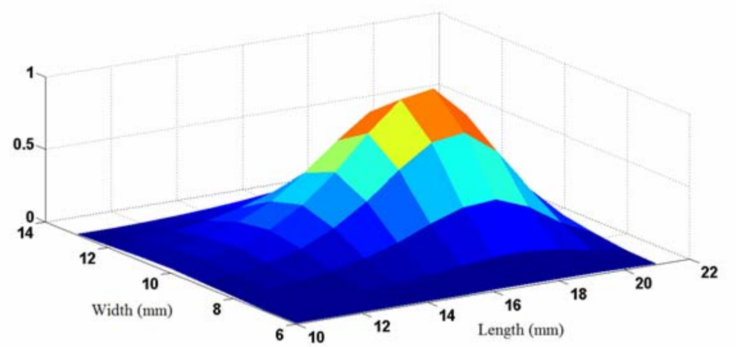

Figure 3 - Bivariate cumulative distribution function of Weibull for seeded raisin berries

The results of the relations No. 15 and 16 are graphically observed in *Fig. 2* and *Fig. 3*, respectively. Using sample data, a classification system can produce an updated basis for improved classification of subsequent data from the same source, and express the new basis and models that can be used to interpret new, unseen test data and to develop and optimize new machineries (Sun, 2008). Similarly, these graphs can be used for identifying and distinguishing desired and undesired raisins or unwanted materials in separating or sorting process. Practically, curves of two components of mixture (desired and undesired raisins) overlap so that it is not possible to completely separate the mixture by class. However, by using a combination of two criteria, for example, the length and the width, the mixture could be classified and separated (Klenin *et al.*, 1986). In other words, in the condition of existing a large degree of overlap between intact (desired raisins) and defective berries (undesired raisins), determining the hole (orifice) size of classifier and separator screens based on the only one dimension is not reasonable and feasible. It can be an ameliorated way to simultaneously apply bivariate Weibull model for two dimensions of defective and intact berries together in order to decrease the overlap between intact and defective berries and determine the appropriate hole size of separator screens.

Geometric mean diameter

The results showed (*Fig. 4, a*) that geometric mean diameter of seedless berries increased ($p< 0.01$) from 8.37 to 11.27 mm when the moisture content increased from 16.12 to 35.63% (d.b.). As shown in *Fig. 4 (a)* as the moisture content increased from 17.33 to 34.41% (d.b.), geometric mean diameter of seedless berries increased ($p< 0.01$) from 10.24 to 14.67 mm (*Fig. 4, a*). The relationships between geometric mean diameter of seedless and seeded raisin berries and moisture content can be expressed with the following polynomial equations, respectively:

$$D_{g,1} = -0.003\, M_c^2 + 0.326\, M_c + 4.110 \qquad R^2 = 0.987 \qquad (17)$$

and for seeded raisin berries:

$$D_{g,2} = -0.007\, M_c^2 + 0.642\, M_c + 1.407 \qquad R^2 = 0.984 \qquad (18)$$

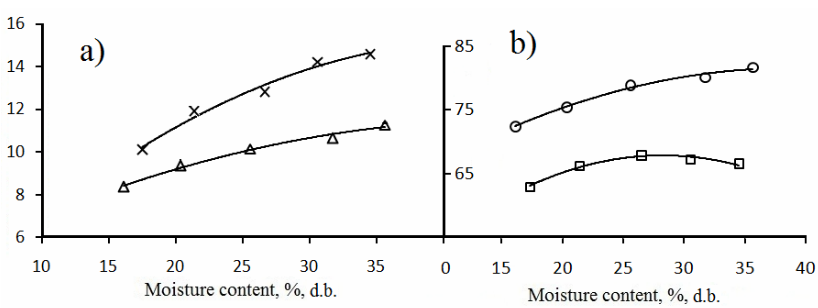

Figure 4 - a) Variation of geometric mean diameter of raisin berries with moisture content: seedless berries (∆); seeded berries (×), b) Sphericity: seedless berries (○) and seeded berries (□)

Sphericity

The results showed (*Fig. 4, b*) that sphericity of seedless raisin berries increased ($p< 0.01$) polynomial from 72.42 to 81.79% as the moisture content increased from 16.12 to 35.63% (d.b.).

The value of sphericity for seeded raisin berries was found increased ($p< 0.05$) from 62.82% to 67.7% as the moisture content increased from 17.33 to 26.51% (d.b.) and then decreased from 67.7% to 66.37%, when the moisture content increased from 26.51% to 34.41% (d.b.), as showed in *Fig. 4 (b)*. Similar initial increasing and subsequent decreasing in sphericity has been reported by Sologubik *et al.* (2013) for barley grains. The relationship between moisture content and the sphericity (Φ) of seedless and seeded raisin berries could be described with the following polynomial equations, respectively:

$$\Phi_1 = -0.017\, M_c^2 + 1.382\, M_c + 54.82 \qquad R^2 = 0.988 \qquad (19)$$
$$\Phi_2 = -0.040\, M_c^2 + 2.283\, M_c + 35.57 \qquad R^2 = 0.980 \qquad (20)$$

Thousand berries mass

The one thousand berries mass of seedless raisins increased ($p< 0.01$) from 5.92 to 7.31 g, as the moisture content was increased from 16.12 to 35.63% (d.b.), while that of the seeded berries increased ($p< 0.01$) from 7.5 to 10.12 g in the moisture range of 17.33–34.41% (d.b). The mass of seeded and seedless raisin berries was found to have the following linear relationships with moisture content:

$$m_1 = 0.069M_c + 4.799 \qquad R^2 = 0.992 \qquad (21)$$
$$m_2 = 0.150M_c + 4.985 \qquad R^2 = 0.988 \qquad (22)$$

These results were similar to hackberry fruits (Demir *et al.,* 2002), areca nut kernels (Kaleemullah and Gunasekar, 2002), gumbo fruits (Akar and Aydin, 2005), and caper fruits (Sessiz *et al.,* 2006).

Bulk and true density

As shown in *Fig. 5 (a)* the bulk density of seedless raisin (GBR) increased polynomial and significantly ($p< 0.01$) from 750.57 to 806.38 kg/m^3 with increase in the moisture content from 16.12 to 35.63% (d.b). The relationship between bulk density and moisture content of raisin berries can be represented by the following equation:

$$\rho_{b,1} = -0.102\, M_c^2 + 8.146M_c + 645.5 \qquad R^2 = 0.994 \qquad (23)$$

On the contrary, the bulk density of seeded raisin (Faxri) decreased linearly ($p< 0.01$) from 831.91 to 701.02 kg/m^3 with increase in the moisture content from 17.33 to 34.41% (d.b.). The decrease in bulk density of raisin berries with increase in moisture content indicates that the increase in the volume of raisin bulk is more than the mass increased owing to moisture gain in the berry and the inside seeds. Linear decrease of bulk density as the moisture content increases was found by Pradhan *et al.* (2009) for jatropha fruits, Dursun and Dursun (2005) for caper seed and Nimkar and Chattopadhyay (2001) for green grams. The bulk density of seeded berries is found to have the following linear relationship with moisture content:

$$\rho_{b,2} = -7.956M_c+964.3 \quad R^2 = 0.978 \quad (24)$$

The true (berry) density of seedless and seeded raisins at the examined moisture levels varied linearly from 1409.41 to 1212.56 kg/m^3 and from 1371.24 to 1261.63 kg/m^3 (*Fig. 5, a*). The decrease in true density values with increase in moisture content may be attributed to the relatively higher rate of increase in each individual berry volume as compared to the corresponding mass of the berries obtained owing to adsorption of water. The variation in true density with moisture content of seeded and seedless raisin berries was significant at a significance level of 0.05 and 0.01, respectively. The negative linear relationship of true density with moisture content is also observed by various other researchers for several products such as chickpea seeds (Konak *et al.,* 2002), green gram (Nimkar and Chattopadhyay, 2001), and pea seed (Yalçin *et al.,* 2007). The following linear regression equations were developed for true density of seedless and seeded raisin berries:

$$\rho_{t,1} = -10.07\ M_c+1556 \quad R^2 = 0.930 \quad (25)$$
$$\rho_{t,2} = -6.619\ M_c+1482 \quad R^2 = 0.979 \quad (26)$$

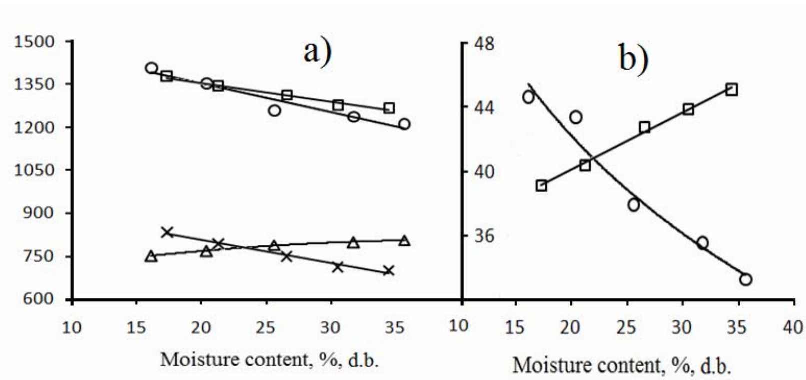

Figure 5 - Effect of moisture content on a) density: true density of seedless raisins (○), true density of seeded raisins (□), bulk density of seedless raisins (Δ) and bulk density of seeded raisins(×), and b) porosity: seedless raisins (○) and seeded raisins (□)

Porosity

It was observed (*Fig. 5, b*) that when moisture content of seedless raisins increased from 16.12 to 35.63% (d.b.), porosity decreased significantly ($p<0.05$) and logarithmically from 44.64 to 33.27%.

The explanation of this decrease can be as follows: as the berries gain moisture, their shrinkage decreases and their volume increases, especially due to the increment of their thickness and width (more than the length). Decreasing shrinkage of berries causes the bulk density of them to increase. At the same time, the uptake of water by the berries semi-solid structure leads to a decrease in their true density. It means that, for a given mass of raisin, an increase in the moisture content results in lower true density, higher bulk density. Consequently, ratio of bulk density to true density increases and based on the porosity equation decreases. Similar behavior was reported for onion seeds, corns and sunflower seeds (Kocabiyik *et al.,* 2004). The variation in porosity with moisture content of raisin berries can be presented by following equation:

$$\varepsilon_1 = -14.9 \ln(M_c) + 87.09 \qquad R^2 = 0.966 \qquad (27)$$

The porosity of the seeded raisins increased gradually and significantly ($p < 0.05$) as the moisture content was increased. As seen from *Fig. 5 (b),* the porosity of the seeded raisins increased linearly from 39.15 to 45.11% as the moisture content increased from 17.33 to 34.41% (d.b). In comparison with the seedless raisin berries, the seeded berries because of having the inside seeds represent more intrinsic rigid structure, and therefore increasing moisture content results in expansion and swelling of berries and causes more void space between the berries. Similar observations were reported for areca nut kernels (Kaleemullah and John Gunasekar, 2002), barley grains (Sologubik *et al.,* 2013), and gumbo fruits (Akar and Aydin, 2005). The moisture dependence of seeded berries porosity is described by a linear relationship as follows:

$$\varepsilon_2 = 0.305 M_c + 34.38 \qquad R^2 = 0.979 \qquad (28)$$

CONCLUSIONS

In this study, some physical properties of seedless and seeded raisin berries varieties were evaluated as a function of moisture content varying from 16.12% to 35.63% (d.b) for seedless berries and from 17.33% to 34.41% (d.b.) for seeded raisin berries.

In seedless raisin berries, the average length, width, thickness, sphericity, and the geometric mean diameter of berries were found to increase polynomial. The 1000 berries mass increased linearly. The bulk density increased polynomial, while the true density and porosity decreased linearly and logarithmically, respectively.

In seeded raisin berries, the average length increased linearly, width, thickness, and the geometric mean diameter were found to increase polynomial. Sphericity increased polynomial as the moisture content increased from 17.33 to 26.51% (d.b.) and then decreased when the moisture content increased from 26.51% to 34.41% (d.b). The mass increased linearly. The bulk and true density decreased, while porosity increased linearly.

The two dimensions (the length and width) of seeded and seedless raisin berries, at the moisture content of 16.12 and 17.33% (d.b.), were simultaneously subjected to the Weibull distribution in order to characterize, describe and simulate size distribution of the berries. Characterization of raisin berries as a function of two variables, namely the length and width, made by cumulative distribution function (CDF) of the expanded bivariable Weibull model is a good computational tool in giving practical results in selecting machinery, designing, simulating, validating and determining the holes sizes of raisin berries classifiers and separator cleaners.

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