Physical Characteristics of Corn (*Zea mays* L.) Grains

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Abstract:

Various physical characteristics of two different varieties of corn grains were evaluated as a function of moisture content in the range of 10 to 20% (w.b). Mathematical models describing the change of physical characteristics as dependent variables with moisture content as independent variable were studied. The average length of corn grains increased from 10.81 to11.41mm and from 9.90 to 10.52mm; the width increased from 9.12 to 9.71mm and from 8.19 to 8.64mm; the thickness from 4.64 to 5.24mm and from 5.39 to 5.54mm for Taiz-2 and Taiz-3 varieties, respectively as the moisture content increased from 10 to 20 %. The sphericity of corn grains was linearly increased for Taiz-2 variety, while it was linearly decreased for Taiz-3 variety. The thousand grains mass was linearly increased for the two varieties. The porosity was linearly decreased for Taiz-2 variety, while it was linearly increased for Taiz-3 variety. Each of the bulk and true densities were decreased with the increase in moisture content for the two varieties. The static friction coefficient of grains on various surfaces increased with the increase in moisture content for the two varieties of corn grains. Plywood as a surface for sliding offered the maximum friction followed by galvanized iron and stainless steel. The developed mathematical models were highly accurate and can be used to describe the physical characteristics as a function of moisture content of other corn grains varieties.

Keywords: Physical characteristics, moisture content and corn grains.

Introduction:

Cereal crops represent the chief items in the diet for world people because they are a comparatively cheap source of calories, and playing an important role in the economics of many countries. Corn is one of the leading food crops of the word and one of the most important crops produced in Yemen. Its total area in 2018 was (32,762) hectares, with a total production of (36,438) metric tons, with an average yield of (1.112) ton/Ha (Agric. Stat. Yearbook 2019). Little researches concerning physical characteristics and mechanical properties of local cereal crop and the effects of moisture content on them are available in Yemen.

Data on physical properties of agro-food materials are valuable because: they are needed as input to models predicting the quality and behavior of produce in pre-harvest, harvest, and post-harvest situations; and aid the understanding of food processing. (Nesvadba, *et al.*, 2004). The physical properties of grains are essential for the design of equipment for handling, harvesting, aeration, drying, storing, and processing. These properties are affected by numerous factors such as size, form, superficial characteristics, and moisture content of the grain (Baumler, *et al.*, 2005). Physical characteristics of the material such as shape, size, volume, density and surface area; and mechanical properties such as stress-strain behavior, resistance to compression, impact and shear, and coefficient of friction are important and essential engineering data in design of machine, structures, and controls; in analyzing and determining the efficiency of a machine or an operation; and in evaluating and retaining the quality of the final product (Mohsenin, 1986). Bulk density, true density, and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes (Seifi and Alimardani,2010). The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute (Varnamkhasti, *et al.*, 2007). Hence, this study was performed to establishing a database on the physical characteristics of some local corn varieties grains namely, dimensions, sphericity, thousand grain mass, bulk density, true density, porosity, and static coefficient of friction as a function on moisture content.

Materials and Methods:

Two varieties of corn grains were used in this study from the prevalent varieties in the median area of Yemen. These varieties were Taiz-2 and Taiz-3 which obtained after harvesting, shelling, and drying of the 2017 crop. The initial moisture content of each variety was determined, which were 10.6%, and 9.12% for Taiz-2 and Taiz-3 varieties, respectively. The desired moisture content levels of grains nominal 10,15,17, and 20% ±1% (w.b) were achieved by one of two methods, natural drying or moistening the grains by calculated amount of water (Sacilik *et al.*,2003). The initial moisture content of grains was determined by oven method (ASAE Standards,1992).

To determine dimensional characteristics of grains namely: length(L), width (W) and thickness(T) randomly samples of 50 grains were taken out from each variety for each level of moisture content, a digital caliber with an accuracy 0.01mm was used. The equivalent diameter (D_e) and sphericity (S) of grains were calculated by using the following relations (Sahay and singh,1994).

$$D_e = (L \times W \times T)^{1/3} \qquad (1)$$

$$S = \frac{D_e}{L} \qquad (2)$$

Mass of one thousand grains was measured by counting randomly samples of one hundred grains and weighted them by an electric digital balance with an accuracy 0.001g and multiplied by 10 to give mass of 1000 grains.

The bulk density was determined by filling a known volume graduated cylinder (500ml) with the grains from a height of 15cm at constant rate, and the base of the cylinder was tapped a dozen times on a table (Boumans,1985). Then, the cylinder was refilled again to its maximum reading (500ml). The grains in the cylinder were weighed and the bulk density was calculated (kgm^{-3}) by dividing the mass of grains (kg) on its volume (m^3). The particle density was determined by measuring the volume of a known weight of a random grains sample. The actual volume of the grains was determined using the Toluene displacement method (Matouk, et al., 2004). The porosity was calculated using the following relation (Mohsenin, 1986):

$$P = (\rho_p - \rho_b) / \rho_p \qquad (3)$$

Where

P = the porosity, %

ρ_p = particle density, kgm^{-3}.

ρ_b = bulk density, kgm^{-3}.

A manual static friction coefficient measuring apparatus was described by (Soliman,1994) was used to measure the angle of friction (α) in ten replicates for each level of moisture content of the studied varieties on three different material surfaces namely: Plywood sheet, Galvanized iron sheet and Stainless-steel sheet. Then, the static coefficient of friction (μ) was calculated as follow (Ozarslan, 2002).

$$\mu = \tan \alpha \qquad (4)$$

Results:

1. Dimensional Characteristics:

The measurements of length (L), width (W) and thickness (T) in (mm) of every sample grains for each moisture level samples for the two varieties (Taiz-2 and Taiz-3) were conducted and demonstrated in figures (1).

The sphericity (S, %) of each grains varieties were calculated and demonstrated in figure (2).

Regression statistical analysis were conducted to clarify the relationship between each item of physical dimensions and actual moisture content. The regression appeared a linearly dependent on the moisture content. Therefore, the following linear regression equations were developed in order to describe the relationship between each dimensional parameter and the actual moisture content percent (w.b):

$L_{T2} = 10.20334 + 0.060263Mc$ $R^2 = 0.99978$

$L_{T3} = 9.349115 + 0.058579Mc$ $R^2 = 0.99972$

$W_{T2} = 8.524221 + 0.059397Mc$ $R^2 = 0.999863$

$W_{T3} = 7.790248 + 0.042461Mc$ $R^2 = 0.99948$

$T_{T2} = 4.029005 + 0.060381Mc$ $R^2 = 0.999639$

$T_{T3} = 5.256557 + 0.014194Mc$ $R^2 = 0.998037$

$S_{T2} = 69.41196 + 0.185653Mc$ $R^2 = 0.999787$

$S_{T3} = 77.56311 - 0.09742Mc$ $R^2 = 0.999934$

The results showed that the relationship between dimensional characteristics and moisture content of the studied corn grains were similar in trend with the results of (Seifi and Almardani,2010) which work on corn grains, (Matouk, *et al.*, 2004) which work on different cereals as barley, rice, wheat and corn, (Al-Mahasneh and Rababah, 2006) which worked on green wheat, (Soliman, *et al.*, 2009) which work on wheat grains and (Karababa, 2005) which worked on popcorn.

The results indicated that Taiz-2 variety have the higher length and width than Taiz-3 variety, while Taiz-3 have higher thickness and sphericity than Taiz-2.

2. Mass of one thousand grains:

The mass of one thousand corn grains (WTG) as a function of moisture content wet basis were demonstrated in figure (3). Linear relationship for one thousand grain mass based on moisture content was determined as follows.

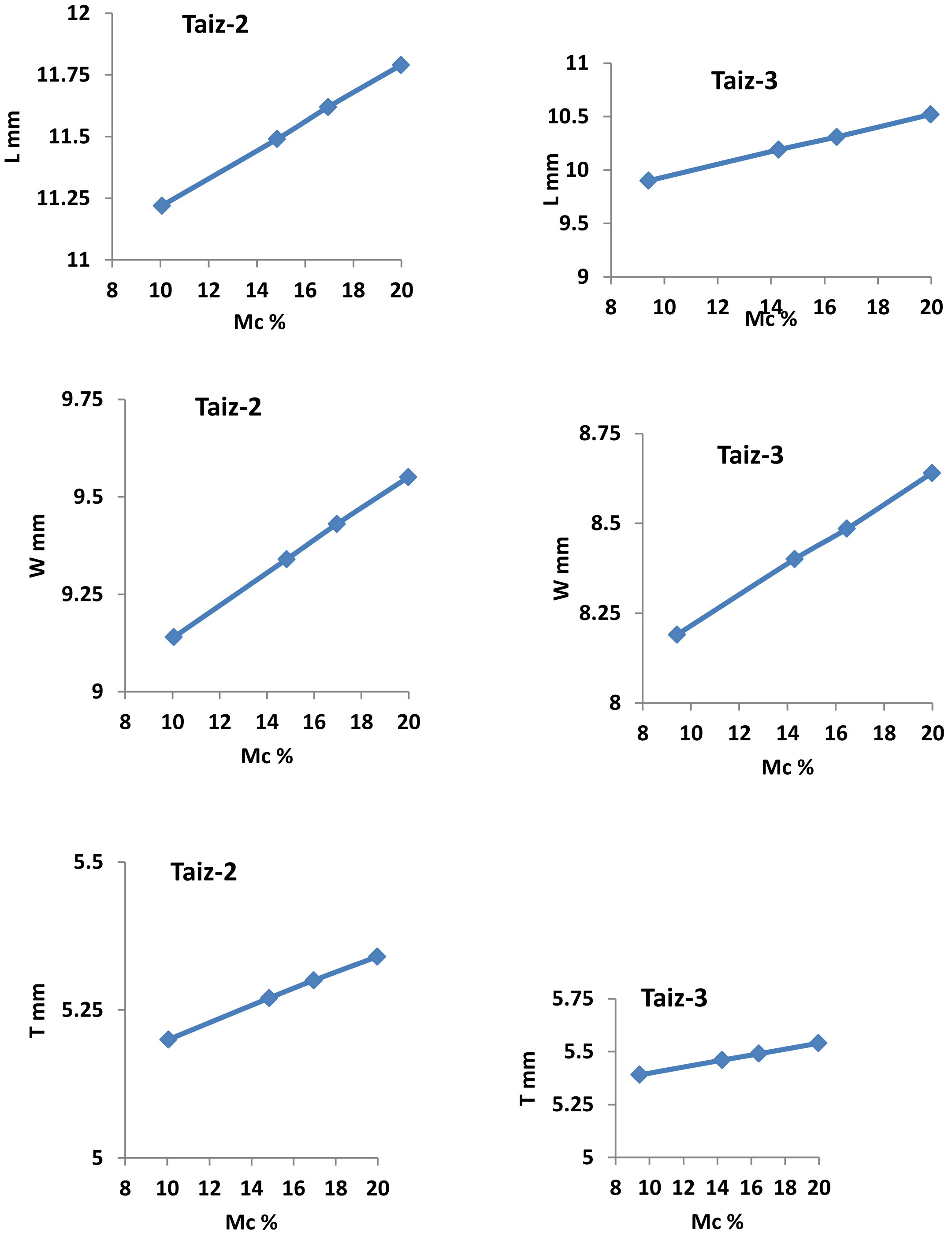


Fig.(1): Effect of moisture content on grains dimensions.

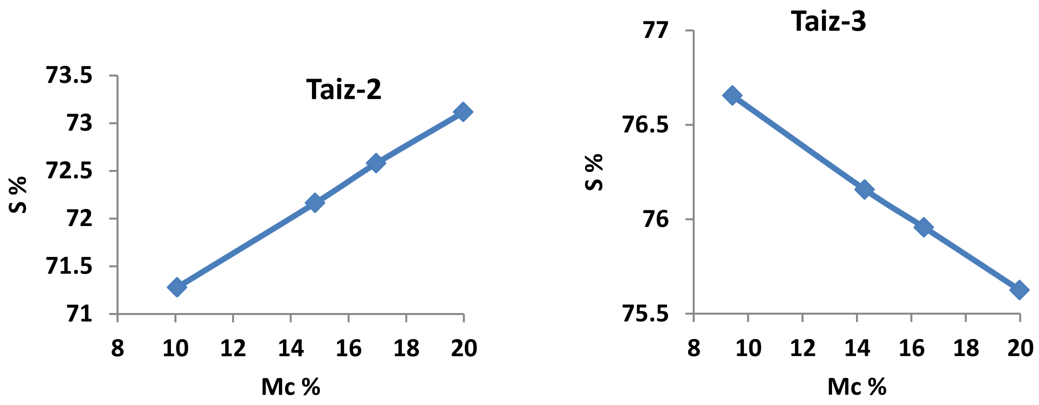


Fig.(2) Effect of moisture content on grains sphericity.

$$WTG_{T2} = 338.6079 + 2.923324Mc \qquad R^2 = 0.999952$$
$$WTG_{T3} = 265.8303 + 3.905718Mc \qquad R^2 = 0.998373$$

Taiz-2 variety recorded the highest values of mass of one thousand grains, which varied, from 368 to 396.95g for increasing grains moisture content from 10.06 to 19.98% (w.b). While, Taiz-3 variety showed the lowest mass of one thousand grains which varied from 303 to 344.38 g for increasing grain moisture content from 9.12 to 19.98% (w.b). The results agreed with experimental data of (Seifi and Almardani,2010) for corn grains, (Matouk, *et al.*, 2004) for some Egyptian wheat varieties, (Al-Mahasneh and Rababah 2006) for green wheat kernels, (Baryeh 2002)for millet, (Amin *et al.*, 2004)for lintel seeds,(Altuntas *et al.*, 2005) for fenugreek and (Karababa 2005) for popcorn.

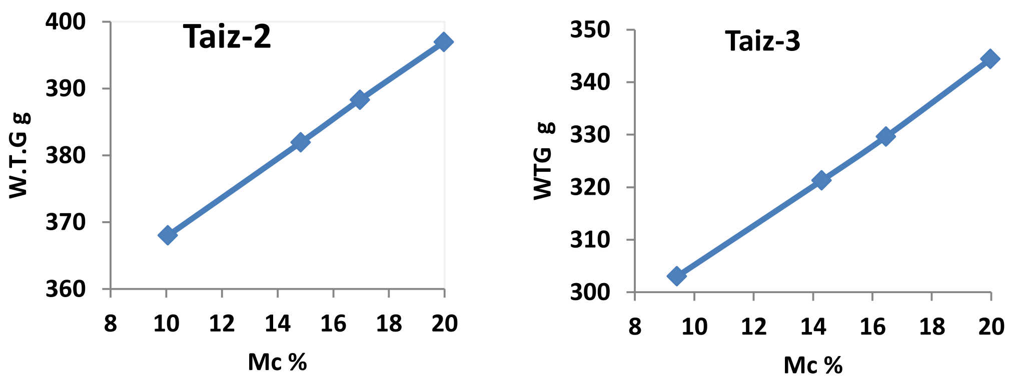


Fig.(3): Effect of moisture content on mass of one thousand grains.

3. Bulk and Particle Density and Porosity:

The results as shown in figure (4,5 and 6) each of bulk and particle density were decreased with increase of moisture content for investigated corn varieties. While the porosity of Taiz-2 variety was decreased with increasing of moisture content. But the porosity of Taiz-3 variety was increased with increasing of moisture content as shown in figure (6). The following linear regression equations described the relationship between each of bulk density (ρb, kgm^{-3}), particle density (ρp, kgm^{-3}) and porosity (P,%) and the moisture content in percent (w.b):

$\rho b_{T2} = 938.3477 - 4.29243 Mc$ $R^2 = 0.999995$

$\rho b_{T3} = 899.7204 - 3.60834 Mc$ $R^2 = 0.999537$

$\rho p_{T2} = 1612.684 - 9.71372 Mc$ $R^2 = 0.994516$

$\rho p_{T3} = 1480.533 - 4.06019 Mc$ $R^2 = 0.999355$

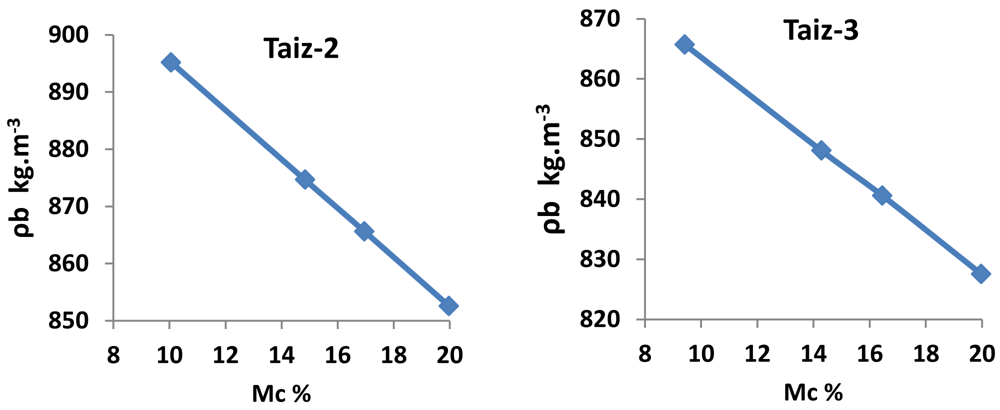
$P_{T2} = 42.04495 - 0.10474 Mc$ $R^2 = 0.992195$

$P_{T3} = 39.18388 + 0.083675 Mc$ $R^2 = 0.987096$

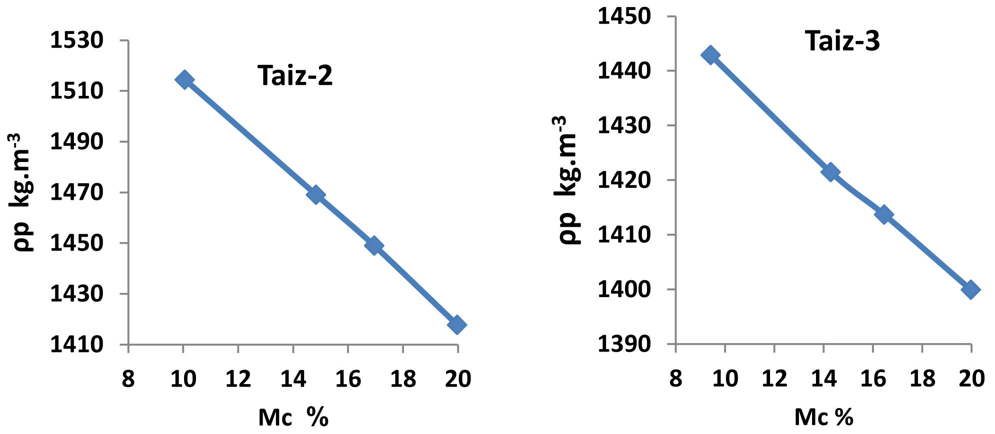
A similar decreasing trend in bulk density has been reported by (Seifi and Almardani,2010) for corn grains and (Soliman, *et al.,* 2009) for wheat grains. While similar results of particle density and porosity has been reported by (Soliman, *et al.*, 2009) for wheat grains. Whereas the results of the porosity of Taiz-3 variety was suggested in the trend with the results of (Al-Mahasneh and Rababah, 2006) which work on green wheat kernels, and (Wozniak, 1985) which work on winter and spring wheats.

<u>4. Static Friction Coefficient:</u>

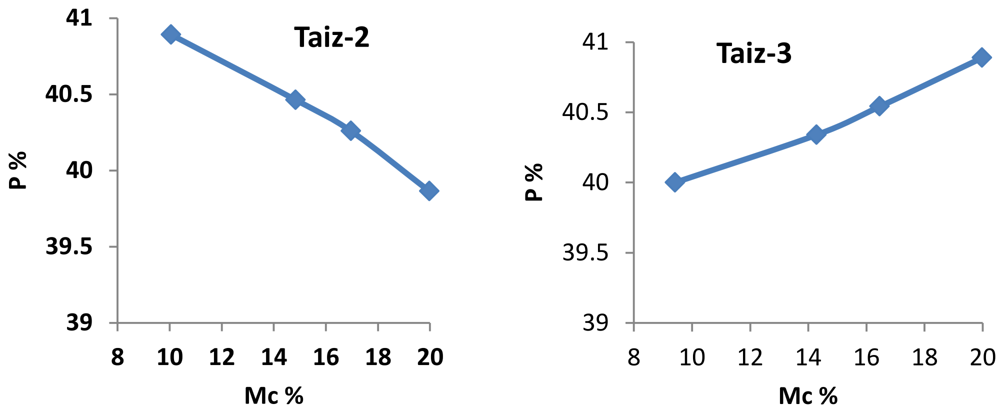
Static coefficient of friction of corn kernels on different surfaces were measured at different levels of moisture content for the two corn kernels verities. It was found that static coefficient of friction increased with increasing of kernels moisture content on plywood (PW), galvanized iron (GI) and stainless steel (SS) surfaces as shown in figure (7). The average values of the coefficient of friction demonstrated in table (1).



Fig(4)Effect of moisture content on bulk density grains.



Fig(5) Effect of moisture content on particle density grains.



Fig(6) Effect of moisture content on corn grains porosity.

Table (1) Average static friction coefficient for corn grains of the investigated varieties.

Variety	mc. %	Materials Surfaces		
		Plywood	Galvanized iron	Stainless Steel
Taiz-2	10.06	0.4433	0.4307	0.4163
	14.84	0.4761	0.4615	0.4484
	16.96	0.4895	0.4766	0.4658
	19.98	0.5097	0.4996	0.4899
Taiz-3	9.42	0.4368	0.4247	0.4114
	14.29	0.4723	0.4596	0.4409
	16.46	0.4876	0.4734	0.4513
	19.98	0.5082	0.4966	0.4663

Statistical linear regression analysis was conducted to the experimental data to observe this relation as follow:

For Taiz-2 variety:

$\mu_{ss} = 0.340531 + 0.007411Mc$ $R^2 = 0.997292$

$\mu_{GI} = 0.36018 + 0.006916Mc$ $R^2 = 0.998035$

$\mu_{PW} = 0.376309 + 0.006684Mc$ $R^2 = 0.999769$

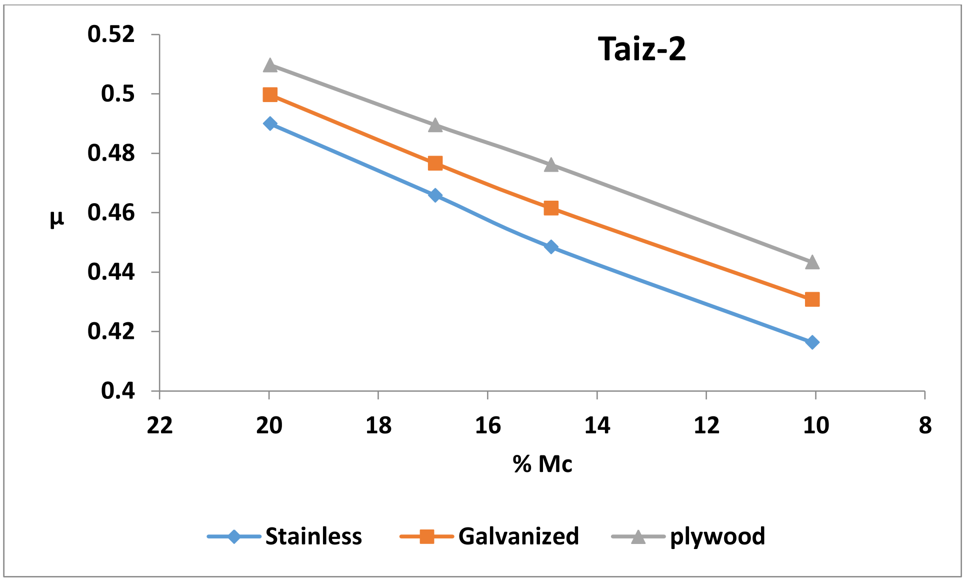
For Taiz-3 variety:

$\mu_{ss} = 0.363894 + 0.005226Mc$ $R^2 = 0.99406$

$\mu_{GI} = 0.361243 + 0.006805Mc$ $R^2 = 0.999886$

$\mu_{PW} = 0.373876 + 0.006806Mc$ $R^2 = 0.998342$

The results were similar in trend with the results of (Seifi and Almardani,2010) which work on corn grains, (Tarighi, *et al.*, 2011) which work on corn seeds, (Coskun, et al., 2006) which worked on sweet corn seeds and (Soliman, *et al.*, 2009) which work on wheat grains.



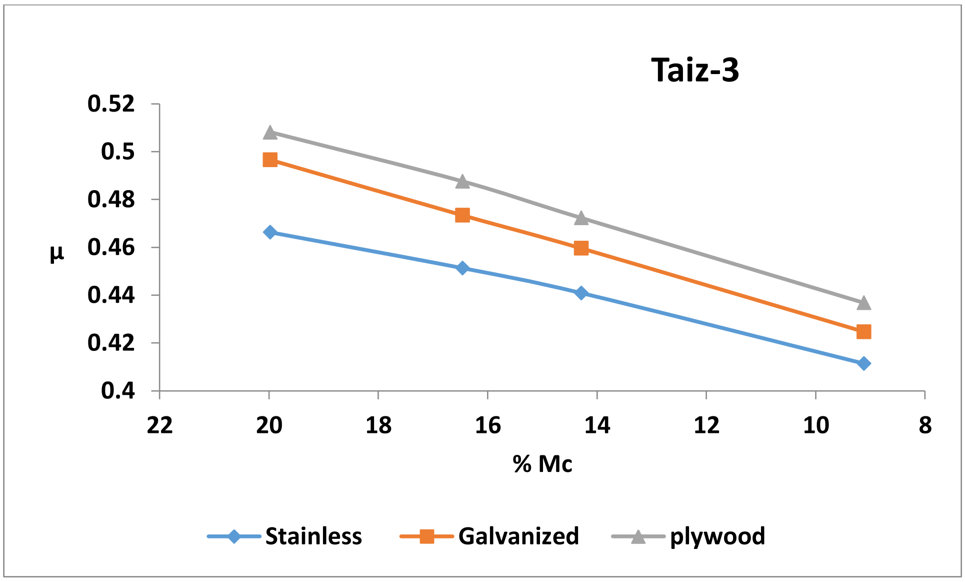


Figure (7) Effect of moisture content on friction coefficient for corn grains.

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الصفات الفيزيائية لبذور الذرة الصفراء (*Zea mays* L.)

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الملخص:

إن لدراسة الخصائص والخواص الطبيعية للمنتجات الزراعية عموما ولحبوب محاصيل الحبوب بشكل خاص أهمية كبيرة لتصميم معدات التعامل مع هذه المنتجات لإجراء عمليات الزراعة والحصاد وعمليات ما بعد الحصاد، ومن اجل ذلك كان هذا البحث الذي يهدف الى توفير قاعدة معلومات للخصائص الطبيعية لحبوب صنفين من اصناف الذرة الشامية اليمنية الجديدة وهي: تعز2 وتعز3 وعلاقة كل منها بالمحتوى الرطوبي للحبوب.

تمت الدراسة للصنفين المذكورين عند اربعة مستويات رطوبية مختلفة واقعة في المدى ما بين 10 إلى 20٪ على اساس الوزن الرطب. وكانت الخصائص المدروسة: الخصائص البعدية (طول وعرض وسمك الحبة وتكورها) وكتلة الالف حبة والكثافة الكمية وكثافة الحبة والمسامية ومعامل الاحتكاك الاستاتيكي للحبوب مع ثلاثة أسطح مختلفة.

ويمكن تلخيص النتائج التي توصل اليها البحث فيما يلي:

ارتفع متوسط طول حبوب الذرة من 10.81 إلى 11.41 ملم ومن 9.90 إلى 10.52 ملم. زاد العرض من 9.12 إلى 9.71 ملم ومن 8.19 إلى 8.64 ملم؛ والسمك من 4.64 إلى 5.24 ملم ومن 5.39 إلى 5.54 ملم لأصناف تعز2و تعز3 على التوالي مع زيادة محتوى الرطوبة من 10 إلى 20٪. اما تكور حبوب الذرة فقد زادت بشكل خطي مع زيادة المحتوى الرطوبي بالنسبة لصنف تعز2، بينما تناقصت خطيًا للصنف تعز3. كتلة الالف حبة زادت بشكل خطي للصنفين مع زيادة المحتوى الرطوبي. المسامية انخفضت بشكل خطي للصنف تعز2، في حين زادت خطيًا للصنف تعز3. حدث انخفاض لكل من الكثافة الكمية وكثافة الحبة مع زيادة محتوى الرطوبة في الصنفين. ازداد معامل الاحتكاك الاستاتيكي للحبيبات على أسطح المواد المدروسة المختلفة مع زيادة محتوى الرطوبة في الصنفين وكان اعلى احتكاك مع الابلكاش يليه الحديد المجلفن ثم الفولاذ المقاوم للصدأ.

كلمات مفتاحية: خصائص طبيعية، ومحتوى رطوبي، وحبوب الذرة الشامية.