Effect of Moisture Content on Physical Characteristics of Sorghum Grains

Yahya Abdul Galil Qaid Sallam and Ismael Al-mosanief

Plant Production Department, Faculty of Agriculture, Ibb University, Yemen.

Abstract.

Physical characteristics of sorghum grains of three varieties, Taiz-7, Taiz-8 and Taiz-9 at three levels of moisture contents (10%, 15% and 20% w.b) were investigated. Physical characteristics included dimensions, sphericity, mass of one thousand grains, particle and bulk density, porosity and static coefficient of friction on three different surfaces (plywood, galvanized iron and stainless-steel). Mathematical models describing the change of physical characteristics as dependent variables with moisture content as independent variable were developed. The average length of sorghum grains increased from 4.61 to 4.77 mm, from 4.21 to 4.38 mm and from 4.52 to 4.68 mm; the width increased from 4.41 to 4.51 mm, from 4.14 to 4.26 mm and from 4.31 to 4.43 mm; the thickness from 3.19 to 3.31 mm, from 2.74 to 2.86 mm and from 2.89 to 3.00 mm for Taiz-7, Taiz-8 and Taiz-9 varieties respectively as the moisture content increased from about 10 to 20%. The mass of one thousand grains were linearly increased with the increase in moisture content. While, the sphericity, particle density and porosity were decreased with the increase in moisture content. The bulk density was linearly decreased for Taiz-7 and Taiz-8 varieties, while it was linearly increased for Taiz-9 variety. The static coefficient of friction of grains on various surfaces increased with the increase in moisture content for all different varieties of sorghum grains. The highest values of static coefficient of friction were on plywood followed by galvanized iron and stainless steel.

Keywords: Physical characteristics, moisture content and sorghum grains.

1- Introduction.

Sorghum is one of the world's most important cereals which could be processed into flour and used for making diverse food products for world people and livestock feed. Sorghum is one of the most important crops produced in Yemen. Its total area in 2011 was 312,436 hectares, with a total production of 162,277 metric tons, with an average yield of 0.519 ton/Ha **(Agric. Stat. Yearbook 2016).** The grains of some varieties of sorghum are now being used in the industries for the production of biscuits, confectionaries, beverages, pharmaceutical syrups and also for making of beer in beer industries **(Adinoyi, et al., 2017).** Sorghum is

considered the fifth most important cereal crop in the world after wheat, rice, maize and barley. Sweet sorghum is considered as potential sources for fuel ethanol **(OECD 2010).** The spike is cut from the standing stalk at about 16-20 percentage moisture content and the safe level of moisture for grains storage must be reduced to 10-12 percentage **(FAO 1999).** While, for roller milling, tempering the grain to 15-16% moisture just before milling improves the separation of bran from flour **(OECD 2010).**
Mohsenin (1986) reported that the physical properties of material such as shape, size, volume, density and surface area are important in many problems associated with design or development of specific machine, analysis of the behavior of the product in handling of the material. Physical properties of agricultural materials are needed to adequately design appropriate equipment and systems for planting, harvesting and post-harvest operations such as cleaning, conveying and storage (**Asoegwu, et al., 2006) and (Kenghe, et al., 2015)** mentioned that the shape and size of agricultural materials had been found useful in understanding the problem of separating grains from undesirable materials, while the size of grains represented by their equivalent diameter and sphericity. 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).** Little researches concerning physical characteristics and physical properties of local cereal crop and the effects of moisture content on them are available in Yemen. Therefore, this study aimed to the determination of selected physical characteristics of three local sorghum varieties grains affected by moisture content**.**

2. Materials and Methods.

Three varieties of sorghum grains were used in this study from the prevalent varieties in the central area of Yemen. These varieties were Taiz-7, Taiz-8 and Taiz-9 which were obtained after harvesting, threshing and drying of the 2017 crop. The grains were thoroughly cleaned manually to remove foreign materials such as dirt, stones, dust, immature grain, broken grains. The initial moisture contents of each variety was determined. It was 10.20% for Taiz-7, 9.70% for Taiz-8 and 9.95% for Taiz-9 varieties. The moisture content of grains was determined using the standard method, samples each weighing about 15g were placed in a natural convection oven set at 103C° for 72 hours **(ASAE, 1992),** then, the sample was cooled, weighed and moisture content of the grains was calculated.

The desired moisture content levels of grains 10,15, and 20% ±1% (w.b) were achieved by moistening the grains by calculated amount of distilled water which was calculated from the following relation **(Sacilik, et al., 2003)**.

$$Q = \frac{Wi(Mf - Mi)}{(100 - Mf)} \qquad (1)$$

Where:

Q = mass of the added water, kg.
W_i = initial mass of the seeds sample, kg
M_i = initial moisture content of seeds sample, (w.b%)
M_f = final moisture content of seeds sample, (w.b%)

To measure dimensional characteristics of grains namely: length(L), width(W) and thickness(T) randomly samples of 100 grains were taken out from each variety for each level of moisture content and a digital caliber YATO 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):**

$$D_e = (L \times W \times T)^{1/3} \qquad (2)$$

$$S = \frac{D_e}{L} \qquad (3)$$

The mass of one thousand grains was measured by counting randomly samples of one hundred grains from each variety for each level of moisture content and weighted them by an electric digital scale 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 a height of 15cm, 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 of each investigated variety for each level of moisture content 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. 2004a).** The actual volume of the grains sample was determined by immersing the grains sample in a known volume of Toluene using a graduated cylinder of 100ml capacity and 1ml accuracy. The particle density was calculated by dividing the weight of the grains sample on the displaced volume of toluene.

The porosity was calculated using the following relation **(Mohsenin, 1986):**

$$P = [(\rho_p - \rho_b) / \rho_p] \times 100 \qquad (4)$$

Where:

P = the porosity, %

ρ_p = particle density, kgm^{-3}.

ρ_b = bulk density, kgm^{-3}.

A manual static friction coefficient measuring apparatus (fig.1), 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. The apparatus was adjusted on the horizontal level and a sheet of the selected material was put on the bottom of the box. The randomly sample of grains was put in one layer on the sheet surface. Then, the handle was turned by hand to raising the out end of box until about 75% of the grains sliding down. The angle of the goniometer (α) was recorded. Then, the static coefficient of friction (μ) was calculated as follow **(Ozarslan, 2002):**

$$\mu = \tan \alpha \qquad (5)$$

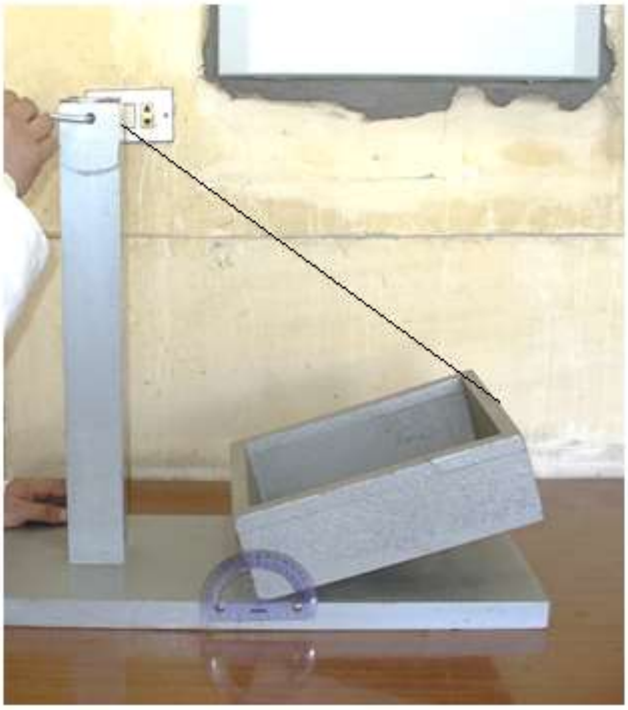


Fig. (1) Static Friction Coefficient Measurement Apparatus.

3. Results and Discussion.

3.1. Dimensional Characteristics.

A summary of the dimensions (length, width and thickness) of the investigated three varieties of sorghum grains (Taiz-7, Taiz-8 and Taiz-9) is shown in figures (2). All dimensions were increased with an increase in moisture content at the studied range. The sphericity (S, %) of each grains varieties were calculated and demonstrated in figure (3).

Regression statistical analyses were conducted to clarify the relationship between each items 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):

For Taiz-7 variety:

$L = 4.4463 + 0.0160Mc$ $\quad R^2 = 0.9999$

$W = 4.3077 + 0.0100Mc$ $\quad R^2 = 0.9999$

$T = 3.0627 + 0.0120Mc$ $\quad R^2 = 0.9999$

$S = 87.414 - 0.0259Mc$ $\quad R^2 = 0.9997$

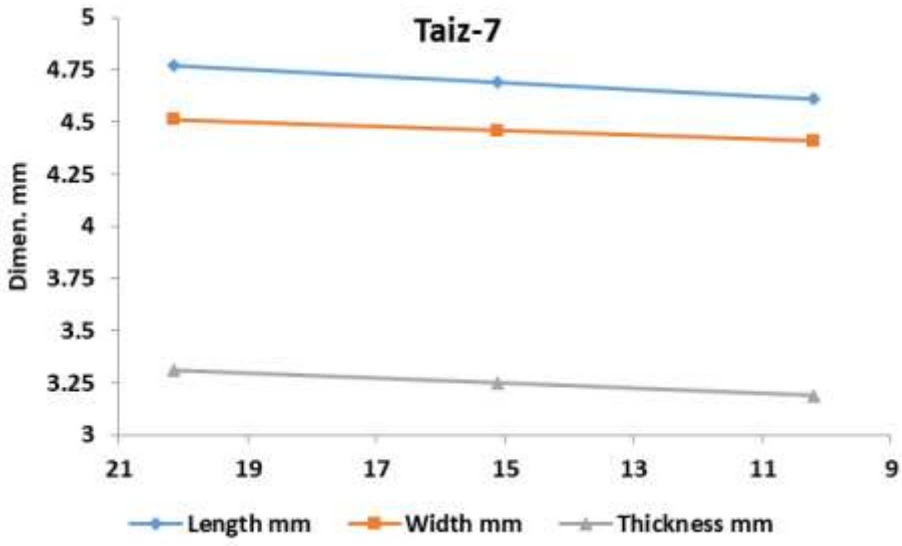
For Taiz-8 variety:

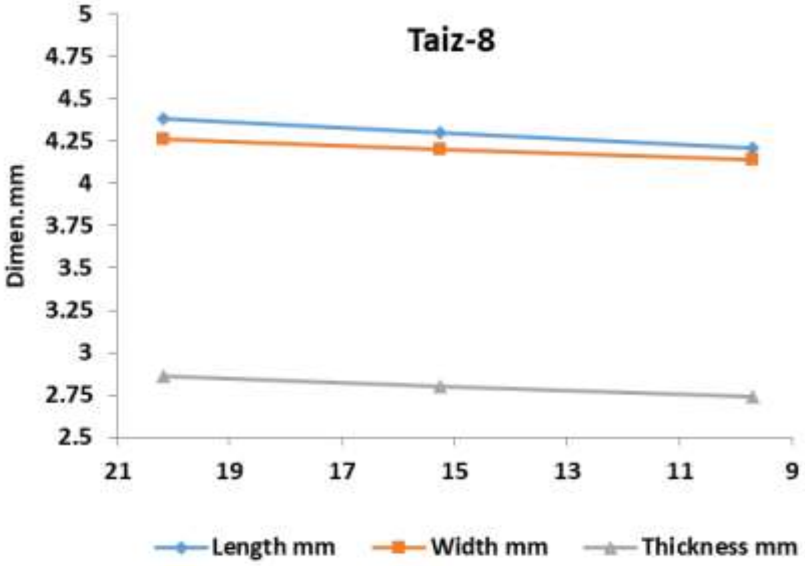
$L = 4.0526 + 0.0162Mc$ $\quad R^2 = 1.0000$

W = 4.0279 + 0.0114Mc R^2 = 0.9988
T = 2.6279 + 0.0114Mc R^2 = 0.9988
S = 86.3660 - 0.0214Mc R^2 = 0.9078

For Taiz-9 variety:

L = 4.3635 + 0.0157Mc R^2 = 0.9999
W = 4.1926 + 0.0118Mc R^2 = 0.9999
T = 2.7841 + 0.0108Mc R^2 = 0.9966
S = 84.9415 - 0.0132Mc R^2 = 0.8638





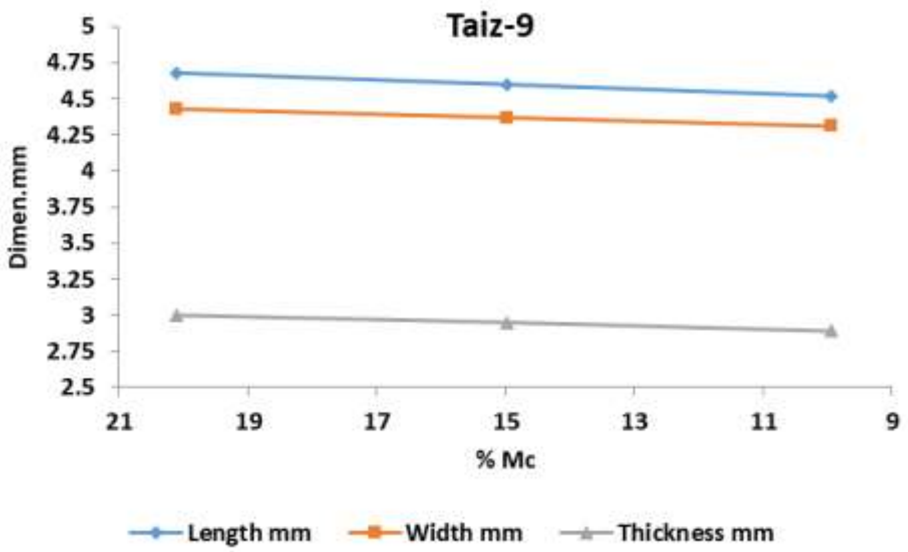


Fig. (2): Effect of moisture content on grains dimensions.

The above equations showed that the dimensional characteristics for the studied grains increased as the moisture content was increased at the studied range. The increasing trend in axial dimensions of grains with increased moisture content were due to filling of voids upon absorption of moisture and then swelling.

The results of the relationship between dimensional characteristics and moisture content of the studied sorghum grains were suggested in trend with the results of **(Kenghe, et al., 2015)** which work on physical properties of sorghum grains**, (Poomsa-ad, et al., 2014)** which work on physical and aerodynamic properties of sorghum grains, (**Soliman, et al., 2009)** which worked on wheat grains**, (Matouk, et al., 2004b)** which work on different cereals as barley, rice, wheat and corn**, (Soliman, 1994)** which measured the dimensions of different paddy rice varieties and its products **(Karababa, 2006)** which worked on popcorn.

The results indicated that, Taiz-7 variety had the highest of dimensions (length, width and thickness) followed by Taiz-9 and the lowest dimensions was of Taiz-8. While, Taiz-7 variety showed the highest sphericity followed by Taiz-8 and the lowest sphericity was of Taiz-9.

The equations also showed that the sphericity was linearly decreased with increasing of moisture content. A similar result of sphericity was reported by (**Kenghe, et al., 2015)** for sorghum grains.

3.2. Mass of one thousand grains.

As shown in figure (4); The mass of one thousand sorghum grains (M.Th.Gr.) appeared to be linearly dependent on the moisture content.

The following linear regression equations described the relationship between mass of one thousand grains (M.Th.Gr.) and their moisture contents (Mc) in percent (w.b):

For Taiz-7 variety:

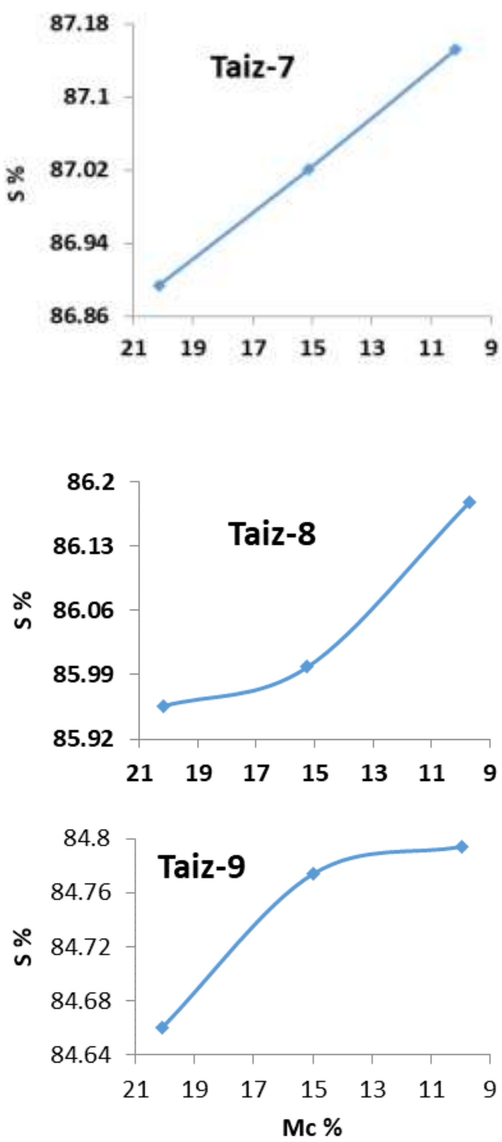
M.Th.Gr. =40.0689 + 0.2683Mc $\qquad R^2 = 0.9999$

For Taiz-8 variety:

M.Th.Gr.= 42.8797 + 0.2192Mc $\qquad R^2 = 0.9999$

For Taiz-9 variety:

M.Th.Gr. = 44.9511 + 0.2471Mc $\qquad R^2 = 0.9998$



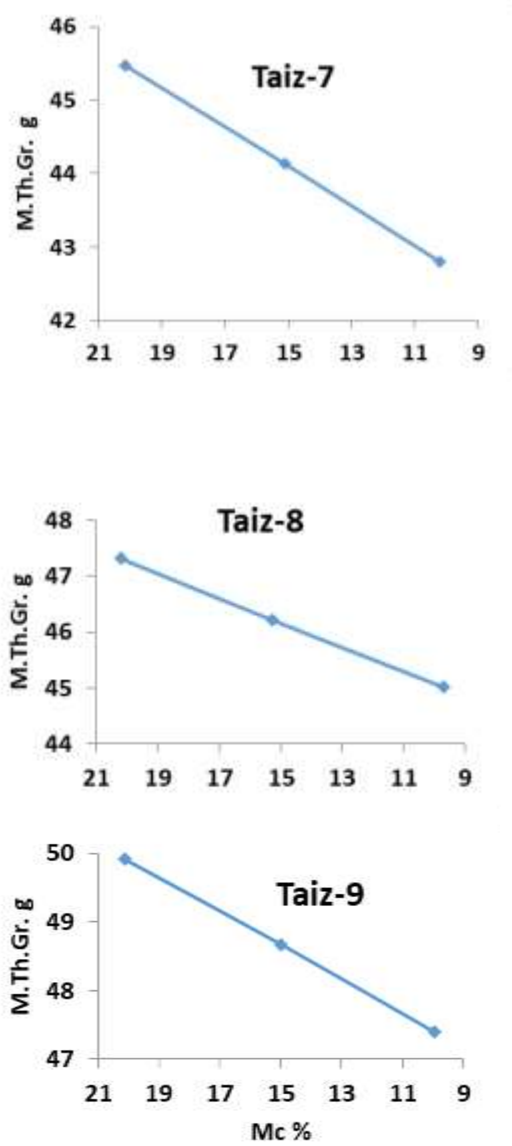


Fig. (3)
Effect of moisture content on grains sphericity.

Fig. (4)
Effect of moisture content on one thousand grains mass.

The equations showed that the mass of one thousand grains for the three varieties studied sorghum grains increased as the moisture content was increased at the studied range.

The results about mass of one thousand grains which were obtained in this study agreed with experimental data of **(Kenghe, et al., 2015)** which work on physical properties of sorghum grains**, (Poomsa-ad, et al., 2014)** which work on physical and aerodynamic properties of sorghum grains**, (Mwithiga and Sifuna, 2006**) which studied the Effect of moisture content on the physical properties of sorghum seeds, **(Karababa, 2006)** for popcorn**, (Matouk, et al., 2004b)** for some Egyptian wheat varieties, **(Al-Mahasneh and Rababah, 2007)** for green wheat kernels and **(Baryeh, 2002)** for millet.

The results indicated that Taiz-9 variety had the highest of mass of one thousand grains followed by Taiz-8 and the lowest was Taiz-7.

3.3. Bulk and Particle Density and Porosity.

The results as shown in figures (5, 6 and 7) were found to be each of bulk density, particle density and porosity dependent on moisture content. 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):

For Taiz-7 variety:

$\rho b = 711.16 - 0.9595Mc$ $\quad R^2 = 0.9999$

$\rho p = 1458.19 - 16.0948Mc$ $\quad R^2 = 0.9960$

$P = 52.8133 - 0.6817Mc$ $\quad R^2 = 0.9995$

For Taiz-8 variety:

$\rho b = 710.26 - 0.7225Mc$ $\quad R^2 = 0.9989$

$\rho p = 1160.25 - 3.5960Mc$ $\quad R^2 = 0.9999$

$P = 38.8725 - 0.1401Mc$ $\quad R^2 = 0.9989$

For Taiz-9 variety:

$\rho b = 504.99 + 0.4790Mc$ $\quad R^2 = 0.9962$

$\rho p = 1168.22 - 4.0524Mc$ $\quad R^2 = 0.9969$

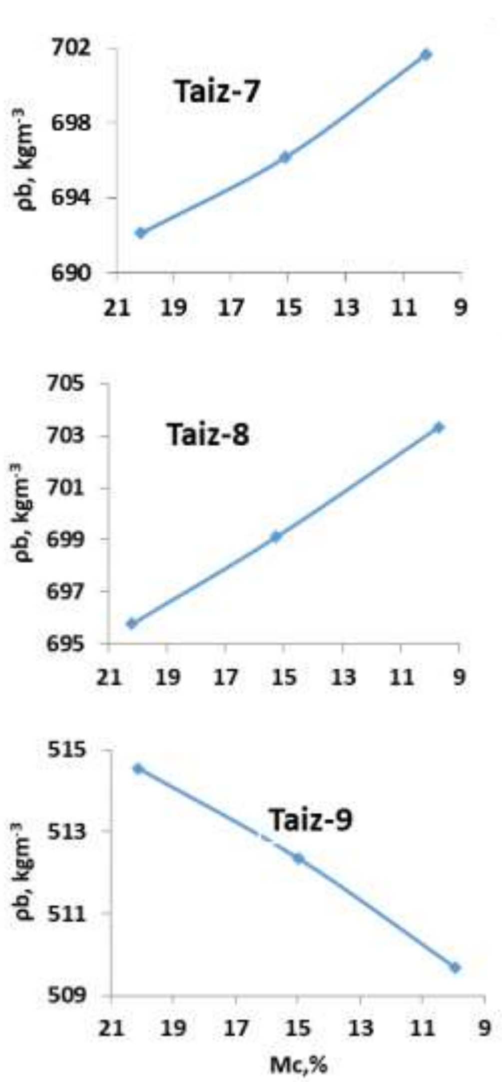
$P = 56.9229 - 0.2123Mc$ $\quad R^2 = 0.9978$

The results as shown in figures (5, 6 and 7) and above equations each of particle density and porosity were decreased with increase of moisture content for investigated sorghum varieties. While, the bulk density of Taiz-7 and Taiz-8 varieties were decreased with increasing of moisture content. But, the bulk density of Taiz-9 variety was increased with increasing of moisture content.

The results, about particle density and porosity which were obtained in this study agreed with **(Kenghe, et al., 2015)** which work on physical properties of sorghum grains and **(Poomsa-ad, et al., 2014)** which work on physical and aerodynamic properties of sorghum grains**.** The results of bulk density for Taiz-7 and Taiz-8 were similar to the results of **(Kenghe, et al., 2015)**. While, The results of bulk density for Taiz-9 were similar to the results of **(Poomsa-ad, et al., 2014)**.

3.4. Static Friction Coefficient.

Static coefficient of friction for sorghum grains of the investigated varieties on the selected materials surfaces including plywood (Pw), galvanized iron (Gi) and stainless steel (Ss) at different levels of moisture content as shown in figure (8) appeared to be linearly dependent on the moisture content.



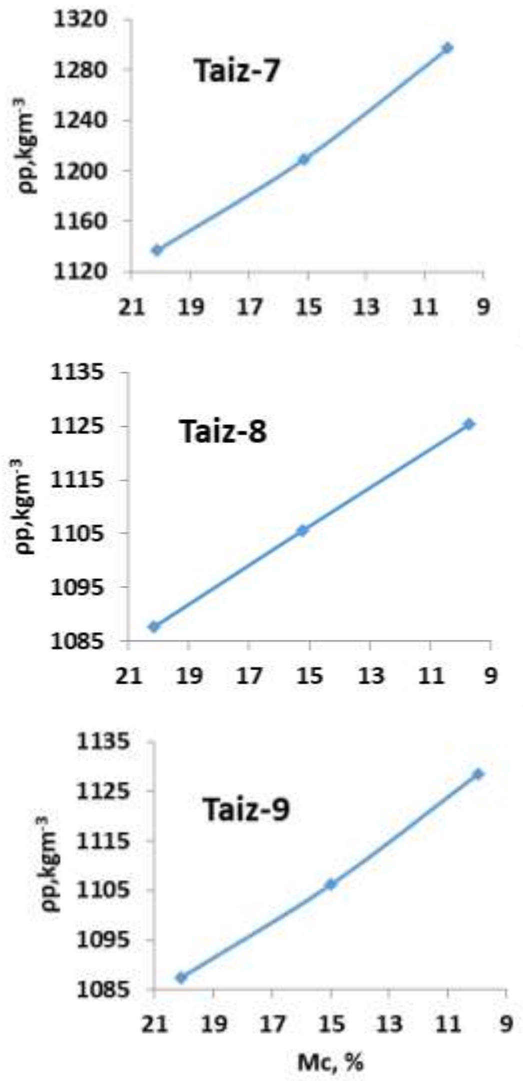


Fig. (5)
Effect of moisture content on grains bulk density.

Fig. (6)
Effect of moisture content on grains particle density.

The relationship between moisture content (w.b) and static coefficient of friction on plywood (μpw), galvanized iron (μGi) and stainless steel (μSs) can be represented by the following linear regression equations:

For Taiz-7 variety:

$\mu pw = 0.3628 + 0.0046Mc \qquad R^2 = 0.9999$

$\mu Gi = 0.1696 + 0.0114Mc \qquad R^2 = 0.9987$

$\mu Ss = 0.2153 + 0.0044Mc \qquad R^2 = 0.9999$

For Taiz-8 variety:

$\mu pw = 0.3591 + 0.0044Mc \qquad R^2 = 0.9980$

$\mu Gi = 0.1601 + 0.0126Mc \qquad R^2 = 0.9945$

$\mu Ss = 0.2080 + 0.0052Mc \qquad R^2 = 0.9962$

For Taiz-9 variety:

$\mu pw = 0.3514 + 0.0042Mc \qquad R^2 = 0.9986$

$\mu Gi = 0.1881 + 0.0106Mc \qquad R^2 = 0.9999$

$\mu Ss = 0.2254 + 0.0038Mc \qquad R^2 = 0.9988$

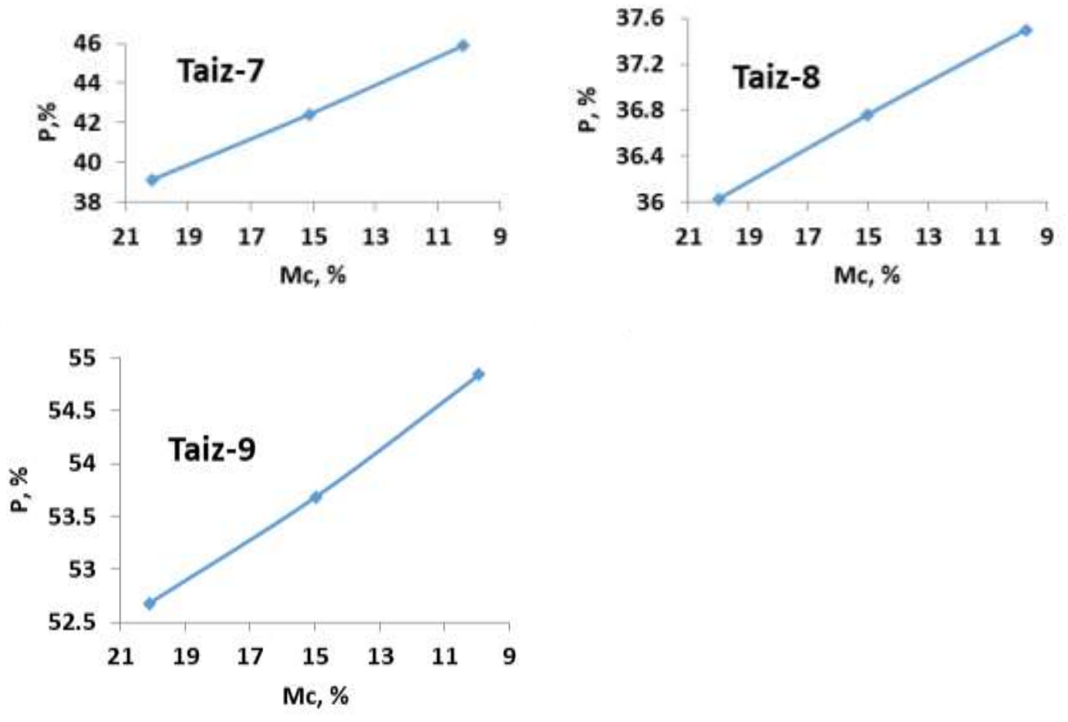


Fig. (7) Effect of moisture content on grains porosity.

The equations showed that the static coefficient of friction for sorghum grains of the studied varieties increased with the increasing of the moisture content at the studied range on each of the three materials surfaces.

At all moisture content levels for each of the three varieties, the highest values of static coefficient of friction were on plywood followed by galvanized iron and the lowest on stainless steel.

Similar results of static coefficient of friction were found by other researchers; **(Kenghe, et Al., 2015)** for sorghum grains**, (Poomsa-ad, et al., 2014)** for sorghum grains, **(Helmy, 1995)** for some Egyptian wheat varieties, **(Lawton, 1980)** for wheat and barley grains, **(Amin, et al., 2004)** for lentil seeds and **(Ozarslan, 2002)** for cotton seeds.

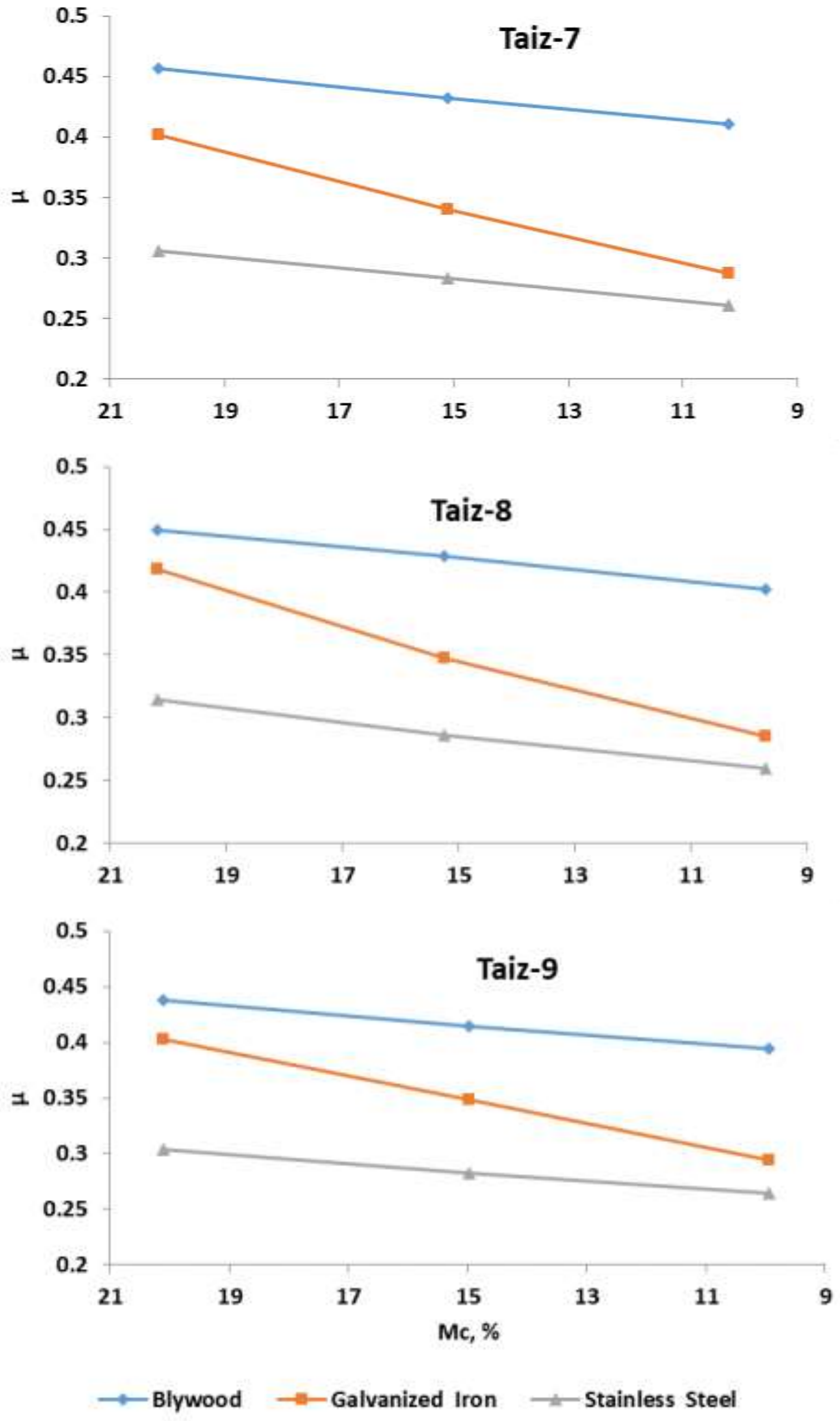


Fig. (8) Effect of moisture content and materials surface on grains static coefficient of friction.

References:

Adinoyi, A., Ajeigbe, H. A., Angarawai, I.I. and Kunihya, A. (2017). Effect of Grain Moisture Content on the Physical Properties of Some Selected Sorghum Varieties. *International Journal of Scientific & Engineering Research*, 8(6), 1796-1805.

Agricultural Statistics Yearbook (2016) Ministry of Agriculture and Irrigation. Republic of Yemen.

Al-Mahasneh, M. A. and Rababah, T.M. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering*, 79(4),1467-1473.

Amin, M.N., Hossain, M.A. and Roy, K.C. (2004). Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering*, 65, 83-87.

ASAE. (1992). Standard, S352.2, Moisture measurement-unground grain And seeds. St. Joseph: *American Society of Agricultural Engineering*.

Asoegwu, S. N., Ohanyere, S.O., Kanu, O.P. and Iwueke, C.N. (2006). Physical properties of African oil bean seed (*Pentaclethra macrophylla*) Agricultural Engineering International: the CIGR E journal Manuscript FP 05 006 Vol VIII.

Baryeh, E.A. (2002). Physical properties of millet. *Journal of Food Engineering*, 51, 39-46.

Boumans, G. (1985). *Grain handling and storage*. Elsevier Science Publishers. B. V. Amsterdam, Belgium.

Food and Agriculture Organization (FAO) (1999). Sorghum: Post-harvest Operations.

Helmy, M. A. (1995). Determination of static friction coefficient of some Egyptian agricultural products on various surfaces. Misr, J. Ag. Eng, 12(1), 267-282.

Karababa, E. (2006). Physical properties of popcorn kernels. *Journal of Food Engineering*, 72(1), 100-107.

Kenghe, R.N., Jadhav, M.S. and Nimbalkarm C.A. (2015). Physical Properties of Sorghum (SORGHUM BICOLOR) Grains as a Function of Moisture Content. *International Journal of Engineering Sciences & Research Technology*, 4(10), 496-505.

Lawton, P.J. (1980). Coefficients of friction between cereal grain and Various silo wall materials. *J. agric. Engng.Res*, 25, 75-86.

Matouk, A.M., Radwan, S.M., El-Kholy, M.M. and Ewies, T.R. (2004 a). Determination of grains density and porosity for some cereal Crops. Misr, J. Ag. Eng.21(3):623-641.

Matouk, A. M., Radwan, S. M., Hamam, A. and Ewies, T. R. (2004b). Determination of physical properties for some cereal crops. *Misr, J. Ag. Eng*, 21(3), 567-584.

Mohsenin, N.N. (1986). *Physical Properties of Plant and Animal Materials*. New York: Gordon and Breach science Publisher.

Miwithiga, G. and Sifuna, M.M. (2006). Effect of moisture content on the physical properties of three varieties of sorghum seed. *Journal of Food Engineering*, 75(4), 480-486.

Organization for Economic Co-operation and Development (OECD). (2010). Consensus Document on Compositional Considerations
for New Varieties of GRAIN SORGHUM [Sorghum bicolor(L.) Moench]: Key Food and Feed Nutrients and Anti-nutrients.

Poomsa-ad, N., Wiset, L. and Duangkhamchan, W. (2014). Effect of Moisture Content on Physical and Aerodynamic Properties of Sorghum. *Journal of Medical and Bioengineering*, 3(3), 167-170.

Ozarslan, (2002). Physical properties of cotton seed. *Biosystem Engineering*, 83, 169-174.

Sacilik, K., Ozturk, R. and Keskin, R. (2003). Some physical properties of hemp seed. *Biosystems Engineering*, 86(2), 191-198.

Sahay, K. M. and Singh, K. K. (1994). *Unit Operations of Agricultural Processing*. New Delhi, Viska Publishing House. PVT. LTD.

Seifi, M. R. and Alimardani, R. (2010) The moisture Content Effect on Some Physical and Mechanical Properties of Corn (Sc 704). *Journal of Agricultural Science*, 2(4), 125-134.

Soliman, N.S. (1994). Effect of moisture content on angle of repose of Paddy rice and its products. *Misr, J. Ag. Eng*, 11(1), 163-173.

Soliman, N.S., Abd El Maksoud, M. A., Gamea, G. R. and Qaid, Y.A. (2009) Physical Characteristics of Wheat Grains. *Misr, J. Ag. Eng*, 26(4), 1855-1877.

Varnamkhasti, M. G., Mobbli, H., Jafariee, A., Rafiee, S., Heidary Soltanabadi and Kheiralipour, K. (2007) Some Engineering Properties of Paddy (Var. Sazandegi). *International Journal of Agricultural and Biology*, 5, 763-766.

الملخص العربي:

إن لدراسة الخصائص والخواص الطبيعية للمنتجات الزراعية عموماً ولحبوب محاصيل الحبوب بشكل خاص أهمية كبيرة لتصميم معدات التعامل مع هذه المنتجات لإجراء عمليات الزراعة والحصاد وعمليات ما بعد الحصاد، ومن اجل ذلك كانت هذه الدراسة التي تهدف الى توفير قاعدة بيانات لبعض الخصائص الطبيعية لحبوب بعض الأصناف المحلية الجديدة للذرة الرفيعة وعلاقتها بالمحتوى الرطوبي للحبوب.

تمت دراسة الخصائص الفيزيائية لحبوب الذرة الرفيعة لثلاثة أصناف هي: تعز-٧، وتعز-٨، وتعز-٩ عند مستويات مختلفة من المحتوى الرطوبي للحبوب على أساس رطب. تضمنت الخصائص الفيزيائية: الأبعاد، والتكور، وكتلة الألف حبة، والكثافة الظاهرية، والكثافة الحقيقية، والمسامية، ومعامل الاحتكاك الاستاتيكي على ثلاثة أسطح مختلفة (خشب الابلكاش، والحديد المجلفن، والصلب المقاوم للصدأ) عند ثلاثة مستويات مختلفة من المحتوى الرطوبي تراوحت بين (١٠ إلى ٢٠٪ على أساس رطب) تم استنباط النماذج الرياضية التي تصف تغير الخصائص الفيزيائية كمتغيرات تابعة مع المحتوى الرطوبي كمتغير مستقل. ارتفع متوسط طول حبوب الذرة الرفيعة من ٤.٦١ إلى ٤.٧٧ ملم، من ٤.٢١ إلى ٤.٣٨ ملم ومن ٤.٥٢ إلى ٤.٦٨ ملم. زاد العرض من ٤.٤١ إلى ٤.٥١ ملم، من ٤.١٤ إلى ٤.٢٦ ملم ومن ٤.٣١ إلى ٤.٤٣ ملم. سمك من ٣.١٩ إلى ٣.٣١ ملم، من ٢.٧٤ إلى ٢.٨٦ ملم ومن ٢.٨٩ إلى ٣.٠٠ ملم للأصناف تعز -٧ ، و تعز -٨ وتعز -٩ على التوالي مع زيادة محتوى الرطوبة من حوالي ١٠ إلى ٢٠٪. كتلة الألف حبة زادت زيادة خطية مع زيادة المحتوى الرطوبي للحبوب. في حين أن التكور والكثافة الحقيقية والمسامية انخفضت مع زيادة المحتوى الرطوبي. اما الكثافة الظاهرية فقد انخفضت خطيا مع زيادة المحتوى الرطوبي للحبوب بالنسبة لأصناف تعز-٧، وتعز-٨ في حين زادت خطيا للصنف تعز-٩. معامل الاحتكاك الاستاتيكي للحبوب على مختلف الأسطح المدروسة ازداد مع زيادة المحتوى الرطوبي للحبوب لجميع الأصناف المدروسة من حبوب الذرة الرفيعة. كانت أعلى قيم معامل الاحتكاك على خشب الابلكاش يليها الحديد المجلفن واقلها مع الصلب المقاوم للصدأ.