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RESEARCH ARTICLE

Effect of Moisture Content and Variety on the Some Physical and Aerodynamic Properties of Sesame Seeds Relevant to Its Processing

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Abstract: Abstract. The physical and aerodynamic properties of black and white sesame were determined at Moisture Content(MC%) range of 8.5 – 30.6%(d.b).The major, minor, intermediate, arithmetic mean, geometric mean diameters and sphericity, projected area of the two varieties were 2.96 – 3.94mm, 1.47 -2.40mm,0.54 -1.26mm,1.66 – 2.50mm, 0.78 - 3.66mm and 26.53 – 93.45, 1.91 – 42.08mm² respectively.The increase in MC resulted decrease in true density from 1038.61 – 994.93 kg/mm² and 1039.61 – 998.47 kg/mm² for white and black sesame seed respectively.The terminal velocity of white sesame seed ranged from 3.12 – 7.82m/s while black sesame seed ranged from 3.16 – 7.94m/s at MC range of 8.5 – 30.6% (d.b).The drag coefficient were 3.750.31 and 2.26 – 0.23 for white and black sesame seed respectively as MC ranged from 8.5 – 30.6% (d.b) while Reynold number varied from 2363.9 – 23067.3 and 3401.5 – 15121.6 for white and black sesame seed respectively at MC range of 8.5 - 30.6% (d.b).The properties of sesame seed determined varied significantly with variety and MC.This findings are the prerequisite in the design and selection of sesame seed separating machine. A pneumatic separator can be designed with provision for effective separation of undesired light material with average terminal velocity below 5.17m/s and 5.67m/s for white and black sesame seeds respectively.

Keywords: aerodynamic properties, moisture content, physical properties, sesame seed, varieties

1. Introduction

Harvested and mashed, dehulled, threshed agricultural products contains some unwanted materials suchlike chaff, stalks, plant leaves, and non-viable seeds which determines the market value and end use of such agricultural products. These unwanted materials need to be separated from the viable materials before processing them into different bio products (Aglave, 2017). Also, agricultural products are regularly conveyed using air stream in a normal pneumatic conveyers, perhaps if these systems are not properly used, they could cause problems. For instance, a combine harvester with low air speed cannot ensure proper separation, there will be extra foreign material with the product. In the other hand, if the air speed is high, the product will be blown-off along with extra material, product and energy loss will be high (Agu & Oluka, 2012). The proper air speed required of any agricultural material for their proper separations can be determined from some physical and



aerodynamic properties suchlike, projected area, sphericity, true density, major, minor, intermediate, arithmetic mean, geometric mean diameters, moisture content and terminal velocity, drag coefficient, drag force of that agricultural material respectively. This property has been noticed to be effected mostly by moisture content and variety of the agricultural products (Aglave, 2017). Effects of moisture content and variety on the some physical and aerodynamic properties of sesame seed are vital in order to develop a machine that can process this underutilized biomaterial to exploits its numerous health benefits and commercial values (Akinoso, et.al., 2008; Akpata & Miachi, 2001; Bukya & Vijayakumar, 2013; AOAC, 2002; Aviara, Onuh, & Ehiabhi, 2012; Aviara, Power & Abbas, 2013; Bart-Plange & Mohammed, 2012; Baryeh, 2002; Chavoshgoli, et.al., 2014).

Sesame (*Sesamum indicum* L.) is also known as Sesamum or Benniseed that belongs to the family of Pedaliaceae and it is one of the oldest oilseed widely grown in the world (Eze & Oluka, 2014). It plays important role in human nutrition as most of the seeds are used for oil extraction and the rest are used for edible purposes (Eze & Eze, 2017). It is known as Queen of oilseeds because of its marvelous qualities of the seed, oil and meal (Fariku, Ndongya, & Bitrus, 2007). Sesame is grown primarily for its oil-rich seeds and prior to its ability to add nutty-like flavor or garnish foods, they were initially used for oil and wine production (Gandhi, 2009). The cake left after expression of oil from sesame seeds are mostly for livestock feeds and often as manure. The sesame colour varies from cream-white to charcoal-black but it is mainly refer to as white or black sesame seeds while other colours suchlike yellow, red and brown are very scarce (Ide, Eze, & Offor, 2019). In Nigeria, the species of sesame widely grown are mainly white and black (Khier, Ishag, & Yagoub, 2008). Sesame has very high commercial, nutritional and health benefits and it known to contain about 42-54 % quality oil, 22-25 % protein, 20-25 % carbohydrates and 4-6% ash. Its hull contains large quantities of oxalic acid, crude fiber, calcium and other minerals (Khoshtaghaza & Mehdizadeh, 2006). When the seed is properly dehulled, the oxalic acid content is reduced from about 3 % to less than 0.25 % of the seed weight (Kingsly, et.al., 2006). Sesame seed contains antioxidants which inhibit the development of rancidity in the oil. For this reasons, therefore there need to bulk process this underutilized bio material in order to exploit its wonderful benefits which cleaning, sorting, grading, separation of chaffs and non-viable seed from viable become paramount important. Therefore, this research is limited to the some physical and aerodynamic properties of sesame seed varieties at varying moisture content.

2. Materials and Methods

2.1. Source and preparation of sample.

The two varieties of Sesame seed used in this experiment were obtained from a local market in Rimi, Fagge Local Government Area of Kano State, Nigeria at a stable moisture content. The sourced sample were manually cleaned to remove all foreign materials such as dust, dirt, stones, broken and cracked materials. The initial moisture content of the sample were determined by the equation described by Koocheki, et.al. (2007). The desired moisture contents were obtained by adding distilled water calculated from equation reported by Marathe, Jaybhaye, & More (2017).

$$Wm = Mi (Mf - Mci) / (100 - Mf)$$

where;

Wm = mass of water to be added (g),

Mi = initial mass of the sample (g),

Mf = final (desired) moisture content sample % db,

Mci = initial moisture of the sample, % wet basis (w. b).



Each sample was sealed in a separate polyethylene bag. These samples were kept at 50C in a refrigerator for a week to enable the water to distribute uniformly. The physical properties of the samples were determined at five moisture content levels of 8.5, 12.5, 18.5, 26.7 and 30.6% (db).

3. Physical properties

For.

Dimension and mass of seeds were measured by a digital caliper with an accuracy of 0.01 mm and a digital scale with 0.01 g respectively (Mohesnin, 1986a). The sphericity of seeds was calculated using Equation (1) reported by Mohsenin (1986b). Projected area was obtained according to method of Mohsenin (1986b) in Equation (2). True density is defined as the ratio of mass of the sample to its true volume (Mohsenin, 1986b), it was calculated using equation (3). Arithmetic and geometric mean diameters were calculated using the equation (4 & 5) reported by Aviara, Power, & Abbas (2013).

$$\text{Sphericity } (S)\% = \frac{GMD}{a} \quad (1)$$

where:

GMD = geometric mean diameter of sample (mm),

a = major diameter (mm).

$$S = (\pi D_e)^2 \quad (2)$$

where:

S = surface area of the sample (mm²)

D_g = geometric mean diameter of the sam(mm)

$$\rho_t = (M_u / V_U) \quad (3)$$

where:

ρ_t = True density (kg/m³); M_u = unite mass of the sample (kg)

V_u = unite volume of the sample (m³)

$$AMD = \frac{(a + b + c)}{3} \quad (4)$$

$$GMD = (a \times b \times c)^{1/3} \quad (5)$$

where:

a = Major diameter;

b = Minor diameter;

c = Thickness;

AMD = Arithmetic Mean Diameter (mm);

GMD = Geometric Mean Diameter (mm).

4. Determination of the Aerodynamic properties of the samples

4.1. Terminal Velocity of the Seeds.

Terminal velocity of sesame seed, the air velocity at which the seed remains in suspension was measured by using a vertical wind tunnel (air velocity rig) as was reported by Mohsenin

(1987). This test equipment was complemented by a manometer and pivot static tubes. A duct 1 m long with a rectangular section of 0.1 m x 0.1 m was used to suspend the seed in an air stream. Air was supplied by a centrifugal fan driven by an electric motor. The seeds were placed on a wire net within the duct and were blown upwards using a centrifugal blower whose speed was controlled by a variable speed motor (Agu & Oluka, 2012). The air velocity at which the grains were lifted off the contacting surface was determined as terminal velocity (V_t) (Marathe, Jaybhaye, & More, 2017; Mohsenin, 1987).

4.2. Drag Force of the Sesame Seed

A drag force is the resistance force caused by the motion of a body through a fluid, such as water or air. A drag force acts opposite to the direction of the oncoming flow velocity (Marathe, Jaybhaye, & More, 2017). This is the relative velocity between the body and the air. Drag force, F_D , depends on the density of the sample, the upward velocity, and the size, shape, and orientation of the sample. (Khoshtaghaza and Mehdizadeh, 2006). It is calculated using the equation reported by Mohesnin (1986a);

$$F_d = M_{Pg} \frac{[\rho_p - \rho_f]}{\rho_p} \quad (6)$$

where:

F_d = drag force (N),
 M_p = Mass of the sample kg],
 g = gravitational force m/s^2
 ρ_p = density of the sample,
 ρ_f = density of air kg/m^3

4.3. Drag Coefficient of the Seed

It is used to quantify drag or resistance of an object is a fluid environment such as air or water, it was calculated using the equation reported by Marathe, Jaybhaye, & More (2017) and Mohsenin (1987) given as:

$$C_d = \frac{2F_d}{A_p \rho V_t} \quad (7)$$

where:

C_d = drag coefficient,
 $2F_d$ = drag force,
 A_p = surface area of the sample,
 V_t = erminal velocity,
 ρ = density of air kgm^{-3}

4.4. Reynolds number of the seed

Reynolds number is generally used to determine the flow regime. The Reynolds number (NR_c) is a dimensionless value that represents the ratio of inertial forces to viscous force in the fluid, it used tom categorize the fluid systems in which the effect of viscosity is important in controlling the velocities or the flow pattern of a sample in a fluid or in air (Marathe, Jaybhaye, & More, 2017).

It is calculated using the equation reported by Marathe, Jaybhaye, & More (2017) and Mohsenin (1987).

$$NR_e = \frac{V_t d_p \rho}{\mu} \quad (8)$$

where:

NR_e = Reynolds number,

V_t = terminal velocity m/s,

d_p = geometric mean diameter (mm),

μ = kinematic viscosity of air of kgsm⁻²,

ρ = mass density of air, given as (1.164kg/m³)

5. Effect of moisture content on the some physical properties of sesame seed

The geometric dimensions and the geometric mean increased with increase in moisture content of the two varieties of sesame seed (see table. 1). The mean values for the major, minor and intermediate diameter determined at different moisture contents in the range of 8.5 – 30.6 % d.b. for the two varieties are given in Table 1. It was observed that as the moisture increased from 8.5 – 30.6%, the three basic axial dimensions (major, minor and intermediate) also increased from 2.96 – 3.89mm, 1.47-2.02mm, 0.54 – 1.26mm and 3.00 – 3.94mm, 1.56 – 2.40mm, 0.62 – 1.16mm for white and black sesame seed respectively and this can be attributed to the swelling of the seeds when it absorb moisture and this is similar with what was reported by Naturland (2002) on physical properties of sesame seed, it was observed that , the major and intermediate diameters of the two varieties varied significantly different at (P < 0.05), while no significant difference in minor diameter was noticed and this is due to the fact that swelling and increase in moisture content was higher in the major and intermediate diameter than the minor diameter and this is in line with what was reported by Oluka & Nwuba (2001). The regression equation and R² generated from figure 1 to 3 showed that relationship between major, minor and intermediate diameter and moisture content were found to be linear for both sample.

Major diameter $0.000MC^3 - 0.020MC^2 + 0.348MC + 1.270$ $R^2 = 0.980$,

Minor diameter = $0.000MC^3 - 0.023MC^2 + 0.460MC - 0.864$ $R^2 = 0.991$,

Intermediate diameter = $0.000MC^3 - 0.007MC^2 + 0.148MC - 0.199$

$R^2 = 0.999$ for black sesame seed and

Major diameter = $0.000Mc^3 - 0.021Mc^2 + 0.344Mc + 1.279$

$R^2 = 0.968$,

Minor diameter = $0.000Mc^3 - 0.008Mc^2 + 0.208Mc + 0.257$

$R^2 = 0.988$,

Intermediate diameter = $0.000MC^3 - 0.012MC^2 + 0.252MC - 0.824$

$R^2 = 0.977$ for white sesame seed sample.

The variation of 1000 seed mass with moisture content are presented in Table 1. It was observed that 1000 seed mass of sesame seed sample increased from 1.3 – 4.76g and 1.40 – 4.43g for white and black sesame seed samples respectively as moisture content increased from 8.5 – 30.6%. From Table 1. result shown below, it was observed that as the moisture content increased from 8.5 to 30.6%, the Sphericity ranged from 26.53 - 84.83 and 32.20 - 93.45 for white and black sesame seed sample respectively, this finding is in agreement with what Oluka & Nwuba (2001), Rahman, et.al. (2007); Tunde-Akintunde & Akintunde (2007) reported on watermelon, millet and Beniseed respectively. The variation in sphericity may be attributed to the large increase in major diameter relative to intermediate and minor diameters. It was observed that the projected area of sesame seeds increased from 1.91 - 34.22 mm² and 2.96 - 42.08 mm² for white and black samples respectively when moisture

content of the sample increased from 8.5 to 30.6% (d.b).with increase in moisture content from 6.785 to 7.367 mm² (table 1). This shows that the projected area increased linearly with increasing in moisture content. The findings was in in line with what Tunde-Akintunde & Akintunde (2004) and Oluka & Nwuba (2001) reported on dried pomegranate seeds and Bennisseed. It was observed that the true density of the sesame seed decrease from 1038.50 - 994.93kg/m³ and 1039.61 to 998.47 kg/m³ for white and black sesame seed sample respectively, as the moisture content increased from 6.5 to 30.6%. This can be attributed to the higher rate of increase in volume than weight. The trend of moisture content variation and the relationship between true densities of the sesame seed samples can be best described with the figure 4 regression equation with R² value shown.

$$\text{True Density} = 0.003\text{MC}^3 - 0.209\text{MC}^2 + 1.719\text{MC} + 1037.$$

$$R^2 = 0.994 \text{ for black sample and;}$$

$$\text{True Density} = 0.001\text{MC}^3 - 0.056\text{MC}^2 + 1.798\text{MC} + 1057.$$

$$R^2 = 0.999 \text{ for white sample.}$$

Table 1: Some physical Properties of Sesame Seeds Varieties at Varying Moisture Content.

Properties	Moisture content									
	White sample					Black sample				
	8.5%	12.5%	18.5%	26.7%	30.6%	8.5%	12.5%	18.5%	26.7%	30.6%
Major Diameter (mm)	2.96 (0.23)	3.00 (0.43)	3.10 (0.32)	3.20 (0.31)	3.89 (0.52)	3.00 (0.18)	3.10 (0.41)	3.20 (0.72)	3.32 (0.54)	3.94 (0.13)
Minor Diameter (mm)	1.47 (1.23)	1.78 (3.13)	1.90 (2.31)	2.00 (3.13)	2.02 (1.32)	1.56 (0.63)	1.98 (0.32)	2.00 (0.92)	2.10 (0.46)	2.40 (2.13)
Intermediate Diameter (mm)	0.54 (3.07)	0.86 (0.87)	0.89 (2.13)	1.10 (3.13)	1.26 (0.13)	0.62 (0.13)	0.78 (2.13)	0.87 (0.61)	1.00 (31.43)	1.16 (0.94)
AM (mm)	1.66 (0.54)	1.88 (0.35)	1.96 (3.10)	2.10 (0.17)	2.39 (0.23)	1.73 (0.23)	1.98 (1.23)	2.03 (0.34)	2.14 (2.30)	2.50 (0.54)
GMD (mm)	0.78 (0.17)	1.53 (0.65)	1.75 (2.03)	2.35 (0.46)	3.30 (0.65)	0.97 (0.32)	1.59 (0.12)	1.86 (1.26)	2.32 (1.02)	3.66 (0.36)
Sphericity	26.53 (3.06)	51.00 (4.02)	56.45 (2.05)	73.44 (2.09)	84.83 (0.67)	32.20 (2.04)	51.13 (1.21)	58.12 (0.54)	69.62 (0.11)	93.45 (0.36)
Projected area (mm ²)	1.91 (1.00)	7.36 (4.05)	9.62 (1.65)	17.35 (0.65)	34.22 (0.59)	2.96 (1.17)	7.94 (0.75)	10.87 (1.52)	16.91 (0.81)	42.08 (2.03)
Mass(g/mm ³)	1.3 (0.34)	2.6 (1.04)	2.89 (0.54)	4.16 (0.76)	4.76 (1.98)	1.40 (0.69)	2.60 (0.34)	2.80 (1.93)	3.48 (0.41)	4.43 (0.45)
True density (kg/mm ³)	1038.50 (6.03)	1034.82 (7.32)	1018.27 (3.97)	1002.72 (0.99)	994.93 (1.87)	1039.61 (0.95)	1029.14 (5.49)	1016.48 (3.75)	1001.23 (2.32)	998.47 (3.76)

Note: Values in brackets are the standard deviation

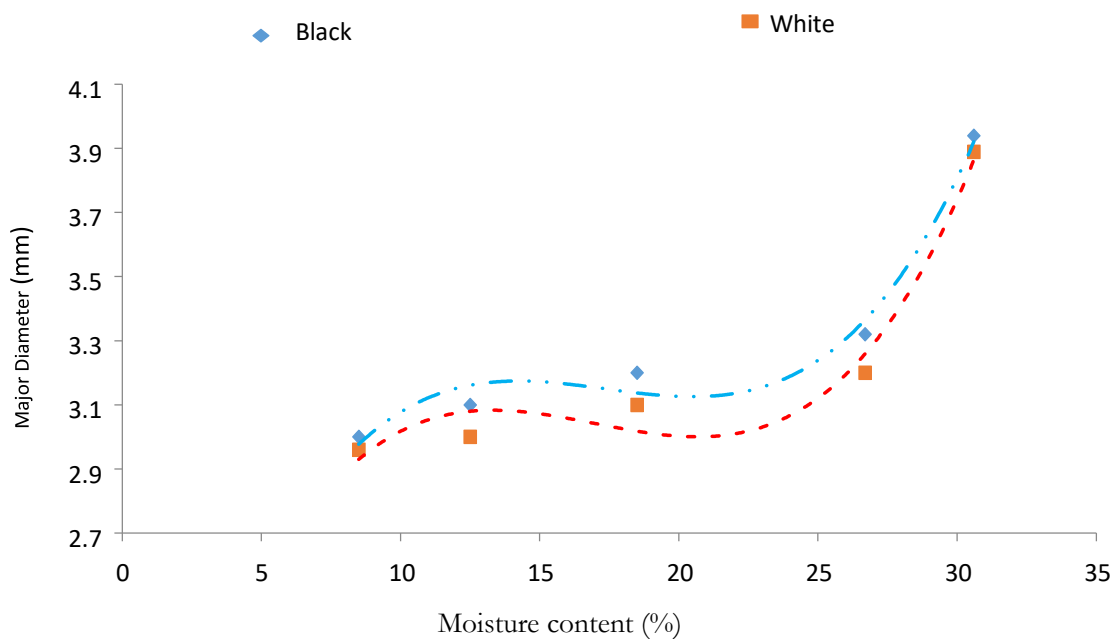


Figure 1: Effect of moisture content on major diameter of Sesame seed samples.

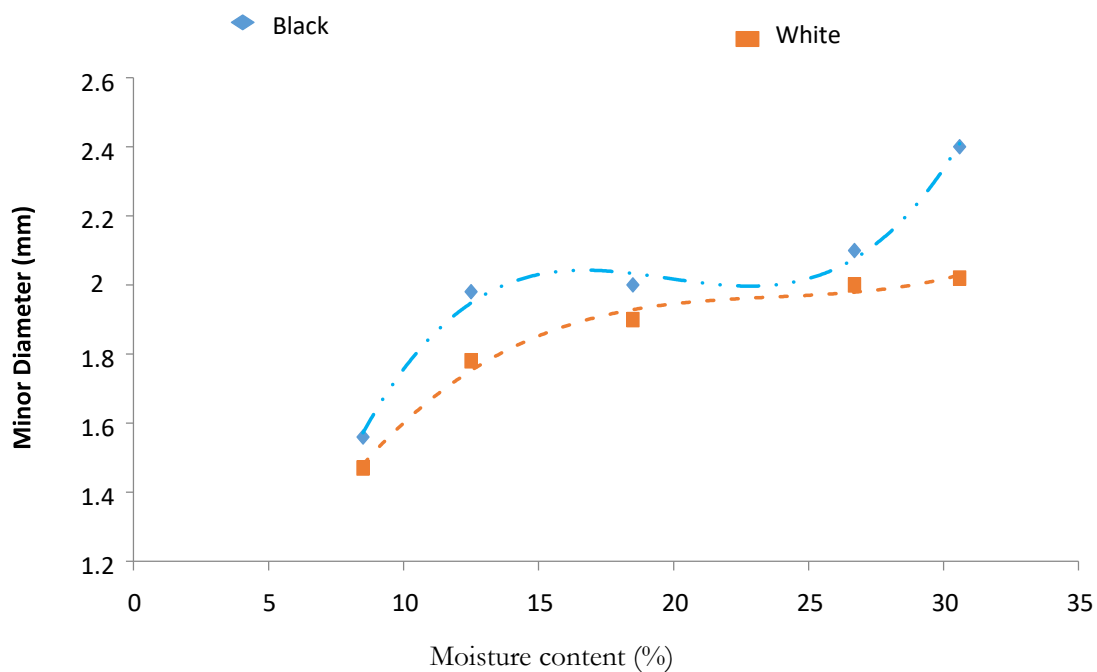


Figure 2: Effect of moisture content on minor diameter of Sesame seed samples.

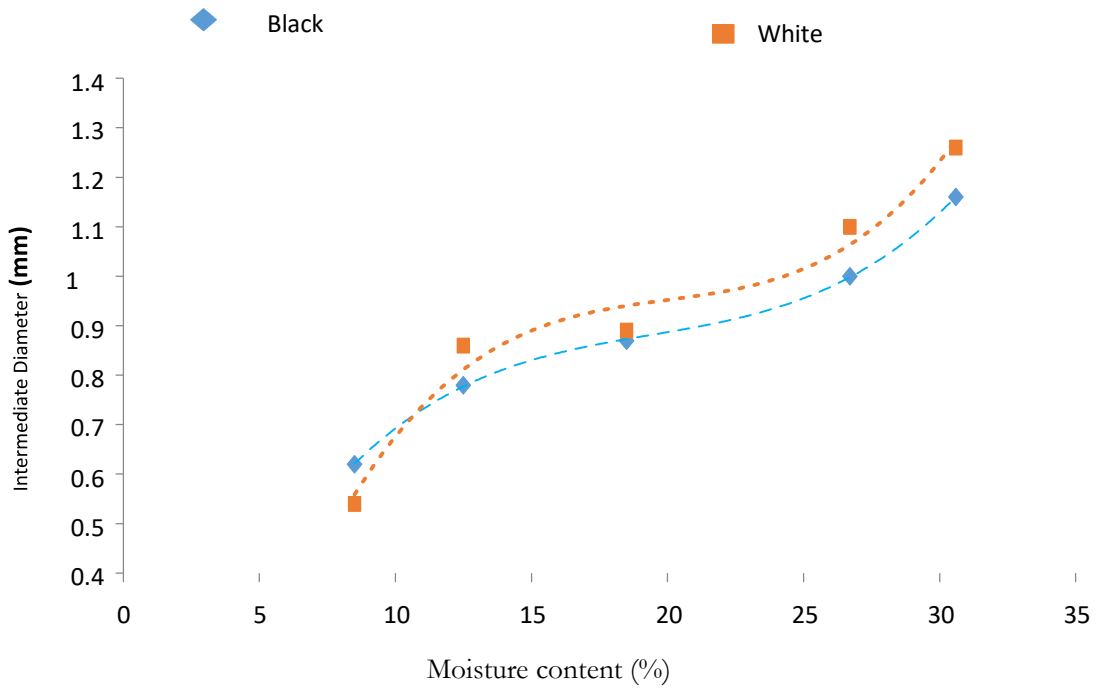


Figure 3: Effect of moisture content on minor diameter of Sesame seed samples.

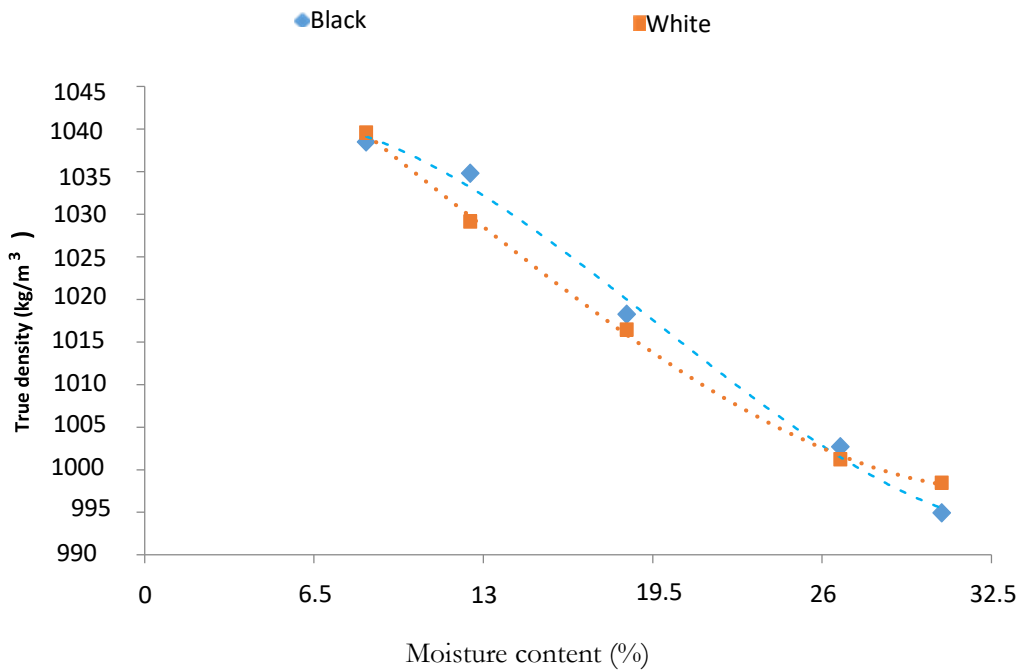


Figure 4: Effect of moisture content on true density of Sesame seed samples.

6. Effect of Moisture Content on the Aerodynamic Properties of Sesame Seeds Relevant to Its Separation

6.1. Terminal velocity

Experimental values obtained for terminal velocity of sesame were presented in the (Table 2), it was observed that it terminal velocity varied from 3.12 to 7.82m/s and 3.16 to 7.94m/s for white and black sesame seed sample at moisture content range of 8.5 to 30.6%. It was observed that terminal velocity increased linearly with the increase in moisture

contents. The increase in terminal velocity with particle size may be as a result of the increase in mass of an individual seed per unit area of the sample to the air stream. It follows that larger particles of similar shape need higher terminal velocities than smaller ones. The variations observed in terminal velocity of sesame with increase in the moisture content are shown in Figure 6. Similar results were obtained by Mohsenin (1987) and Oluka & Nwuba (2001) on NERICA and Cowpea respectively. The increase in terminal velocity was found to increase with increasing moisture contents, inferring that low moisture content is appropriate for designing pneumatic equipment to reduce energy input (Aglave, 2017). The functional relationship between terminal velocity and moisture contents of the sesame seeds are shown below

$$T_{vi} = 0.002x^2 + 0.117x + 1.743$$

$$R^2 = 0.977$$

$$T_{vi} = 0.001x^3 - 0.070x^2 + 1.$$

$$486x - 5.093$$

$R^2 = 0.999$ for black and white respectively.

The terminal velocities of the two varieties varied significantly different at ($P < 0.05$) with moisture content.

6.2. Drag co-efficient

The experimental result obtained from for drag coefficient of sesame seed sample were presented in the Table 4. It was observed that terminal drag coefficient decreased linearly with the increase in moisture contents. The values of drag co-efficient of white sesame seed sample were found decreased from 3.75 to 0.31 while black sesame seed decreased from 2.26 to 0.23, as the moisture content increased from 6.5 to 30.6%. The relationship between drag co-efficient and moisture contents of the sesame seeds could be described the following equation;

$$D_{eff} = -0.000x^3 + 0.041x^2 - 0.914x + 7.384$$

$$R^2 = 0.994$$

$$df = 0.010x^3 - 0.593x^2 + 11.68x - 48.28$$

$R^2 = 0.993$ (see figure 8), for white and black sample respectively.

There was significant effect of moisture content on the drag co-efficient.

6.3. Reynolds number

The result obtained from the experiment carried out for Reynolds number of sesame were presented in the Table 2, it was observed Reynolds number increased linearly with the increase in moisture contents. The values of Reynolds number of white sample were found increased from 2363.9 to 23067.3 while black sample 3401.5 to 15121.6 with corresponding increase in moisture content from 6.5 to 30.6% (w.b.), respectively. Addition of moisture to the investigated seed increased its weight, thus more force required to lift the material. This could necessitate the observed increase in terminal velocity with increase in moisture content. Thus, Reynolds number is directly proportional to terminal velocity and size while these parameters are inversely proportional to drag co-efficient. As is shown, both terminal velocity and size of sesame seed increase with increase in moisture contents. Therefore, behavior of Reynolds number of studied variety of sesame to treatments is rational. The graphical relationship is shown in Fig.9. The linear regression obtained for Reynolds number of sesame and moisture contents are shown below $Rn = -16.64x^2 + 1186.x - 5298$. $R^2 = 0.987$ and $Rn = 4.006x^3 - 204.9x^2 + 3869.x - 18266$ $R^2 = 0.999$. The Reynolds number varied significantly with changes in moisture content of seeds.

Table 2: Aerodynamic Properties of Sesame Seeds Varieties at Varying Moisture Content

Varieties	Moisture content (%)	Terminal velocity(m/s)	Drag force (N)	Drag coefficient	Reynolds number
White sample	8.5	3.12 (0.09)	12.99 (0.11)	3.75(0.04)	2363.9 (0.93)
	12.5	3.18 (0.04)	25.97 (0.07)	1.59 (0.33)	5662.4(1.30)
	18.5	5.16 (0.45)	28.87 (0.10)	0.99 (0.28)	8771.5 (3.05)
	26.7	6.57 (0.23)	41.55 (0.25)	0.63 (0.04)	14997.6(0.25)
	30.6	7.82 (0.03)	47.54 (0.39)	0.31(0.04)	23067.3(0.37)
Black sample	8.5	3.16 (0.06)	13.98 (0.07)	2.26 (0.16)	3401.5 (1.04)
	12.5	4.84 (0.32)	25.96 (0.12)	1.16 (0.09)	7475.3 (0.35)
	18.5	5.68 (0.38)	27.97 (0.25)	0.78 (0.02)	10262.4 (0.29)
	26.7	6.71 (0.42)	34.76 (0.28)	0.53 (0.02)	15121.6 (0.13)
	30.6	7.94 (0.02)	44.24 (0.56)	0.23 (0.02)	15121.6 (0.19)

Note: Values in brackets are standard deviations.

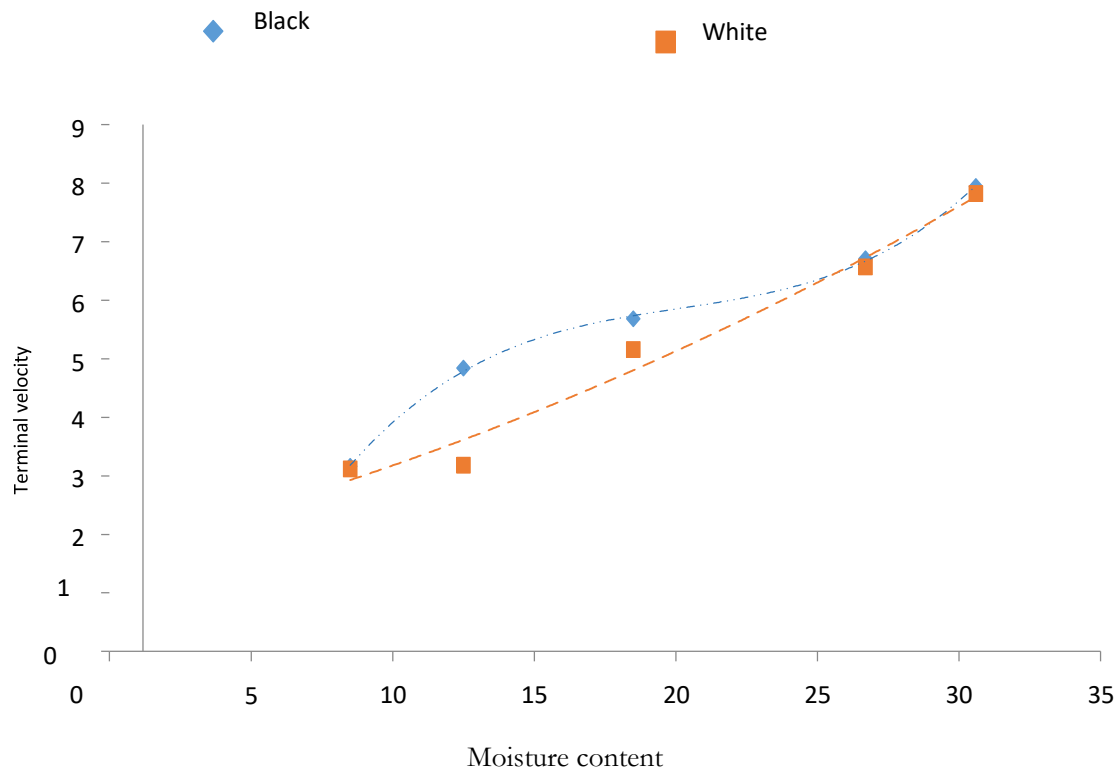


Figure 5: Effect of moisture content on Terminal velocity of Sesame seed samples.

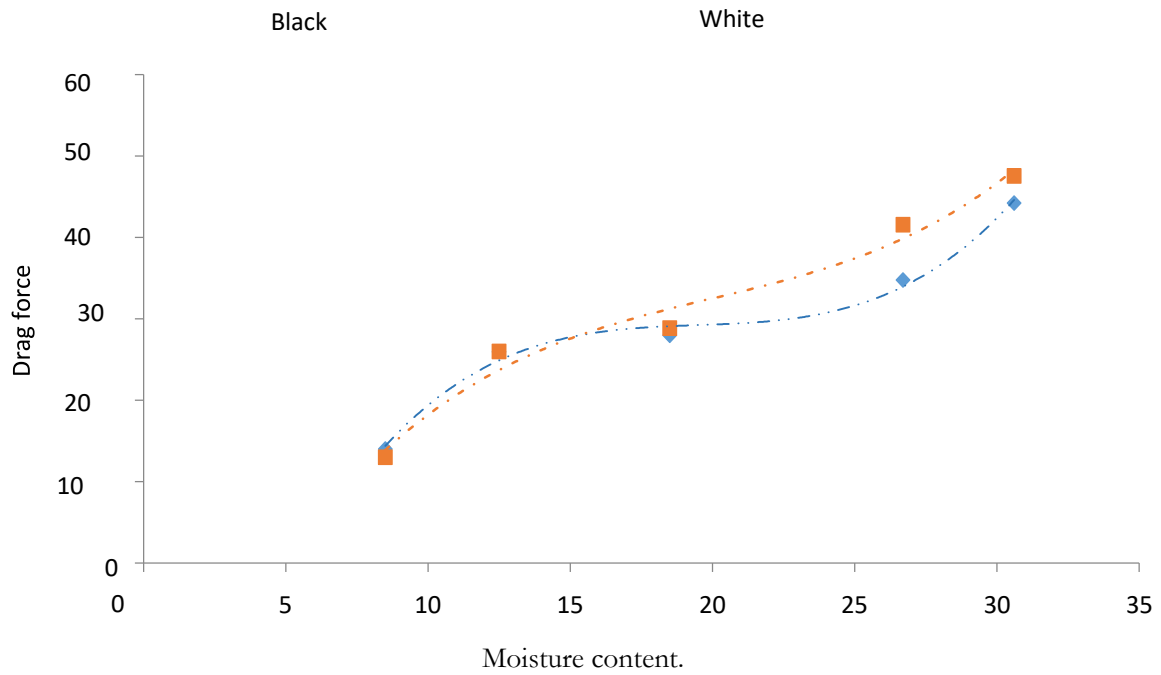


Figure 6: Effect of moisture content on Drag Force of Sesame seed samples.

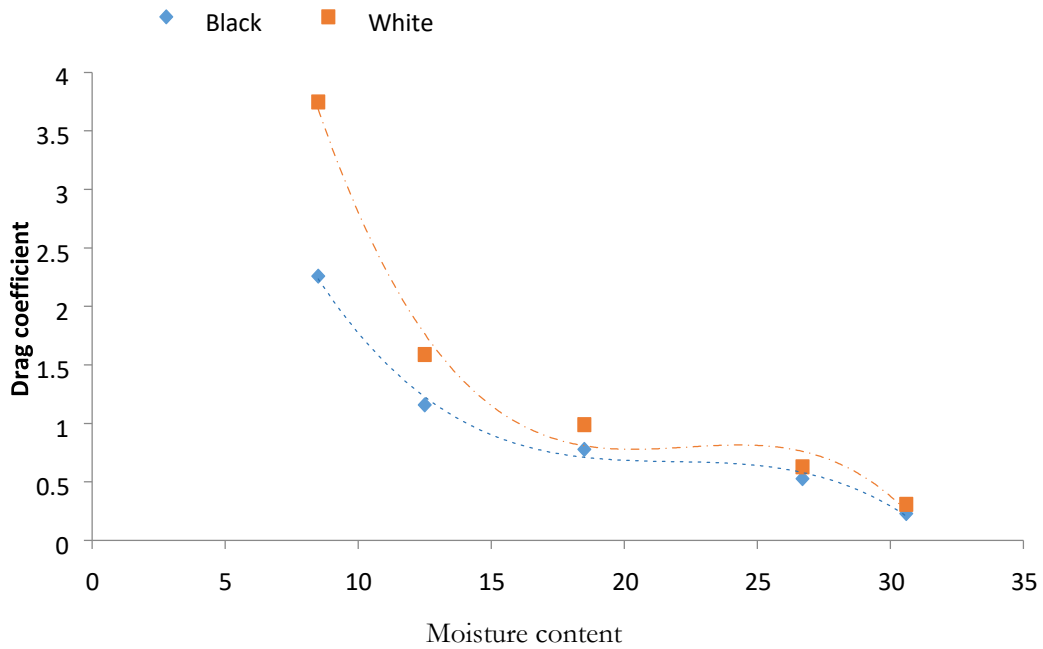


Figure 7: Effect of moisture content on Drag coefficient of Sesame seed samples.

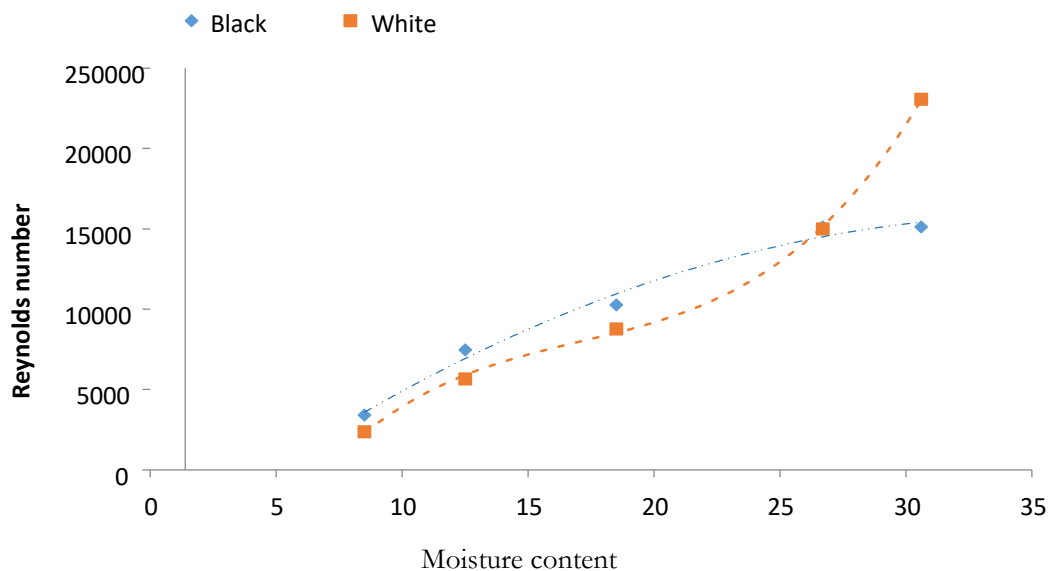


Figure 8: Effect of moisture content on Drag coefficient of Sesame seed samples.

7. Conclusion

Some physical properties of sesame seed varied with moisture content levels. The major, minor, intermediate diameters, sphericity, projected area and 1000 weight increased with increased in moisture content, this is because the samples swells as moisture content increases but true density was inversely proportion to moisture content increment, this can be attributed to the fact that, as moisture content increase, the weight of the sample occupies more volume in the cylinder which caused decrease in true density. The terminal velocity and Reynolds number increased with increase in moisture content but drag coefficient was inversely proportional to the moisture content and terminal velocity. A pneumatic separator can be designed with provision for effective separation of undesired light material with average terminal velocity below 5.17m/s and 5.67m/s for white and black respectively.

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