



Science

INFLUENCE OF MATURATION ON ENGINEERING PROPERTIES OF THREE BEAN (*PHASEOLUS VULGARIS L.*) VARIETIES, RELATED TO MACHINE DESIGN

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Abstract

Knowledge of the engineering properties of seeds is essential for the design and development of their harvesting, handling and processing machines. Engineering properties of post-harvest bean seeds have been well studied, but the influence of maturation on the engineering properties of most crops including bean seeds have not been fully studied. The objective of this study was to determine the effect of maturity stage on some engineering properties of three bean varieties (butter, brown and white cowpea) grown in Nigeria. The bean seeds were harvested at 15, 20 and 25 days after flowering, and these engineering properties; average thousand seed mass, size, volume, geometric mean, sphericity, surface area, arithmetic mean, bulk density, true density, porosity, coefficient of static friction, hydration capacity and coefficient, and swelling capacity and coefficient were investigated. The results showed that maturity stage of the bean seeds significantly ($P \leq 0.05$) affects all their studied. Correlations between the engineering properties and maturity stage for the three bean varieties were relatively high. Over the course of a maturation time, the moisture content declined from 83.40 to 42.31, 86.59 to 46.73, and 87.15 to 47.82 % (wb) for butter, white cowpea and brown bean seeds respectively. From the results, the ideal period for bean pods harvest, processing and handling for the three bean varieties is between 20 to 25 days after anthesis, since the seeds will be having maximum dry weight and higher viability. The results gotten from this research are important in the design and development of processing and handling machines.

Keywords: Butter Bean; Cowpea; Physical Properties; Functional Properties; Maturation; Moisture Content.

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Nomenclature

L	Length (mm)	T	Thickness (mm)
W	Width (mm)	S	Surface area (mm ²)
D _a	Arithmetic mean (mm)	V	Volume (mm ³)
D _g	Geometric mean (mm)	D	Diameter (mm)
φ	Sphericity (%)	H	Height (mm)
ρ _b	Bulk density (kg/m ³)	ε	Porosity
ρ _t	True density (kg/m ³)	ψ	Angle of repose
DAF	Days after flowering	H _c	Hydration capacity
S _c	Swelling capacity		

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is a plant species widely cultivated due to its good nutritional composition (high protein content in dry seed and a good source of fibre in snap bean) and its high market value is consumed either as a dry bean or as a snap bean (fresh vegetable). Consumers have progressively shown specific preferences for various combinations of size and shape of bean seeds and pods and the market reflects this trend by giving preference to types of good quality rather than high yield (Santalla *et al.*, 1999; Marzo *et al.*, 2002). Common bean is a major grain legume crop in the world (Leterme and Carmenza, 2002) and widely consumed in Africa (Singh *et al.*, 2004; HarvestPlus, 2014). Its third in importance after soybean and peanut as a legume crop, but first in direct human consumption (Broughton *et al.*, 2003). Beans have been extensively cultivated under different climatic conditions and by producers with different technology levels. Thus, to obtain higher profitability, it would be necessary to search for varieties adapted to the cultivation conditions and with high grain yield to meet consumer demands (Carneiro *et al.*, 2005). Beans present great variety in color, size, chemical composition and hardness, depending on the cultivar to which they belong. These differences come from intrinsic factors (genotype, which is partially responsible for the differences between cultivars and varieties) or from extrinsic factors such as storage conditions, type of cultivation soil, agronomic practices and climatic and technological factors (González *et al.*, 2005; Aghkhani *et al.*, 2012). Bean seeds form a major staple food in rural and urban areas in Nigeria, rich in significant amounts of protein, minerals and vitamins. They contain reasonable amount of protein and their mineral contents: calcium and iron are higher than that of meat, fish and egg and the iron content equates that of milk (Agbogidi and Egho, 2012). Besides its health-related benefits, beans are inexpensive, considerably cheaper than rice or any other dietary fibre type (Ayenlere *et al.*, 2012).

Information on the physical properties of bean seed such as their dimensions, porosity, volume, density (true and bulk) is important in designing the equipment for harvest, transport, storage, processing, cleaning, hulling, and milling (Akaaimo and Raji, 2006; Coşkuner and Karababa, 2007). One hundred seeds mass is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces (Lvin, 1971). The true density indicate that the seeds are heavier than water and this characteristic can be used to design separation or cleaning process for the beans; while bulk density is used as an indication of quality during storage of beans (Mpotokwane *et al.*, 2008). Porosity is used to calculate the rate of aeration and cooling, drying and heating and the design of heat exchangers and other similar equipment for bean handling (Asoegwu *et al.*, 2006). Previous researchers such

as: Altuntas and Demirtola (2007) and Nciri *et al.*, (2014) have researched on some engineering properties of bean (*Phaseolus vulgaris* L.) seeds. The hydration capacity of a substance is a measure of the relative amount of water that can be taken up by the substance while the swelling capacity is a measure of increase in the volume of the substance sequel to hydration (Isah *et al.*, 2012). According to some authors, soaking time is directly related to cooking time, which tends to decrease, as beans remain immersed (Rodrigues *et al.*, 2005a and 2005b). Water-holding capacity and cooking time of beans were evaluated by Rodrigues *et al.* (2005a and 2005b) and these showed that cooking time decreased as soaking time increased. Romano *et al.* (2005) studying the hydration curve and cooking time, verified that after three hours of soaking, the cooking time of the cultivars *Pérola* and *Guapo Brilhante* was reduced to half.

Despite comprehensive literature review on some engineering properties of bean seeds, there is a dearth of information on the effect of maturation on the engineering properties of bean seeds. Any data obtained from other countries cannot be directly ploughed into the design of planting, harvesting, handling and processing machines, because most engineering properties of bean seeds are clearly influenced by both environmental and genetics factors (Nciri *et al.*, 2014). Therefore, the objective of this study is to provide data about the engineering properties of three bean varieties (*butter*, *Brown* and *white cowpea*), as they are influenced by their maturity age, which will be useful in the design of harvesting, handling and processing machineries.

2. Materials and Methods

2.1. Plant materials

The three bean (*Phaseolus vulgaris* L.) varieties (*butter*, *Brown* and *white cowpea*) were planted at the research farm of Delta State Polytechnic, Ozoro, Delta state, Nigeria, on January, 2018 and harvested April, 2018. The bean seeds were selected and cleaned manually, to ensured that the seeds were free of dirt, broken ones, and other foreign materials.

2.2. Moisture Content (Wet Basis) Determination

The moisture content (% w.b) was determined with hot air oven drier using the method recommended by (AOCC, 2000) using Equation 1. Bean seeds weighing 10 g were placed in a moisture can and placed in an electric oven set at the temperature of 105°C. the weight of the bean seeds was taken even 2 hours until a stable weight was obtained. The result of moisture content was calculated (Equation 1).

$$MC = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (1)$$

2.3. Dimensional Properties

A total of forty bean seeds were randomly selected from each variety, and their three principal dimensions (L, W and T) measured using a digital venier caliper (accuracy of 0.01 mm). From the dimensions obtained (for L, W and T), the geometric mean diameter, arithmetic mean diameter, surface area, sphericity and volume of the seed can be calculated.

Geometric Mean Diameter

The geometric mean was determined based on the measured dimensions of bean seeds samples using Equation 2 (Mpotokwane *et al.*, 2008).

$$D_g = \sqrt[3]{L \times B \times T} \quad (2)$$

Arithmetic Mean Diameter

The arithmetic mean of the bean seed was obtained using equation 3 (Mpotokwane *et al.*, 2008).

$$D_a = \frac{(L+W+T)}{3} \quad (3)$$

Sphericity

The sphericity (ϕ) was calculated as a function of the three principal dimensions as shown in the equation (4) below (Mohsenin, 1986).

$$\phi = \frac{\sqrt[3]{L \times B \times T}}{L} \times 100 \quad (4)$$

Surface Area

The surface area, also expressed as the size, of the seed was calculated using the relationship in the equation (5) below (Mohsenin, 1986).

$$S = \pi D_g^2 \quad (5)$$

Volume

The volume of the seeds was calculated using the relationship presented in equation 6 (Mohsenin, 1986).

$$V = \frac{\pi D_g^3}{6} \quad (6)$$

2.4. Gravimetric Properties Determination

Thousand Seed Mass (TSM)

The one thousand seed mass (TSM) of the two bean varieties was measured by counting 100 seeds from each variety and weighing them in an electronic balance to an accuracy of 0.001 g. To evaluate the thousand seed mass, the result of the 100 seeds is multiplied by 10 to give mass of 1000 bean seeds.

Bulk Density

The bulk density of the seeds was determined using the mass/volume relationship, by filling an empty plastic container of predetermined volume (500 cm³), by pouring from a constant height, striking off the top level and weighing (Ghasemi *et al.*, 2008).

$$\rho_b = \frac{M_a}{V} \quad (7)$$

True Density

The true density of seeds was determined by using the liquid displacement method. Toluene (C₇H₈) was used in place of water because it has lesser extent absorb by seed. Fifty grams of the seed were filled in a calibrated pipe and the displaced toluene was measurement from the pipe. True density was obtained as the ratio of seeds weight to the volume of displaced liquid.

Porosity

The porosity of the bean seeds which depends on their bulk and true densities, is calculated by equation 8 (Mohsenin, 1986).

$$\varepsilon = \left(1 - \frac{\text{Bulk density}}{\text{True density}}\right) \times 100 \quad (8)$$

2.5. Frictional Properties

Coefficient of Static Friction

The coefficient of static friction (μ) was obtained with respect to three surfaces: plywood, laminate, and glass surfaces. These materials are commonly used in transportation, storage and handling operations, construction of storage and drying bins. An open-ended hollow cylinder of 50 mm diameter and 50 mm height, was filled with the seeds and placed on an adjustable tilting table. The hollow cylinder was pulled up slightly to avoid contact between it and the friction surface. The tilting surface was raised gradually by means of a screw device; the angle of tilt (α , degree) at which the cylinder with seeds just began to slide down was recorded as the angle of static friction (Akaaimo and Raji, 2006).

$$\mu = \tan\theta \quad (9)$$

2.5.1. Angle of Repose

The angle of repose (ψ) was determined by using a hollow cylindrical mould of 100 mm diameter and 150 mm height. The cylinder was placed on a wooden table, filled with bean seed and raised slowly until it forms a cone of seeds. The diameter and height of the cone were recorded. The angle of repose (ψ) was calculated by the following equation (Mullah, 1992).

$$\psi = \tan^{-1} \frac{2H}{D} \quad (10)$$

2.5.2. Functional Properties

Hydration Capacity

Fifty bean seeds (uniform size and shape) were soaked overnight (16 hours), after which the water was drained. The soaked seeds were blotted dry and weighted again. After soaking, the beans were cut into half along the fissure, and free water was removed using a blotting paper. Hydration capacity was calculated as change in weight per number of seeds as given in the equation 11.

$$H_c(\text{g/seed}) = \frac{(M_a - M_b)}{N} \quad (11)$$

Where M_b , weight of seeds before soaking; M_a , weight of seeds after soaking; N , number of seeds.

Swelling Capacity

The initial volume of fifty bean seeds (uniform size and shape) was noted in a graduated cylinder (Bishnoi and Khetarpaul, 1983) and the bean seeds were soaked overnight. Swelling capacity (S_c) was calculated as change in volume per number of as shown in the equation 12.

$$S_c(\text{mL}/\text{seed}) = \frac{(V_a - V_b)}{N} \quad (12)$$

Where V_b , volume of seeds before soaking; V_a , volume of seeds after soaking; N , number of seeds.

Hydration and Swelling Coefficients

Fifty seeds of each bean variety were soaked in distilled water for 16 hours and the volume of the bean seeds was estimated before and after soaking by determination of displaced water. After soaking, the beans were cut into half along the fissure, and free water was removed using a blotting paper. The hydration coefficient was calculated as the percentage increase in weight of beans. The swelling coefficient was calculated as the percentage increase in volume of beans after soaking (Nciri *et al.*, 2014).

$$H_{\text{coefficient}} = \frac{M_a}{M_b} \times 100 \quad (13)$$

$$S_{\text{coefficient}} = \frac{V_a}{V_b} \times 100 \quad (14)$$

2.6. Data Analysis

The data gotten from this research were subjected to analysis of variance (ANOVA) using SPSS version 22 (SPSS, IBM, Chicago USA) and means were separated using the Duncan multiple range test. Significance will be accepted at 95% confidence interval ($p < 0.05$). Total of twenty replica were recorded and the average determined.

3. Results and Discussion

3.1. Seed Moisture Content

The presentation in Figure 1 results showed that there is significant ($P < 0.05$) differences in the moisture content of the three bean varieties for the three maturity stages. From the results (Figure 1), the moisture content of the three bean varieties moisture declined with increased in maturity stage from 15 DAF to 25 DAF; and followed same behaviour during maturity. Seed moisture content has also been used as an index of optimum harvest time (Bedance *et al.*, 2006; Demir and Ellis 1993). The pattern of declining seed moisture content during seed development was similar to that reported in marrow (Demir and Ellis, 1993) and spring barley (Pieta and Ellis, 1991). According to (Gonçalves *et al.*, 2005), the total moisture content decreases in the course of maturity, this reduction in moisture content tends to cause an increase in firmness, as fruits tend to lose flexibility, when they lose water. The coefficient of determination (R^2) and correlation (r) values obtained from the regression relationship between the moisture content and maturity stage for the three bean varieties are presented in Table 1.

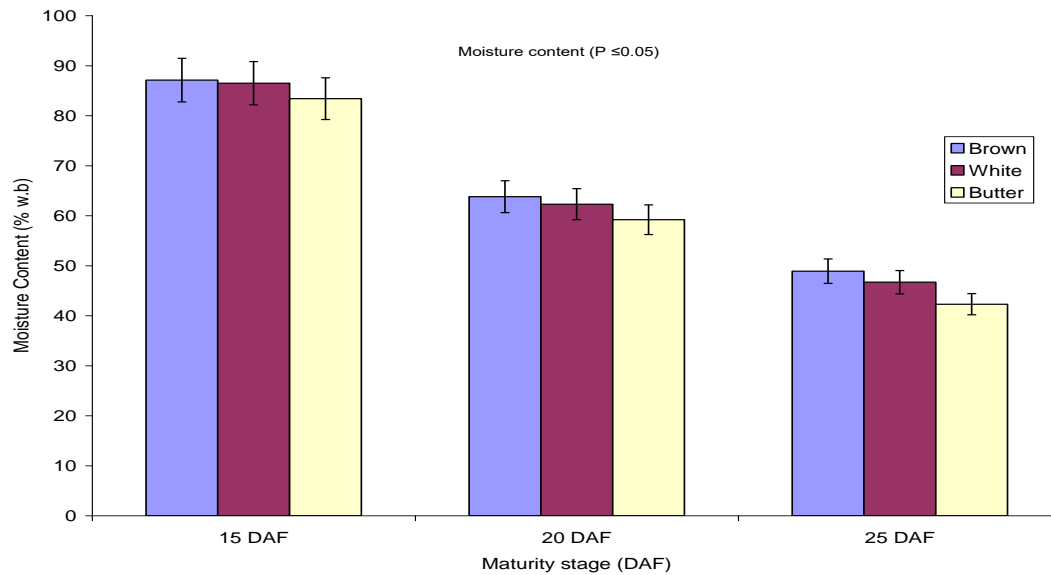


Figure 1: Influence maturity stage on bean seed moisture content

Table 1: Regression equations moisture content as function of maturity stage with their respective coefficient of determination (R^2) and correlation (r)

Parameter	Bean variety	Linear equation	R^2	r
Moisture content	White	$y = -19.9 x + 104.97$	0.984	-0.992
	Butter	$y = -20.55 x + 102.73$	0.989	-0.994
	Brown	$y = -1.85 x + 89.367$	0.867	-0.992

3.2. Seed Size and Dimensional Properties

The analysis of variances (ANOVA) of the dimensional properties of the bean seeds are presented in Table 2. As shown in Table 2, maturity stage had significant ($P \leq 0.05$) effect on all the dimensional properties of the three varieties of bean seeds. The detail evaluation of length, width, thickness, arithmetic mean, geometric mean, surface area, volume and sphericity of the bean seeds are reported in Table 3; while their respective coefficient of determination (R^2) and correlation (r) values presented in Table 4. All the parameters investigated increased significantly ($P \leq 0.05$), as maturity period increases from 15 DAF to 25 DAF (Table 2). In reference to Table 3, there was linear increase in the length of the bean seeds with increased in maturation; and *white* bean was the highest in seed Length while *butter* bean was the lowest, this difference in seeds length may be due to genetic differences (Hu *et al.*, 2013). From the results, the sphericity of the bean seeds was at the range of 74 to 76 % at 25 DAF; a litter bit higher than what was reported for kidney beans (61.03-61.28 %) by Altuntas and Demirtola (2007). The closer the sphericity to 1.0, the higher the tendency to roll about any of the three axes and the closer the ratio of thickness to width to 1.0, the higher the tendency to rotate with reference to the major axis (Akaaimo and Raji, 2006). This tendency to either roll or slide is very important in the design of hoppers and de-hulling equipment for the seed, because most flat seeds slide easier than spherical seeds which roll on structural surfaces (Ixtaina *et al.*, 2008; Ijadunola, 2015). From the values shown in Table 3, it can be comprehended that the increment in maturity stage from 15 DAF to 25 DAF, increased of the volume and size 77.28, 78.87 and 76.05 %, from white, butter and Brown beans seeds respectively.

Physical properties of agriculturally valuated seed materials are important in designing the equipment for harvest, transport, storage, processing, cleaning, hulling, and milling (Akaaimo and Raji, 2006; Coskuner and Karababa, 2007; Sirisomboon *et al.*, 2007). Size of bean seeds is considerably crucial parameter in terms of designing the seed metering mechanism of seed drills, and transportation, separating and sizing systems (Nciri *et al.*, 2014); bean varieties with large seeds exhibit slower water uptake and longer cooking time than small seeded varieties (Van Loggerenberg, 2004). Seed size influences electrical conductivity tests during soaking (Basra, 2006). Surface area plays a vital role in heat and mass transfer processes such as drying and other thermal applications. The surface area of an agricultural product is generally indicative of its pattern of behaviour in a flowing fluid such as air, as well as the ease of separating extraneous materials from the product during cleaning by pneumatic means (Omobuwajo, *et al.*, 1999). The coefficient of determination (R^2) and correlation (r) values obtained from the regression relationship between the dimensional properties and maturity stage for the three bean varieties, signified that any dimensional properties investigated can be predicted at any specific maturity stage.

Table 2: ANOVA of effect of maturity stage and variety on the dimensional properties of bean seeds

Source	df	Length		Width		Thickness		Dg	
		F	Sig	F	Sig	F	Sig	F	Sig
M	2	219.09	2.04E-17*	176.88	3.05E-16*	190.34	1.21E-16*	304.94	2.94E-19*
V	2	31.50	8.74E-08*	13.49	8.68E-05*	33.70	4.58E-08*	39.25	1.02E-08*
M x V	4	0.218	0.9261 ns	3.468	0.0207*	0.722	0.5847 ns	1.467	0.2396 ns

* =Significant at $P \leq 0.05$, ns = non-significant, M = Maturity stage, V = bean variety,

Table 2: continued:

Source	df	Da		Sphericity		Area		Volume	
		F	Sig	F	Sig	F	Sig	F	Sig
M	2	301.26	3.44E-19*	29.59	1.56E-07*	281.41	8.29E-19*	237.22	7.42E-18*
V	2	37.93	1.44E-08*	2.03	0.15085 ^{ns}	39.54	9.49E-09*	37.00	1.84E-08*
M x V	4	1.323	0.2867 ^{ns}	3.012	0.0355*	2.751	0.0486*	4.316	0.0079*

* =Significant at $P \leq 0.05$, ns = non-significant, M = Maturity stage, V = bean variety,

Table 3: Dimensional properties of bean seeds at different maturity stage

Parameter	Variety	Maturity stage (DAF)		
		15	20	25
Length	White	8.40 ^b ±0.48	10.58 ^a ±0.33	12.15 ^a ±0.49
	Butter	7.0 ^b ±0.29	9.98 ^a ±0.46	10.93 ^a ±0.30
	Brown	7.45 ^b ±0.42	10.31 ^a ±0.39	11.26 ^a ±0.72
Width	White	5.35 ^a ±0.44	7.65 ^b ±0.31	9.18 ^c ±0.46
	Butter	5.18 ^a ±0.17	7.20 ^b ±0.29	8.15 ^c ±0.13

	Brown	5.48 ^a ±0.61	7.33 ^b ±0.59	8.28 ^c ±0.46
Thickness	White	4.10 ^c ±0.22	5.95 ^b ±0.81	7.30 ^a ±0.22
	Butter	3.18 ^c ±0.25	5.4 ^b ±0.30	6.10 ^a ±0.32
	Brown	3.45 ^c ±0.24	5.68 ^b ±0.15	6.33 ^a ±0.44
Geometric mean	White	5.69 ^c ±0.33	7.83 ^b ±0.46	9.34 ^a ±0.36
	Butter	4.86 ^c ±0.21	7.27 ^b ±0.30	8.16 ^a ±0.18
	Brown	5.20 ^c ±0.40	7.54 ^b ±0.31	8.38 ^a ±0.37
Arithmetic mean	White	5.95 ^a ±0.35	8.06 ^b ±0.39	9.54 ^c ±0.37
	Butter	5.12 ^a ±0.20	7.53 ^b ±0.31	8.39 ^c ±0.16
	Brown	5.46 ^a ±0.41	7.78 ^b ±0.33	8.62 ^c ±0.38
Sphericity	White	67.72 ^a ±0.73	74.03 ^b ±4.11	76.85 ^c ±0.98
	Butter	69.44 ^a ±0.48	73.08 ^b ±1.32	74.69 ^c ±1.99
	Brown	69.75 ^a ±2.24	73.12 ^b ±1.28	74.51 ^c ±2.50
Surface area	White	101.94 ^a ±11.63	193.00 ^b ±23.02	274.12 ^c ±21.02
	Butter	74.34 ^a ±6.32	167.15 ^b ±11.66	209.11 ^c ±8.89
	Brown	85.33 ^a ±13.06	178.79 ^b ±13.67	221.01 ^c ±19.32
Volume	White	97.13 ^c ±16.13	253.10 ^b ±45.38	427.44 ^a ±49.51
	Butter	60.40 ^c ±7.67	203.19 ^b ±18.08	284.47 ^a ±18.09
	Brown	74.60 ^c ±17.02	224.78 ^b ±23.97	309.60 ^a ±40.21

Values are mean ± Standard Deviation; Means with similar superscript in the same row did not differ significantly ($p \leq 0.05$).

Table 4: Regression equations as a function of maturity stage with their respective coefficient of determination (R^2) and correlation (r) values for dimensional properties of the bean seeds

Parameter	Bean variety	Linear equation	R^2	r
Length	White	$y = 1.875 x + 6.6267$	0.991	0.995
	Butter	$y = 1.965 x + 5.3733$	0.918	0.958
	Brown	$y = 1.905 x + 5.5533$	0.999	0.960
Width	White	$y = 1.915 x + 3.5633$	0.986	0.993
	Butter	$y = 1.485 x + 3.54$	0.968	0.979
	Brown	$y = 1.4 x + 4.1967$	0.979	0.983
Thickness	White	$y = 1.915 x + 3.5633$	0.986	0.995
	Butter	$y = 1.46 x + 1.65$	0.993	0.957
	Brown	$y = 1.44 x + 2.2733$	0.908	0.953
Geometric mean	White	$y = 1.915 x + 3.5633$	0.986	0.995
	Butter	$y = 1.65 x + 3.13$	0.993	0.966
	Brown	$y = 1.59 x + 3.86$	0.931	0.941
Arithmetic mean	White	$y = 1.915 x + 3.5633$	0.987	0.994
	Butter	$y = 1.635 x + 3.41$	0.993	0.964
	Brown	$y = 1.58 x + 4.12$	0.935	0.965
Sphericity	White	$y = 4.565 x + 63.737$	0.954	0.977
	Butter	$y = 2.625 x + 67.153$	0.952	0.976
	Brown	$y = 2.38 x + 67.893$	0.873	0.934
Surface area	White	$y = 86.09 x + 17.507$	0.998	0.999
	Butter	$y = 67.385 x + 15.43$	0.954	0.912

	Brown	$y = 67.84 x + 26.03$	0.954	0.977
Volume	White	$y = 86.09 x + 17.507$	0.998	0.999
	Butter	$y = 112.04 x - 41.383$	0.975	0.987
	Brown	$y = 117.5 x - 32.007$	0.974	0.987

3.3. Gravimetric Properties

In reference to the ANOVA table (Table 5), maturity stage had significant ($p < 0.05$) effect on all the gravimetric properties of the three bean varieties. The regression equations of maturity stage as a function of gravimetric properties of bean seeds with their respective coefficient of determination (R^2) and correlation (r) values given in Table 6, shows a strong relationship between maturity stage of the bean seeds and the gravimetric properties investigated in this research. The section below discusses how maturity stage influenced the gravimetric properties of the three bean varieties seeds.

Table 5: The ANOVA of effect of maturity stage and variety on the gravimetric properties of bean seeds

Source	df	1000		Bulk		True		Porosity	
		F	Sig	F	Sig	F	Sig	F	Sig
M	2	114.05	6.79E-14*	15725	3.98E-42*	24922	7.98E-45*	918	1.48E-25*
V	2	27.285	3.29E-07*	447	2.02E-21*	1949	6.41E-30*	72	1.42E-11*
M x V	4	1.2207	0.3252	15	1.27E-06*	11	2.28E-05*	12	3.03E-08*

* =Significant at $P \leq 0.05$, ns = non-significant, M = Maturity stage, V = bean variety,

Table 6: Regression equations of the gravimetric properties as a function of maturity stage with their respective coefficient of determination (R^2) and correlation (r) values

Parameter	Bean variety	Regression equation	R^2	r
1000 seed mass	White	$y = 76.75 x + 156.42$	0.945	0.992
	Butter	$y = 61.5 x + 141.5$	0.909	0.953
	Brown	$y = 76 x + 165.42$	0.964	0.982
Bulk density	White	$y = 157.38 x + 376.17$	0.973	0.986
	Butter	$y = 144.13 x + 454.5$	0.943	0.971
	Brown	$y = 152.63 x + 407.83$	0.969	0.985
True density	White	$y = 176.75 x + 703.17$	0.925	0.962
	Butter	$y = 180.5 x + 789.83$	0.930	0.964
	Brown	$y = 167.75 x + 734.75$	0.918	0.957
Porosity	White	$y = -4.125 x + 43.317$	0.997	-0.998
	Butter	$y = -2.555 x + 40.853$	0.959	-0.979
	Brown	$y = -3.965 x + 41.713$	0.997	-0.998

Thousand Seed Mass

The thousand seed mass differed significantly ($P < 0.05$) among the various bean varieties. Referring to Figure 2, it can be seen that *Brown* bean seeds had the highest thousand seed mass at

25 DAF (385.00 ± 14.26 g), while *butter* bean seeds had the lowest highest thousand seed mass at 25 DAF (314.75 ± 12.31 g). In addition, there was not much changes in the mass of the three bean varieties, between 20 DAF and 25 DAF, signifying that the beans seeds attain full maturity as from 20 DAF. Thousand seeds mass is an important parameter in the design bean storage facility (capacity) and machinery design. Therefore, the size data of beans is of mostly importance to Agrofood engineers, machine manufacturers, and machine designers (Kara *et al.*, 2013). Gathu *et al.*, (2012) reported the 100-seed mass values of eight bean lines (*Phaseolus vulgaris*) varied from 15.77 to 36.90 g/ 100 seeds; while Borji *et al.*, (2007), studied the seed mass of 10 genotypes of dry bean, and found the averages weight values to be in the range of 23.20-38.43 g/ 100 seeds. Harvesting crops at early maturity stage usually resulted in yield loss due to high seed moisture content, high percentage of immature seeds and low 1000 seed weight; while delayed harvesting resulted in more seeds were filled and consequently, average seed weight increased (Siddique and Wright, 2003; Nimje and Gandhi, 1994).

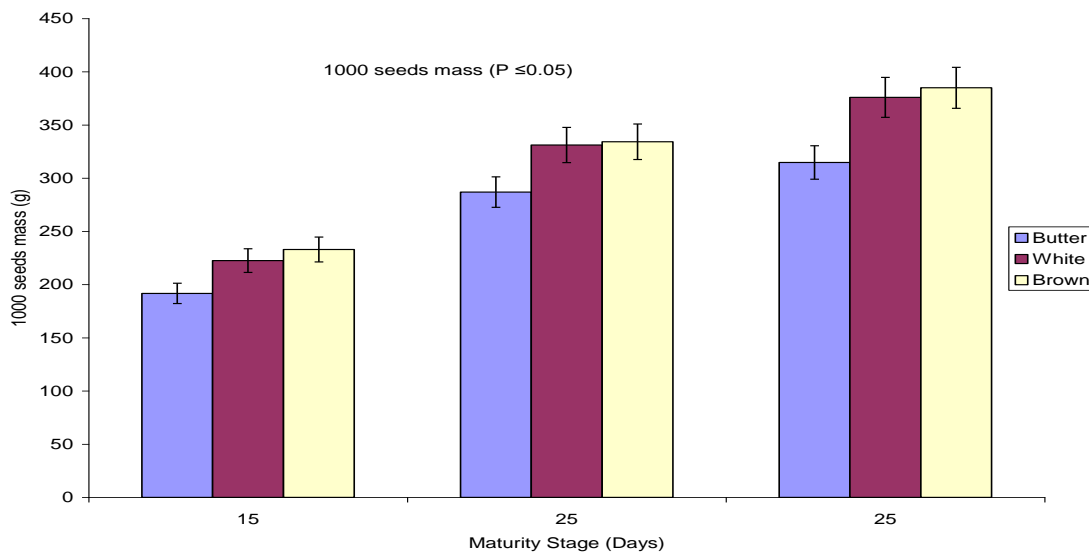


Figure 2: Influence maturity stage on bean seed 1000 seed mass

Bean Seeds Bulk and True Density

Examining Figure 3, it can be seen that the bean seeds bulk and true density increased with increase in maturation of the bean seeds. From the figure, *Butter* bean seeds had the highest density values, while *white* bean seeds had the lowest density values. The true density of dry bean seeds at 20 and 25 DAF were higher than 1000 kg/m^3 , indicating that the seeds are heavier than water and hence sink. This can be attributed to the change of the bean textural and material structures as the seed matures. Longer photoperiods may also result in greater production of photosynthates and to increase biomass, growth efficiency, duration of crop and yield per plant and thus mitigating source limitations (Indira and Dharmalingam, 1996; Summerfield *et al.*, 1988; Ellis *et al.*, 2000). During initial maturation stage, despite with the high moisture content, the seeds of the two bean varieties have lower bulk density, which increased proportionally during the maturation course. This tendency was probably due to the gradual change in the integrity of the cellular matrix (Gupta and Das, 2000). The true density indicates that the seeds at full maturity are heavier than water; while premature seeds are lighter than water; this characteristic can be used to design separation or cleaning process (Mpotokwane *et al.*, 2008).

Density of food materials and agricultural products play an important role in the design of silos and storage bins (Waziri and Mittal, 1983); determining the purity of seeds (Jaeger, 1997); stability of feed pellet and wafers (Gustustafson and Kjelogard, 2000); mechanical compressing of ensilages (Ige, 1997) and maturity evaluation (Fashina, 1996). Since the true density of the mature bean seeds is more than the density of water, water can be used to design separation or cleaning processes for the bean seeds since premature bean seeds (lighter than water density) will float on top of the water. In related development, bulk density and true density can be useful in sizing grain hoppers and storage facilities; seeds and grain densities have been of interest in breakage susceptibility and hardness studies (Heidarbeigi *et al.*, 2009). (Shimelis and Rakshit, 2005), studied the physical properties of eight improved bean varieties namely: 'Roba', 'Mexican', 'Red wolayita', 'Awash', 'Gofta', 'Beshbesh', 'Gobirasha', and 'Tabor'. And found that the density of varieties varied from 1.177 to 1.343 g/mL.

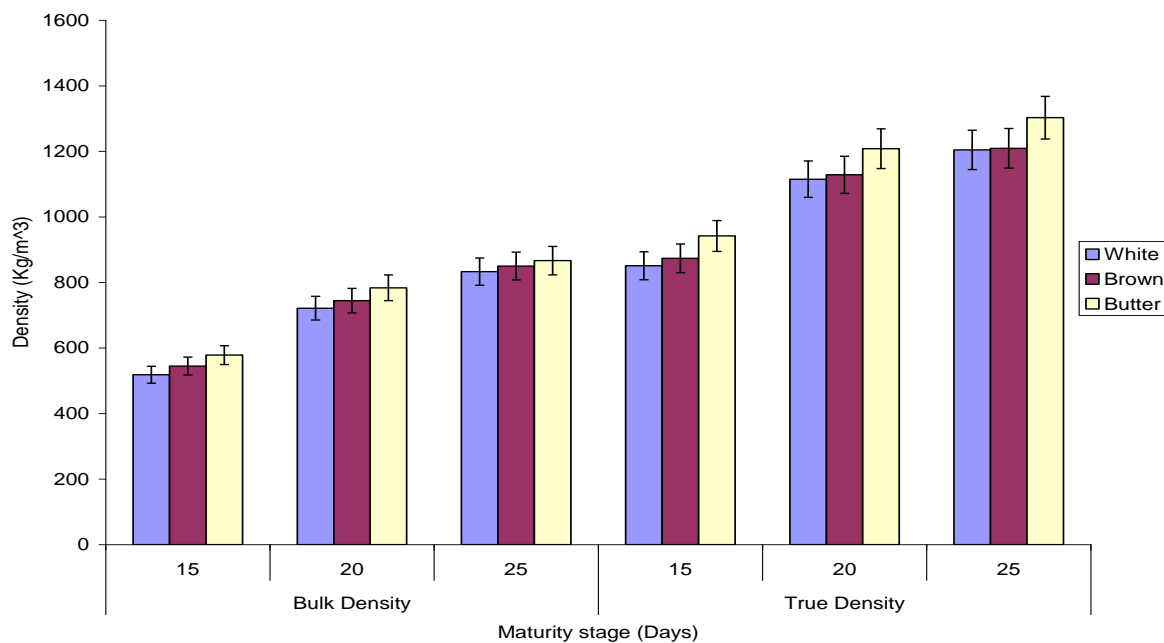


Figure 3: Influence maturity stage on bean seeds bulk and true density

Porosity

The porosity of the three bean varieties decreases with increased in maturation of the bean seeds (Figure 4). In reference to the ANOVA table, maturity stage had a significant effect on the porosity of both bean varieties. Porosity is the fraction of the space in the bulk seeds which is not occupied by the seeds (Coşkuner and Karababa, 2007), and depends on the geometry and surface properties of the material (Mpotokwane *et al.*, 2008) which allow fluid to pass through the bulk. It is useful in the calculation of the rate of aeration and cooling, drying and heating and in the design of heat exchangers and other similar equipment for bean handling (Asoegwu *et al.*, 2006). Porosity has practical applications in the design of aeration systems during storage. It is also needed by the design engineer to know the number of seeds that will enter a hollow seed tube of the planter (Akaaimo & Raji, 2006). Seeds with low porosity dry very slowly, therefore, drying the bean seeds through natural aeration will be difficult.

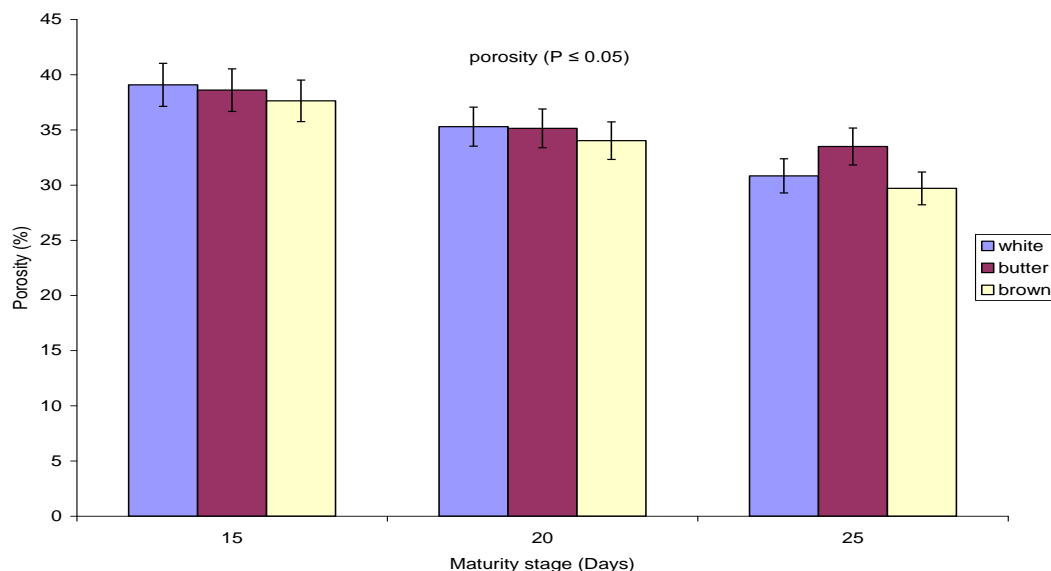


Figure 4: Influence maturity stage on bean seeds porosity

3.4. Functional Properties

Hydration, Swelling Capacities and Their Coefficients

As shown in the ANOVA table (Table 6), significant differences ($P < 0.05$) occurred in the hydration and swelling capacities as well as the hydration and swelling coefficients, during their maturation period. Table 7 illustrates the hydration and swelling capacities, with the respective coefficients of the three bean varieties; and how their behaviour with increased in maturation. From the results of the study, the value of swelling coefficient was highest in *butter* beans, probably due to its textural structure making to swell faster than the other two bean varieties. Hydration and swelling capacities of the three bean varieties increases with increased in maturation of the seeds (from 15 DAF to 25 DAF); *Butter* bean seeds possessed the highest swelling capacity among the three bean varieties, while Brown bean seeds had the lowest value (Table 7). The high value of swelling coefficient of *butter* bean seeds among the three bean varieties beans seeds revealed their high swelling ability.

Table 6: The ANOVA of effect of maturity stage and variety on the functional properties of bean seeds

Source	df	Hydration capacity		Swelling capacity		Hydration coefficient		Swelling coefficient	
		F	Sig	F	Sig	F	Sig	F	Sig
M	2	896.39	2.06E-25*	901.85	1.89E-25*	679.72	8.09E-24*	679.75	8.08E-24*
V	2	167.55	6.02E-16*	44.27	2.99E-09*	366.35	2.72E-20*	409.13	6.44E-21*
M x V	4	1.40	0.260217	2.02	0.119544	23.56	1.79E-08*	15.83	8.69E-07*

* =Significant at $P \leq 0.05$, ns = non-significant, M = Maturity stage, V = bean variety,

These differences in the functional properties of the three bean varieties may be attributed to their difference in size, seed coat thickness, and water absorption characteristics of seeds (Sefa-Dedah *et al.*, 1979). Swelling ability of any seed depends upon its water retention capacity. The hydration and swelling coefficients reflect the capacity to absorb water in a reasonable length of soaking (Nciri *et al.*, 2014; Nasar-Abbas *et al.*, 2008). Hydration and swelling capacities of bean seeds are useful parameters to the food processing industry; for instance, larger hydration capacity leads to better cooking quality while swelling capacity helps in dehusking of the pods. Since large hydration coefficient leads to better cooking texture and cooking time, (Teshome and Emire, 2012); *butter* bean seeds would require lesser fuel and energy to be cooked. The results of this study are consistent with the research findings presented by (Shimelis and Rakshit, 2005; Buzera, *et al.* 2018; Nciri *et al.*, 2014), who reported wide variation in hydration and swelling coefficient across of beans varieties. (Akromah *et al.*, 2015) noted that the swelling volume is desirable characteristic that influences acceptability of beans since high grain expansion during cooking is preferred.

Table 7: Functional properties of the three bean varieties

Parameter	Variety	Maturity stage (DAF)		
		15	20	25
Hydration capacity (g/seed)	White	0.183 ^a ±0.010	0.333 ^b ±0.010	0.400 ^c ±0.018
	Butter	0.165 ^a ±0.013	0.308 ^b ±0.019	0.385 ^c ±0.006
	Brown	0.108 ^a ±0.013	0.240 ^b ±0.008	0.303 ^c ±0.010
Swelling capacity (vol/seed)	White	0.343 ^c ±0.013	0.523 ^b ±0.030	0.680 ^a ±0.022
	Butter	0.425 ^c ±0.013	0.723 ^b ±0.017	0.840 ^a ±0.026
	Brown	0.298 ^c ±0.022	0.435 ^b ±0.021	0.513 ^a ±0.025
Hydration coefficient (%)	White	1.235 ^a ±0.026	1.815 ^b ±0.068	2.113 ^c ±0.059
	Butter	1.320 ^a ±0.026	1.850 ^b ±0.045	2.280 ^c ±0.029
	Brown	1.153 ^a ±0.013	1.680 ^b ±0.104	2.015 ^c ±0.037
Swelling coefficient (%)	White	1.330 ^c ±0.016	2.193 ^b ±0.059	2.363 ^a ±0.087
	Butter	1.933 ^c ±0.135	3.158 ^b ±0.054	3.525 ^a ±0.170
	Brown	1.445 ^c ±0.026	2.165 ^b ±0.061	2.543 ^a ±0.022

Values are mean ± Standard Deviation; Means with similar superscript in the same row did not differ significantly ($p \leq 0.05$).

The regression equations of maturity stage as a function of functional properties of bean seeds with their respective coefficient of determination (R^2) and correlation (r) values given in Table 8, shows a strong relationship between maturity stage of the bean seeds and the functional properties investigated in this research

Table 8: Regression equations of the functional properties as a function of maturity stage with their respective coefficient of determination (R^2) and correlation (r) values

Parameter	Bean variety	Regression equation	R^2	r
Hydration capacity (g/seed)	White	$y = 0.1085 x + 0.0883$	0.954	0.976
	Butter	$y = 0.11 x + 0.066$	0.971	0.985
	Brown	$y = 0.0975 x + 0.022$	0.959	0.979
Swelling capacity (vol/seed)	White	$y = 0.1685 x + 0.1783$	0.998	0.999
	Butter	$y = 0.2075 x + 0.2477$	0.940	0.969

	Brown	$y = 0.1075 x + 0.2003$	0.975	0.987
Hydration coefficient (%)	White	$y = 0.439 x + 0.843$	0.967	0.983
	Butter	$y = 0.48 x + 0.8567$	0.996	0.998
	Brown	$y = 0.431 x + 0.754$	0.983	0.992
Swelling coefficient (%)	White	$y = 0.5165 x + 0.929$	0.870	0.932
	Butter	$y = 0.796 x + 1.28$	0.912	0.954
	Brown	$y = 0.549 x + 0.953$	0.969	0.984

3.5. Frictional Properties

Coefficient of Static Friction

The static friction of the bean seeds was significantly ($P \leq 0.05$) influenced by the maturity stage and variety of the bean seeds (Table 9). It was observed that the static coefficient of friction increased with increase in maturation for all the surfaces, which can be attributed to the changes in the shape and bulk density of the seeds as they matured. In reference to Figure 5, all the bean seeds harvested at 15 DAF, had poorer static friction when compared to those harvested at 25 DAF. Fictional properties of fruits, seeds and nuts are vital in the design of the storage containers, and for loading and unloading during handling (e.g. machine hopper). The angle of internal friction is required to calculate the lateral pressure which causes bending of the wall in storage bin as well as gravity flow in hoppers (Akaaimo and Raji, 2006). The coefficient of static friction was the lowest in the glass surface, this could be attributed to the smooth surface of the glass when compared to the other surfaces used. The coefficient of friction is an important parameter in selecting appropriate materials for different units of machinery, especially for components requiring flow of the seeds (Coşkuner and Gökbudak, 2016). The regression relationships between maturity stage and static coefficients of friction on all test surfaces are presented in Table 10.

Table 9: The ANOVA of effect of maturity stage and variety on the frictional properties of bean seeds

Parameter	Source	df	F	Sig
Coefficient of static friction	M	2	956.86	4.45E-57*
	V	2	7779.19	2.678E-93*
	S	2	946.54	6.771E-57*
	M x V	4	20.56	1.E-11*
	M x S	4	1.74	0.150 ^{ns}
	V x S	4	34.19	1.06E-16*
	M x V x S	8	1.08	0.382 ^{ns}
Angle of repose	M	2	288.308	6.06E-19*
	V	2	174.68	3.57E-16*
	M x V	4	2.1215	0.1056 ^{ns}

* =Significant at $P \leq 0.05$, ns = non-significant, M = Maturity stage, V = bean variety, S = surface of static friction

Table 10: Regression equations of the frictional properties as a function of maturity stage with their respective coefficient of determination (R^2) and correlation (r) values

Parameter	Surface	Bean variety	Regression equation	R^2	r
Coefficient of static friction	Plywood	White	$y = 0.06 x + 0.5367$	0.964	0.982
		Butter	$y = 0.055 x + 0.39$	0.976	0.987
		Brown	$y = 0.065 x + 0.48$	0.983	0.991
	laminare	White	$y = 0.06 x + 0.27$	0.923	0.960
		Butter	$y = 0.045 x + 0.19$	0.964	0.981
		Brown	$y = 0.06 x + 0.22$	0.923	0.961
	Glass	White	$y = 0.045 x + 0.15$	0.964	0.982
		Butter	$y = 0.025 x + 0.1067$	0.987	0.993
		Brown	$y = 0.035 x + 0.1433$	0.855	0.924
Angle of repose		White	$y = -4.335 x + 42.14$	0.972	- 0.985
		Butter	$y = -4.105 x + 47.583$	0.988	- 0.993
		Brown	$y = -3.405 x + 44.8$	0.998	- 0.999

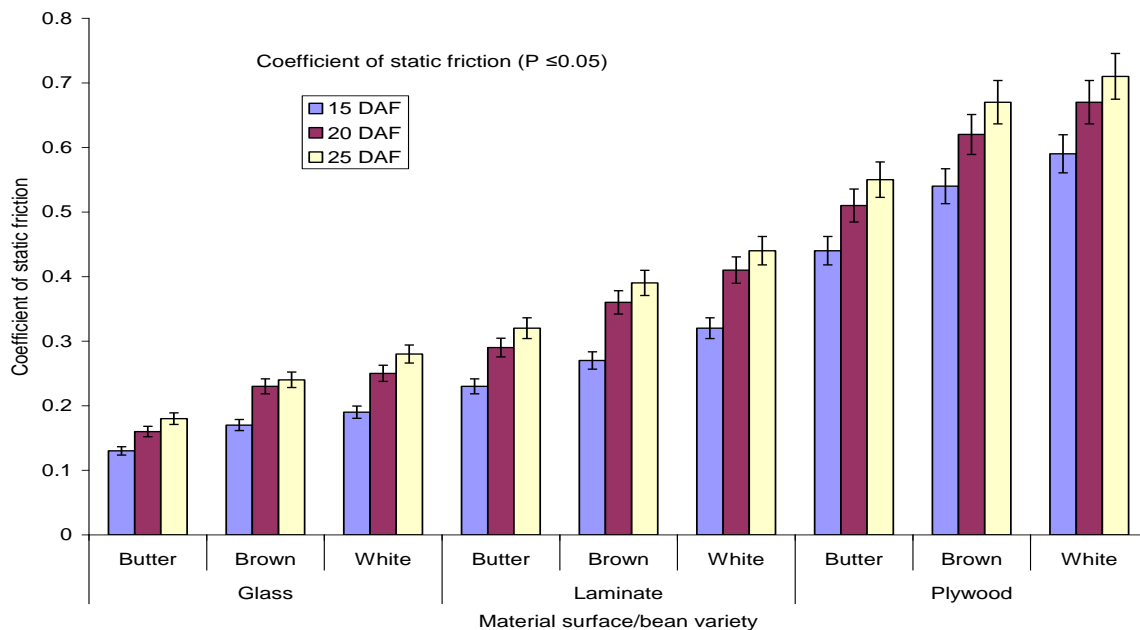


Figure 5: Influence maturity stage on bean seeds coefficient of static friction

Angle of Repose

From the ANOVA table (Table 9), bean variety and maturity stage had significant ($p < 0.05$) effect on the angle of repose of the bean seeds. The angle of repose was higher for *Butter* bean seeds at all the maturity stages evaluated in this study, than the rest two bean variety. The decline in the angle of repose for both variety of beans as maturation progresses (Figure 6), could be attributed to the variation in the bean size and shape as maturation period progresses. In addition, moisture content of the seeds plays a vital role in the declining of the angle of response during maturation

of the seeds. Gharibzahedi *et al.* (2010) reported that seeds might stick together at the higher moisture content, which results in less flowability and better stability, thereby increasing the angle of repose.

Angle of repose is importance in designing hopper openings, sidewall slopes of storage bins, chutes for bulk transporting of seeds and it is particularly useful for calculating the quantity of granular materials which can be placed implies or flat storages (Gharibzahedi *et al.*, 2009); therefore, the maturity stage of bean seeds should be taken into account while designing processing and handling equipment. The increase of dynamic angle of repose was due to increase of internal friction with increase of contact surface area among the seeds, as any increase in internal friction among seeds will bring a resultant increase in the angle of repose of the seeds (Eze and Igwillo, 2018). The regression relationship existing between maturity stage and angle of repose is presented in Table10.

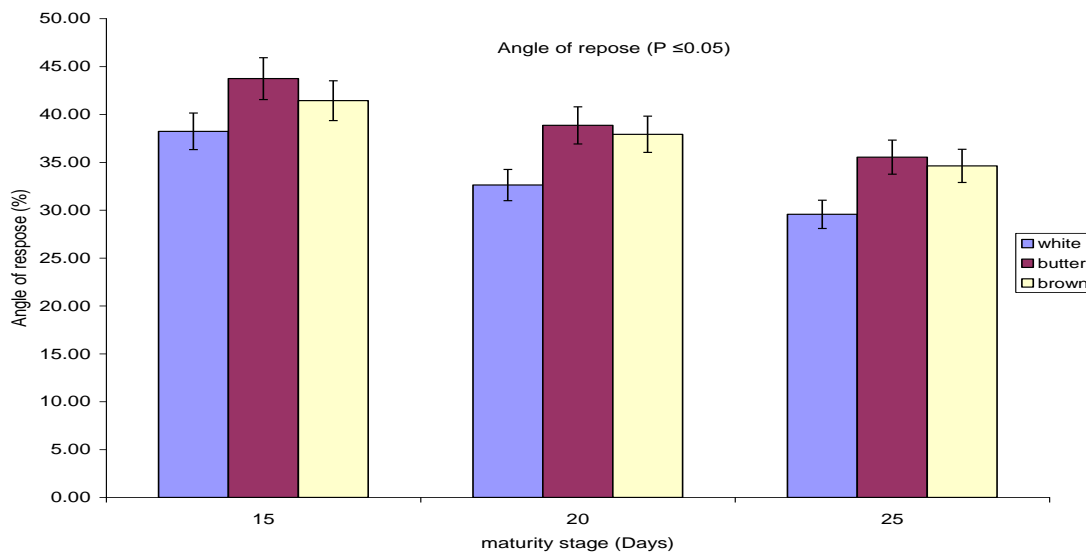


Figure 6: Influence maturity stage on bean seeds angle of response

4. Conclusion

This study provided basic information on engineering properties of three common bean (*Phaseolus vulgaris* L.) varieties namely: butter, brown and white cowpea. The engineering attributes including seed mass, moisture content, sphericity, geometric mean, arithmetic mean, volume, seed size, seed density, porosity, coefficient of static friction, hydration capacity, hydration coefficient, swelling capacity, and swelling coefficient were evaluated. The results maturity stage significantly ($P < 0.05$) influences all the parameters investigated. Apart from the true density and angle of repose, all the other parameters increased linearly with increase in maturation of the bean seeds. In respect to the functional properties, *Butter* beans had the highest swelling capacity and coefficient. In addition, the moisture content of the bean seeds declined with maturity of the bean seeds, signifying increased in dry matter of the bean seeds as maturity progresses. Data gotten from this result will be useful in the design and development of harvesting, handling and processing equipment.

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