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Research Paper

Environmental Factors on the Physical Characteristics and Physiological Maturity of Okra (*Abelmoschus esculentus, cv. Kirikou*) Pods and Seeds

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This study investigated some physical characteristics and physiological maturity of okra (Cv. *Kirikou)* pods and seed. The okra were planted in two planting seasons (rainy and dry season), and harvested in five maturity stages (7 DAP, 11, DAP, 15 DAP, 19 DAP, and 23 DAP). The results revealed that planting season (environmental conditions) had significant (P ≤0.05) effect on all the parameters investigated in this study. The results further showed general increment in the physical characteristics and physiological maturity of the okra pod and seed, as maturation increased from stage 1 to stage 5, in both planting season. In addition, maximum seed weight (mass maturity) was achieved at Stage 3 in both cropping season, while maximum seed quality (specific gravity and porosity) was achieved in Stage 5. The okra seeds true density increased from 640 to 1012 kg/m³ in the dry season farming and 642 to 1038 kg/m³ during the rainy season farming. Likewise, the okra seed bulk density increased from 427 to 593 kg/m³ during the dry season farming, and 432 to 605 kg/m³ in the rainy season farming. Data obtained from this study will help engineers in designing and fabrication of machines/equipment for the mechanization of okra production.

Key words: *Kirikou* okra, maturity stage, environmental factors, Physical characteristics

INTRODUCTION

Okra (*Abelmoschus esculentus*), is one of the important vegetable crops cultivated in Asia and Africa countries. A total world production of 9.64 million metric tonnes was recorded in 2017, with India accounting for 6 million metric tonnes, about 63% (FAOSTAT, 2019). According to the Food Agriculture Organization (FAO) data, Nigeria followed India with 2 million metric tonnes production in 2017 (20.83% of total production), harvested from 1.48 million hectares of land. Okra pods mostly in the immature (green) stage are used in soup preparation, and they contain about 2.2% protein, 9.7% carbohydrate, 1.0% fibre, 30 mg/100 g vitamin C, 90 mg/100 g calcium and 1.5 mg/100 g iron (Saifullah and Rabbani, 2009; Kumar *et al*., 2018). Apart for okra nutritional values, it has the ability of reducing hemorrhoid effects, pains, and curing peptic ulcer (Singh *et al*., 2017).

Physical characteristics of agricultural materials are vital information for the design and development their planting, harvesting, processing, and storage systems. Dimensions are vital elements in the design and fabrication of sizing, cleaning and grading machines/systems of agricultural materials, while porosity is a major parameter in the design of drying and storage systems (Dursun and Dursun, 2005). According to Hazbavi, (2003) the coefficient of friction of agricultural material is necessary in the design of systems for its solid flow and storage structures. Seed development starts from fertilization, accumulates fresh weight during process, until maturation begins at the end of the seed development and continues till harvest (Mehta et al., 1993); and during this processes, all the engineering properties of the seed varies. Seed quantity and quality can be hindered by environmental, biotic and abiotic factors (Indira and Dharmalingam, 1996), both before physiological maturity and after physiological maturity, a stage at which the seed possesses its maximum dry weight (Mehta et al., 1993; Olasoji *et al*., 2012). According to (Demir *et al*., 2008), maturity stage (mostly at harvest) is one of the most important factors that influence the quantity and quality of seeds produced. Environmental conditions that seeds quantity and quality during seed development and maturity are; temperature, water stress or excessive rain, nutrients shortage, diseases infection, and pest pressure (Delouche, 1980).

Previous researchers have shown the importance of physical characteristics of agricultural materials in machines design and development. According to (Scherer and Kutzbach, 1978), separation of foreign elements from seeds and grains is easy through oscillating chaffers when size, shape, and density of the seeds or grains are known. Zewdu and Solomon, (2006) reported that during the design of seeds drying and aeration systems, bulk density and porosity play a significant role as they determine the hindrance caused by airflow. The physical properties of pumpkin seed and kernel were determined by Joshi *et al*., (1993), and reported that correlations among various dimensions of the seed and kernel, indicating that the seed width was closely related to its length. Some physical characteristics of okra seed were determined by Sahoo and Srivastva, (2002) and recorded increment in the seed length (5.92 to 7.30 mm), width (4.71 to 5.40 mm) and thickness (4.59 to 5.36 mm) as the moisture content from 8.16 to 87.57 percent. Eboibi and Uguru, (2018) investigated the effects of variety and maturity stage on some physical characteristics of bean (*Phaseolus vulgaris* L.). They found that maturity stage significantly ($P \leq 0.05$) influenced all the physical characteristics of the bean seeds, for example, the seeds true density increased from 817.75 to 1207 kg/m^3 in *iron* bean, and 774.25 to 1144 kg/m3 in Honey bean; likewise, the bulk density increased from 464.5 to 761.75 kg/m^3 and 544.75 to 867.66 kg/m^3 in the *iron* and *honey* bean respectively (Eboibi and Uguru, 2018). In addition, Nimkar and Chattopadhyay, (2001) reported that the size, thousand grain mass, angle of response, geometric mean diameter and bulk porosity of green gram increased with increase in moisture content (8.39 to 33.40% d.b.). Demir *et al*. (2008) studied the effect of production environment and harvest time on tomato (*Lycopersicon esculentum*), and observed significant difference.

Lack of planting, harvesting, handling, processing machines, and couple with environmental factors are some of the major constraints facing okra production in Nigeria. The need for indigenous technology and better understanding of physiological maturity of okra crop cannot be overemphasized, but currently, there is paucity information to these aspects. Therefore, the objective of this study was to investigate the effect of environment factors and maturity stage on the physical characteristics (principal dimensions, thousand seed mass, thousand pods mass, geometric mean diameter, sphericity, surface area, volume of seed, bulk density, true density, kernel density, porosity, angle of repose and specific gravity) and physiological maturity of *Kirikou* okra variety.

MATERIALS AND METHODS

Study settings

The experiment was carried out at the Delta State Polytechnic Research Centre, Ozoro, Nigeria. It has the coordinates of 5°32′18″N and 6°12′58″E, with elevation of 68 m above sea level, as reported by Polytechnic metrological Station (Eboibi *et al*., 2018), situated 200 m from the experimental area. The rainy season lasts from April to October 2018, with peak rainfall in July 2018. The dry season starts from November 2018 to March 2019.

Research period

The research was out in two planting seasons. Season 1, May 2018 to August 2018, which was considered as the rainy season; and season 2, December 2018 to March 2019, which was considered as the dry season.

Okra cultivation

The *Kirikou* okra variety used for this research study were packed in France and brought from Technisem Seed Company, through their agent in Kano State, Nigeria. The experimental plots were divided into (3 x 15) m, while the seeds were planted in 3 per hole at the spacing of (50 x 100) cm. The okra seeds were plated under organic farming period. Six weeks before planting, cattle dumps and poultry waste were incorporated into the soil at the rate of 500 kg/ha.

Soil analytical analysis

A soil analytical analysis of the experimental area was done in both planting seasons (rainy and dry). This was done in order to determine their spatial distribution in the area, and how they will affect the okra's performance. All the analytical analysis (moisture content, soil pH, soil temperature electrical conductivity, nitrogen, potassium, phosphorous, chlorides, bulk density, porosity) were determined as per the standard methods (APHA, 1995; Hesse, 2002; Akpokodje *et al*., 2018).

Collection and sampling

The *Kirikou* okra pods used for this research were harvested at five maturity stages. The first harvest was done 7 Days after Peak Flowering DAP, and then the subsequent harvests were done at 4 days intervals till 23 days DAP. The okra pods harvested from the research farm were immediately taken to the Food Processing laboratory of Delta State Polytechnic Ozoro, Nigeria for analysis. In the laboratory, tests were done to determine the effects of harvesting stages on physiological maturity and physical characteristics of *Kirikou* okra pod and seed. For each maturity stage, 100 healthy and pest free pods were harvested for the research.

Moisture content determination

The initial weight of the okra seeds and straw was taken with a digital electronic scale, and were put inside an electric laboratory oven, preset at a temperature of 105°C (±1°C). The weight of the okra seeds and straw was taken every one hour until a stable temperature was achieved. Moisture content of the okra seeds and straw was calculated with equation 1 (AOAC, 2000).

$$\text{Moisture content (Mc)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \text{ (wet basis)} \quad (1)$$

Where,
W_1 = Weight of container, g;
W_2 = Weight of wet sample + container, g
W_3 = Weight of dry sample + container, g

Dimensional properties determination

The dimensional properties (Geometric mean, Sphericity, surface area) of okra pods and seeds were measured with an electronic digital caliper (manufactured in Chia) having accuracy of 0.01 mm. Fifty randomly selected okra pod and one hundred randomly selected okra seeds were measured to determine their length "L", width "W" and thickness "T", and the average value recorded. Geometric mean and sphericity of the okra pods and okra seeds were calculated using equations 2, 3 and 4, as recommended by Mohsenin, (1986).

Geometric mean (D_g)

$$Geometric\ mean = \sqrt[3]{L \times W \times T} \quad (2)$$

But due to the cylindrical nature of the okra pod shape, the difference between the pod width and thickness is negligible. Therefore, geometric mean of the okra pod was calculated using equation 3

$$Geometric\ mean = \sqrt[3]{L \times W^2} \quad (3)$$

Sphericity

The sphericity (φ), of pod and seed was calculated by using equation 4.

$$\text{Sphericity} = \frac{\sqrt[3]{L \times W \times T}}{L} \times 100 \quad (4)$$

Surface area

The surface area (S) of the okra pod and seed were calculated using equations 5, as recommended by Mohsenin, (1986).

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

Gravimetric properties determination

Thousand seed and pod mass

The thousand seed mass of the okra seed was calculated by multiplying the mass of 100 healthy and pest free okra seeds, weighed with an electronic balance (accuracy of 0.001 g) by 10. In addition, the thousand pods mass was calculated by weighing the mass of 100 healthy and pest free okra pods (from each maturity stage), and then multiplying the results by 10.

Bulk Density

The bulk density of the okra seeds was measured adopting the mass/volume relationship. A measuring cylinder was weighed with an electronic balance, and the weight recorded. Then the okra kernels were filled into the measuring cylinder up to the volume of 500 ml, by pouring from a constant height (Eboibi and Uguru, 2018) and weighing the cylinder and the kernels again. The bulk density was calculated as shown in equation 6.

$$Bulk\ Density = \frac{Weight\ of\ okra\ seeds}{Volume\ of\ okra\ seeds} \quad (6)$$

True density

The Okra seed true density was evaluated using the liquid displacement method (Eboibi and Uguru, 2018). Toluene (C_7H_8) was the liquid used in place of water because it is not easily absorbed by the seeds unlike water. Hundred (100) okra seeds were counted and were poured into a measuring cylinder with known volume of toluene inside it. The displaced toluene was read from the cylinder, avoiding parallax error. The true density of the okra seed was calculated as the ratio of seeds weight to the volume of toluene displaced (Eboibi and Uguru, 2018).

Porosity

The porosity of the okra seeds was calculated from the true and bulk density using equation 7, recommended by

Mohsenin, (1986).

$$\text{porosity} = 1 - \frac{\rho_b}{\rho_t} \quad (7)$$

Where P = porosity (%)
ρ_b = bulk density (kg/m^3)
ρ_t = true density (kg/m^3).

Angle of repose

The angle of repose (ψ) of the okra seed was determined by using a hollow cylindrical container (diameter = 100 mm, height = 150 mm). The container was filled with the okra seeds and raised slowly until the seeds formed a cone. The seeds angle of repose was calculated using equation 8, as recommended by Eboibi and Uguru, (2018).

$$\psi = tan^{-1}\frac{2H}{D} \quad (8)$$

Where H = height of the cone; D = diameter of the cylinder

Specific gravity

The specific gravity of the okra seeds was determined by weighing method. A specific pycnometer of a known weight was filled with the okra seeds, and the new weight was determined with an electronic scale. Then distilled water was added to the pycnometer with the okra seeds inside up to the upper mark, and weighed again. The Specific gravity of the fine aggregate was calculated using equation 9 (Esegbuyota *et al*., 2019).

$$SG = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad (9)$$

W_1 = Weight of the empty bottle
W_2 = Weight of the bottle filled with 75% of the total volume.
W_3 = Weight of the bottle and its content filled with distilled water up to the meniscus.
W_4 = Weight of the bottle filled with distilled water to the meniscus.

Statistical analysis

All data gotten from this study were subjected to Analysis of variance using SPSS statistical software (version 20.0, SPSS Inc, Chicago, IL). The mean were separated using Duncan's Multiple Range Tests at 95% confidence level. All the experiments were repeated ten times, and the average value recorded.

RESULTS

Environmental conditions

Average temperature during the rainy season was 22±5°C, while the mean temperature during the rainy season was 30±4°C. An average soil temperature of 20±2°C was recorded during the rainy season, and 32±5°C was recorded during the dry season. Changes in the soil nutrient and salt contents (Table 1), shows that apart from the increase in the soil electrical conductivity, signifying increment in the soil saline content. Saline soils are characterized by an EC >4 and pH <8.5 (Gabasawa *et al*., 2014; Mc Bratney *et al*., 2014). The difference in the soil nutrient in both planting seasons was less than 5%, and could be considered to have negligible effects on the performance of the okra plant. The colour of the okra seed during stages 1 and 3 was whitish, before it turned to greenish appearance in stage 3, blackish in stage 4 and finally turned to ash colour in stage 5. The *Kirikou* okra pods changed from greenish appearance to brown appearance, as maturation moved from stage 1 to 5 (Figure 1). The poorer yield in the dry season could be attributed to high saline content in the soil caused by excessive evaporation (Table 1), posing a serious threat to the okra plants. This it does by hindering the absorption of the soil nutrients by the plant's (okra) roots, leading to poor growth performance and yield of the okra plant. Saline soils can be reclaimed by leaching down the salts beyond the plant's root zone by sufficient water (Gabasawa *et al*., 2014). The heavy rain fall experienced in the area during the rainy season helped to accomplish this task, as seen in (Table 1).

Analysis of variance

The analysis of variance (ANOVA) of the physical characteristics of the okra seed and pod varieties showed that they are highly dependent on the maturity stage (Table 3). According to (Table 2), maturity stage significantly ($P \leq 0.05$) influenced these parameters (mass, moisture content, length, width, thickness, geometric mean, sphericity, surface area, bulk density, true density, specific gravity and angle of repose) investigated; in addition, planting season significantly ($P \leq 0.05$) influenced all the parameters studied. But the interaction of maturity stage and planting season did not significantly ($P \leq 0.05$) affects the parameters investigated in this study. From the mean values presented in (Figure 2 and Tables 3 to 5), all the parameters investigated in this study were slightly higher in the rainy season than in the dry season.

Okra seed and straw moisture content

The ANOVA results obtained from this research showed that the differences between moisture contents of the okra

Table 1. Physicochemical properties of the soil samples of the experimental area.

Parameter	Rainy season	Dry season
Electrical conductivity	2.9(dS/m)	5.8(dS/m)
pH	8.7	5.8
Lead	1263 (mg/kg)	1337 (mg/kg)
Total nitrogen	0.239(mg/kg)	0.19(mg/kg)
Available phosphorus	0.337(mg/kg)	0.393(mg/kg)
Copper	4.911(mg/kg)	5.225(mg/kg)
Nitrate	0.324(mg/kg)	0.384(mg/kg)
Sodium	550.75(mg/kg)	585.83(mg/kg)
Extractable potassium	723.227(mg/kg)	767.513(mg/kg)

*dS/m = deci Siemens per meter.

Figure 1. Picture of the five maturity stages of the Kirikou okra pods.

seed and straw were statistically significant (P<0.05) in the five maturity stages, and the two planting seasons. From the results presented in (Figure 2), the moisture content of the okra seed and straw declined with increase

Table 2a. The ANOVA of effect of maturity stage and planting season on the physical characteristics of *Kirikou* okra seeds and pods.

Source	1000 pod mass	1000 seed mass	Seed MC	Straw MC	Angle of repose	Specific gravity
P	0.01958*	0.04385*	7.28E-07*	0.01812*	9.39E-07*	6.19E-07*
S	1.57E-14*	2.17E-11*	1.62E-19*	6.8E-20*	9.89E-15*	7.19E-9*
P x S	0.9609^{ns}	0.9966 ^{ns}	0.0211 ^{ns}	0.2957 ^{ns}	0.18387^{ns}	0.9534^{ns}

* Significant at P≤ 0.05, ns non-significant, S = Maturity stage, P = planting season

Table 2b. continued.

Source	Seed length	Seed Width	Seed Thickness	Seed GMD	Seed sphericity	Seed Area
P	3.01E-05*	2.01E-06*	2.26E-06*	3.53E-06*	1.9E-07*	0.0234*
S	3.82E-11*	4.79E-14*	2.21E-14*	1.64E-13*	0.0130*	1.92E-15*
P x S	0.9566^{ns}	0.8942^{ns}	0.8865^{ns}	0.9017^{ns}	0.9868^{ns}	0.8868^{ns}

Table 2c. continued.

Source	Pod length	Pod width	Pod GMD	Pod sphericity	Pod Area	Bulk density
P	1.47E-05*	2.71E-07*	7.97E-08*	1.76E-07*	1.86E-04*	3.22E-04*
S	5.15E-16*	6.55E-16*	4.24E-17*	1.04E-10*	1.99E-17*	1.61E-22*
P x S	0.81470^{ns}	0.83635^{ns}	0.73904^{ns}	0.99497^{ns}	0.74143^{ns}	0.69479^{ns}

Table 2d. continued.

Source	True Density	Porosity
P	0.01043*	0.66097^{ns}
S	2.48E-20*	8.33E-12*
P x S	0.67723^{ns}	0.80617^{ns}

* Significant at P≤ 0.05, ns non-significant, S = Maturity stage, P = planting season, MC = moisture content, GMD = geometric mean diameter.

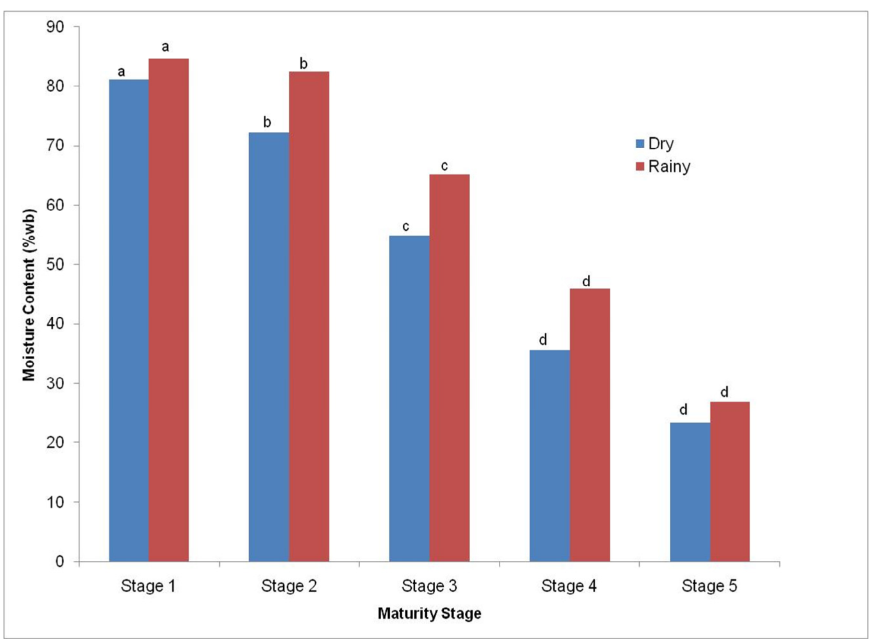

Figure 2a. *Kirikou* okra seed moisture content.

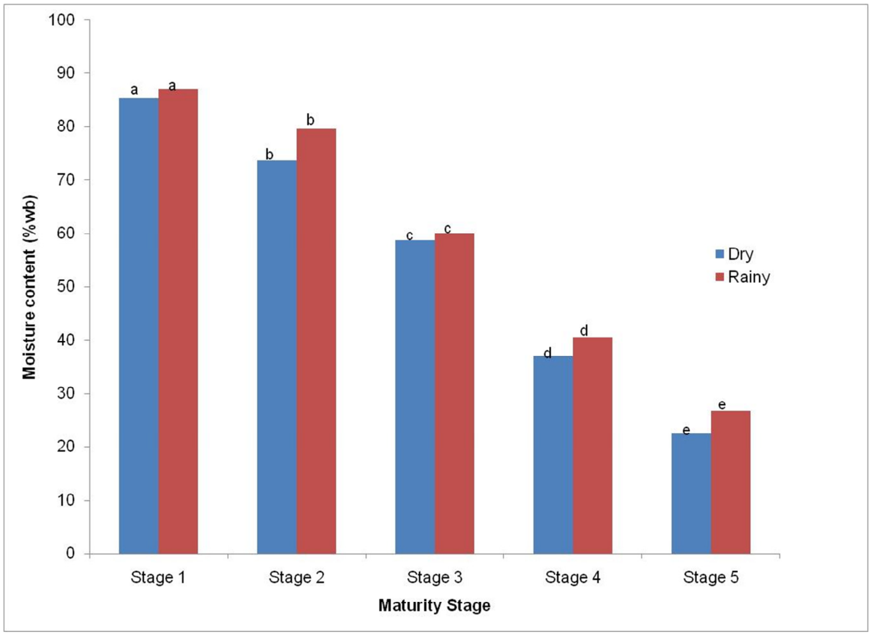

Figure 2b. *Kirikou* okra straw moisture content.

Figure 2. Effect of planting season and maturity stage on the moisture content of *Kirikou* okra seed and straw. Columns with the same common letter not significantly different (P < 0.05) according to Duncan's multiple ranges test.

in maturation, in both planting season. Okra pod harvested at stage 1 (collected after 7 DAP), recorded the highest moisture content. Slightly lower moisture content values recorded in the dry season than the rainy season could be attributed to the high environmental temperature recorded within this period, which aids excessive evapotranspiration within the okra pod in the field. Demir and Ellis, (1993) recorded the same declining pattern of moisture content during marrow maturation. In addition, Olasoji *et al*., (2012) reported a drastic decline (about 60 %), in the moisture content of kenaf (*Hibiscus canabinus)* seed, during maturation period of 45 days. 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, and seed moisture content is an index of optimum harvest time (Bedance *et al*., 2006; Berti *et al*., 2007; Eboibi and Uguru, 2018).

Okra seed and pod dimensional properties

The mean values of dimensional properties of the okra seed and pod in both planting seasons are presented in (Tables 3 and 4). The results showed that the dimensional properties are highly dependent on the maturation of the pod and seed, as the values increased linearly from stage 1 to stage 3, before they inclined insignificantly (about 2%) again to stage 5. The little declined in the dimensional properties could be attributed to the shrinkage (drying) of the okra pod as maturity entered the advanced stage (stages 4 and 5). When plant's material dries up, it weight, size and shape changes in a declining manner. Hazbavi, (2013) and Bagherpour *et al*. (2010) reported similar results for Iranian okra seed and lentil respectively. Kushwaha *et al*. (2007) reported geometrical mean diameter of okra seed as 4.9 mm. Higher sphericity values indicate higher tendency of the material to roll on any of its three axes (Bamgboye and Sadilku, 2015; Eboibi and Uguru, 2017). Therefore, as seen in the results, the ability of the of the okra pod to roll over flat surfaces, decreases as maturity increased. But in the case of the okra seed, the tendency increased in increase in maturation of the seed. Size and shape of the okra seed help in the development of metering mechanism for okra planter.

Gravimetric Properties

Thousand pod and seed mass

The effect of maturity stage on 1000 pod mass and 1000 seed mass of the okra plant is shown in (Table 5). As presented in (Table 5), throughout the course of maturity, the okra pod, straw and seeds undergo weight changes.

Table 3. Effect of maturation on the dimensional properties of *Kirikou* okra seed.

Parameter	Season	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Length (mm)	Dry	4.49^{a}±0.16	4.97^{b}±0.31	5.76^{c}±0.01	5.75^{c}±0.06	5.64^{c}±0.16
	Wet	4.77^{a}±0.25	5.29^{b}±0.31	6.18^{c}±0.01	6.15^{c}±0.02	6.01^{c}±0.15
Width (mm)	Dry	3.69^{a}±0.11	4.09^{b}±0.23	4.90^{c}±0.03	4.89^{c}±0.06	4.84^{c}±0.09
	Wet	3.93^{a}±0.18	4.35^{b}±0.20	5.25^{c}±0.04	5.22^{c}±0.02	5.16^{c}±0.06
Thickness (mm)	Dry	3.55^{a}±0.17	3.98^{b}±0.17	4.82^{c}±0.04	4.76^{c}±0.04	4.74^{c}±0.09
	Wet	3.78^{a}±0.24	4.23^{b}±0.15	5.17^{c}±0.04	5.09^{c}±0.03	5.05^{c}±0.05
GMD (mm)	Dry	3.89^{a}±0.15	4.32^{b}±0.23	5.14^{c}±0.02	5.11^{c}±0.05	5.07^{c}±0.10
	Wet	4.13^{a}±0.22	4.59^{b}±0.21	5.51^{c}±0.03	5.47^{c}±0.02	5.40^{c}±0.08
Sphericity (%)	Dry	81.66^{a}±0.65	82.67^{ab}±0.03	83.14^{b}±0.35	83.06±0.69	85.25±0.41
	Wet	86.71^{a}±0.62	86.94^{ab}±0.49	89.21^{b}±0.38	88.84±0.24	89.75±0.91
Surface area (mm^2)	Dry	50.58^{a}±4.54	70.64^{ab}±4.85	89.01^{b}±0.81	87.80^{bc}±1.12	85.91^{c}±2.90
	Wet	53.78^{a}±5.68	66.38^{ab}±4.32	95.51^{b}±0.87	93.90^{bc}±0.52	91.52^{c}±2.74

Values are mean ± SD, Means with similar superscript in the row did not differ significantly ($p \leq 0.05$).

Table 4. Effect of maturation and season on the dimensional properties of *Kirikou* okra pod.

Parameter	Season	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Length (mm)	Dry	48.82±2.46	64.71±2.29	83.93±0.16	87.25±2.60	84.42±4.73
	Wet	52.78±2.69	69.80±1.99	90.80±0.46	94.63±2.83	91.56±5.13
Diameter (mm)	Dry	18.51±0.67	23.25±1.20	29.32±0.22	26.27±0.41	23.36±0.73
	Wet	20.01±0.71	25.08±1.07	31.72±0.22	28.49±0.45	25.34±0.79
GMD (mm)	Dry	25.57±1.04	32.72±1.59	41.33±0.45	39.19±0.78	35.83±0.55
	Wet	27.64±1.11	35.28±1.38	44.71±0.54	42.51±0.84	38.86±0.59
Sphericity (%)	Dry	48.46±0.82	46.91±1.63	45.27±0.50	41.42±0.48	39.21±2.08
	Wet	52.39±0.67	50.60±1.36	48.98±0.71	44.93±0.52	42.52±2.25
Surface area (mm^2)	Dry	2223.3±178	3631.5±322	5806.8±132	5236.4±206	4375.3±133
	Wet	2403.6±192	3915.5±309	6282.4±153	5679.4±224	4745.5±144

Values are mean ± SD, Means with similar superscript in the row did not differ significantly ($p \leq 0.05$).

Between stages 1 and 3, the mass of both the okra pod and seed increased very rapidly, 65% for the okra pod and 64 for the okra seed). After which the mass decline between stage 4 and stage 5. The increased in the okra pod and seed mass in the early stages of maturation was associated with the greater accumulation of photosynthates in pod in these stages, and after which the growth remained static due to decrease in photosynthesis and accumulation of photosynthates (Indira and Dharmalingam, 1996). These results are in conformity with the works of Reddy *et al*. (2001) for chilli, Oghenerukevwe and Uguru, (2018) for three bean (*phaseolus vulgaris* l.) varieties. Sahoo and Srivastava, (2002) reported weight of 1000 okra seeds as 65.78 g; while Kumar *et al*. (2018) recorded 1000 okra seeds weight varied from 53.2 g to 57 g. Thousand seeds mass is an important parameter in the design and fabrication storage and processing systems for agricultural materials (Kara *et al*., 2013).

According to Olasoji *et al*., (2012) plant seeds and pods as dry weight accumulates during maturity, and the increment in the dry weight reflects the accumulation of nonstructural carbohydrates, reducing sugars and fibre, relative to seed moisture content which showed a sharp fall (Ketsa and Poopattarangk, 1991; Siddique and Wright 2003). Early harvesting of crops usually resulted in poor yield and low 1000 seed Mass; while late harvest resulted in high seeds yield and increased seed weight (Siddique and Wright, 2003; Eboibi and Uguru, 2018).

Bulk density, true density and porosity

As seen in the results, the bulk density, true density and porosity of the okra seed increased with increase in the maturation of the pod (Table 5). According to Kumar *et al*. (2018) the mean porosity of okra seed (variety, *Varsha*

Table 5. Effect of maturation on the gravimetric properties of *Kirikou* okra seed.

Parameter	Season	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
1000 Pod mass (kg)	Dry	13.9^{a}±1.6	17.5^{b}±0.8	26.4^{c}±0.9	24.9^{d}±2.1	19.7^{e}±0.2
	Wet	14.9^{a}±1.1	18.2^{b}±2.2	27.8^{c}±0.8	26.7^{d}±2.2	21.4^{e}±0.5
1000 Seed Mass (g)	Dry	61.7^{a}±1.53	76^{b}±4.36	105^{c}±3.0	98.3^{d}±5.5	90^{e}±2.65
	Wet	65.3^{a}±3.79	81^{b}±7.09	109^{c}±9.1	103^{d}±6.66	95.3^{e}±8.02
Bulk Density (Kg/m^{3})	Dry	427^{a}±5.5	469^{b}±6.2	517^{c}±7.8	569^{d}±2.5	593^{e}±5.5
	Wet	432^{a}±5.6	475^{b}±6.8	529^{c}±2.3	578^{d}±4.0	605^{e}±6.4
True Density (Kg/m^{3})	Dry	640^{a}±22.2	711^{b}±11	831^{c}±12.3	946^{d}±29.6	1012^{e}±3.6
	Wet	642^{a}±11.4	729^{b}±15	855^{c}±7.4	959^{d}±22.5	1038^{e}±6.0
Porosity (%)	Dry	33.4^{a}±1.5	34.0^{b}±0.3	37.8^{c}±0.1	39.7^{d}±2.1	41.4^{e}±0.3
	Wet	32.8^{a}±1.0	34.8^{b}±0.5	38.1^{c}±0.4	39.7^{d}±1.3	41.7^{e}±0.6
Angle of Repose (degree)	Dry	21.2^{a}±0.15	22.7^{b}±0.2	23.5^{c}±0.1	23.1^{d}±0.2	22.5^{e}±0.15
	Wet	21.9^{a}±0.15	22.4^{b}±0.2	23.9^{c}±0.2	23.4^{d}±0.3	22.8^{e}±0.10
Specific gravity		0.32^{a}±0.02	0.46^{b}±0.02	0.58^{c}±0.03	0.64^{d}±0.03	0.75^{e}±0.02
		0.34^{a}±0.03	0.46^{b}±0.05	0.61^{c}±0.02	0.68^{d}±0.03	0.78^{e}±0.06

Values are mean ± SD, Means with similar superscript in the row did not differ significantly (p ≤ 0.05).

Uphar) was 49.1% varying between 43.9% and 55.0%. While Kushwaha *et al*. (2007) reported the porosity of okra seed as 49.1%. Similar result was recorded by Sahoo and Srivastava (2002) where okra seed porosity was 46.3%. Kushwaha *et al*. (2007) reported true density of okra as 1.2 g cm 11.2% moisture content (d.b.). At 8.16% moisture content on dry basis, Sahoo and Srivastava (2002) reported 1.10 g cm^{-3} as true density of the okra seeds. Knowledge of the bulk density of the fruits, kernels and seeds is essential in the design of their storage and packaging structures.

Angle of repose

From the results presented in (Table 5), the angle of repose of the okra seed was higher in the dry season farming than in the rainy season farming. In all the maturity stages investigated in this study, the values increased from stage 1 to stage 3, and then it started to decline to stage 5. This phenomenon could be attributed to the variation in the seed dimensional parameters and moisture content, as maturation of the seed progressed from stage 1 to stage 5. Gharibzahedi *et al*., (2009) in their study reported that seeds stick together at the higher moisture content, which results in less flow ability 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; Eboibi and Uguru, (2018).

Specific gravity of the okra seeds

As seen in the results (Table 5), the specific gravity of the okra seeds increased with increased in maturation of the pods. Sharma and Swaran, (2005) in their study reported significant improvement in seed quality and storability of the heavy seed-fraction okra by subjecting seeds to gravity separation. Seeds (of the same variety) with lower specific gravity are inferior to their counterparts with higher specific gravity (Menon *et al.,* 1985). Nasrin *et al*., (2010) obtained similar results (1.67 for seeds harvested 10 DAF). Specific gravity knowledge helps in good seed separation methods. Good quality seed can be obtained consistently with efficient use of processing machines, irrespective of seed quality of a harvested seed lot (Yogeesha *et al*., 2013). According to Menon *et al*., (1985) seeds of the same crop variety with relative high specific gravity enhance the speedily germination, ensure vigorous seedlings and also reduce the loss by way of ingeminated.

Conclusions

This study was conducted to determine environmental and maturity stages effect on some physical characteristics and physiological maturity of *Kirikou* okra pod and seed. From the results obtained, planting season had significant influenced on all the parameters investigated.

Likewise, the maturity stage significantly influenced almost all of the parameters investigated, apart from the seed porosity. Generally, the results showed a near linear increment of all the parameters investigated, as the maturity stages of the pod increased from stage 1 to stage 5. Maximum mean seed mass was at maturity stage 3 in both planting seasons. The variation in the physical characteristics of the okra pod and seed during maturation and planting seasons will help engineers in designing and fabrication of machines/equipment for the mechanization of okra production.

Authors` Declaration

We declare that this study is an original research by our research team and we agree to publish it in the journal.

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