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Physico-Functional Properties of Some Bean (*Phaseolus vulgaris* L.) Varieties, as Influenced by Maturation

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Abstract

A study of seed development and maturation in edible bean (Phaseolus vulgaris L.) was conducted on field-grown plants. The main objective of this present research was to investigate the physico-functional (bulk and true densities of the flour; hydration capacity, hydration coefficient, hydration index, swelling capacity, swelling coefficient, swelling index, moisture uptake, electrical conductivity and pH) properties of bean seeds during maturity, in view of designing necessary processing and handling equipment, and formulation of complementary foods. Physico-functional properties of three bean varieties (iron, honey and butter brown) were evaluated in three maturity stages of 14, 21, and 28 days after peak anthesis (DAPA). Results of the study showed large variability in all the physico-functional properties of the three bean varieties during maturation. There were significant ($P \leq 0.05$) differences among selected seed lots in most of the parameters, and maximum seed functional quality was recorded at 28 DAPA. As maturation increased from 14 DAPA to 28 DAPA for the iron, honey and butter brown bean seeds, the hydration capacity increased from 0.230 to 0.469 (g/seed), 0.108 to 0.253 (g/seed) and 0.101 to 0.244 (g/seed). Hydration coefficient increased from 1.86 to 2.043%, 1.77 to 1.93% and 1.71 to 1.91%. Hydration index increased from 0.029 to 0.027, 0.026 to 0.109 and 0.024 to 0.109. Swelling coefficient increased from 1.4 to 1.74%, 1.91 to 2.65% and 2.167 to 3.125%; while the swelling index increased from 0.013 to 0.025, 0.031 to 0.053 and 0.038 to 0.071. Conclusively, the three bean varieties investigated have great potential as functional agents in the food processing industries. The results of this study are expected to be useful for plant breeders, consumers, and the food processors.

Keywords: Bean seeds, maturity stage, physico-functional properties, electrical conductivity

INTRODUCTION

Beans (*Phaseolus vulgaris* L.) is a leguminous crop with high nutrient content and ability to fix nitrogen into the soil. Bean seeds are fast becoming a stable food because of their high protein, fiber, prebiotic, vitamins, and chemically diverse micronutrient composition (Lyimo et al. 1992; Geil and Anderson, 1994). Bean flour has been successfully used to produce chips by partially replacing cornstarch and wheat flour; resulting in increases in their protein content and decrease fat content (Kerr et al., 2001). Among the families of plants, legumes are the most utilised as alternative sources of protein; its human consumption of legumes has been increasing recently since the seeds are regarded as a source of beneficial nutrients (Gepts et al. 2005). Legumes reduce the incidences of cardiovascular diseases and cancers; good sources of protein and minerals. Frequent intake of legumes may lower blood cholesterol concentration significantly (Polhil, 1994). Nigerian *honey* bean is a commonly cultivated bean variety in West Africa countries, known for its unique taste and texture.

Early harvesting of crops may result in low yield and poor seed quality, whereas late harvesting may also result in poor seed quality due to changes in weather condition (Bedane et al. 2006). Therefore, to get good quality seed, timely harvest is important to seed viability and

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vigour. Increasing number of researchers have focused on determining the optimum harvest time of the seeds using factors such as seed colour, seed moisture content, and degree-days of growth (Elias and Copeland, 2001; Wang et al. 2006). Electrical conductivity is used to estimate seed vigor and good uniformity indicator of seedlings emergence in field (Vieira and Krzyzanowski, 1999). Cooking of beans inactivates or reduces the levels of anti-nutrients such as trypsin inhibitors and flatulence-causing oligosaccharides, resulting in improved nutritional quality; but longer cooking time is associated with some negative effects such as reduction in nutritive value of proteins (Chandrashaker et al. 1981; Hamid et al. 2016).

A clear knowledge of the most suitable harvest time for various bean varieties will enhance their seed quality and expand their uses. Processing methods of beans such as dehusking, soaking, germination, cooking and roasting inactivate the antinutrients and can be used to improve its nutritional quality (Yellavila et al. 2015). Although previous researchers (Sefa-Dedeh and Stanley, 1979; Appiah et al. 2011; Wacu et al. 2015) have investigated various functional properties of bean seeds, there are limited studies on effects of maturity stage on the physico-functional properties of bean seeds. Therefore, the objective of this present research is to investigate some physico-functional (bulk and true densities of the flour; hydration capacity, hydration coefficient, hydration index, swelling capacity, swelling coefficient, swelling index, moisture uptake, electrical conductivity and pH) properties of selected bean seeds (iron, honey and butter brown) as indicators of optimum seed maturity and elucidate the relationships between the seeds physico-functional properties and maturity stage.

MATERIALS AND METHODS

Study Setting

The experiment was conducted in a plot of 500 m^2 located in the research farm of Delta State Polytechnic, Ozoro, Nigeria. Ozoro is located on latitude 5.544 N, longitude 6.232 East and altitude 14 Meters (45.93 Feet) above sea level. Rainfall distribution pattern in this region is bimodal with peaks in July and September and a short dry spell around mid-August. Ozoro is located in the rain forest vegetation region of Nigeria with temperature of 28 ± 5 ºC, according to data from the Delta State polytechnic metrological station.

Seed sampling procedures

Three local high yield bean varieties, namely; *iron*, *honey*, and *butter- brown* bean seeds, collected from local farmers in Kano state were used in this study, The obtained seeds were planted in the research farm of Delta State Polytechnic, Ozoro. Once the bean plants had started flowering, daily observations were conducted on the bean plants and the flowers coded according to their day of anthesis. Bean pods were harvested at 14, 21, and 28 days of peak anthesis (DAPA), and sun dried, after which the pods were shelled and the bean seeds taken to the laboratory for physical and chemical analysis. The physico-functional properties of the bean seeds evaluated in the present study were: hydration capacity, hydration coefficient hydration index, swelling capacity, swelling coefficient, swelling index, water/moisture uptake, electrical conductivity and pH of the bean seeds; and bulk and true densities of the bean flour.

Bean flour preparation

The harvested bean seeds were cleaned from chaff, damaged and pests infested seeds and dried in an electric oven at 60^0C for 24 hours. Then the dried bean seeds were milled with an attrition mill and sieved through a stainless-steel mesh of 75 µm size (Appiah et al. 2011). Thereafter, the resultant flour samples were stored in sealed low-density polyethylene bags in a cool environment prior the physical and functional analysis.

Bulk density

A measuring cylinder was filled with the flour of each variety of flour, tapped three times and the volume occupied by the flour recorded. The bulk density (kg/m^3) was calculated by using the formula in equation 1 (Wang and Kinsella, 1976).

$$\text{Bulk density } \frac{\text{Weight of flour (kg)}}{\text{flour volume } (m^3)} \qquad (1)$$

True density

A measuring cylinder was filled with the flour of each variety of flour, tapped fifty times and the volume occupied by the flour recorded. The true density (kg/m^3) was calculated by using equation 2 (Narayana and Narasinga-Rao, 1984).

$$\text{True density} \quad \frac{\text{Weight of flour after tapping (kg)}}{\text{flour volume of tapping } (m^3)} \quad (2)$$

Hydration capacity, hydration coefficient and hydration index

Thirty bean seeds (uniform size and shape) were soaked in deionized water for 16 hours. After which the water was drained; and the seeds were blotted dried and cut into half along the fissure in order to remove the free water, and weight again. Hydration capacity was calculated as change in weight per number of seeds as given in the equation 3 (Wacu et al., 2015).

$$H_c \text{ (g/speed)} = \frac{(M_a\text{-}M_b)}{N} \quad (3)$$

Hydration coefficient was calculated from the equation 4.

$$H_c \text{ (coefficient)} \quad \frac{M_a}{M_b} \text{ x } 100 \quad (4)$$

The hydration index (Hi) was determined as the ratio of hydration capacity to the weight of the seeds, as shown in equation 5.

$$H_c \text{ (coefficient)} \quad \frac{H_C}{M_b} \text{ x } 100 \quad (4)$$

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

$$Hi = \frac{H_C}{M_b} \quad (5)$$

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

Swelling capacity, swelling coefficient and swelling index

The initial volume of thirty bean seeds (uniform size and shape) was measured in a graduated cylinder (Bishnoi and Khetarpaul, 1993) before soaking in deionized water for 16 hours.

Swelling capacity (S_c) was calculated as change in volume per number of as shown in equation 6 (Bishnoi and Khetarpaul, 1993).

$$S_{coefficient} = \frac{V_a}{V_b} \text{ x } 100 \quad (6)$$

The swelling index (S_i) was determined as the ratio of S_c to the volume of the seeds (equation 8).

$$S_i = \frac{S_c}{V_b} \quad (7)$$

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

Electrolytes and pH values

Thirty dried seeds of each bean variety were soaked in 100 mL of deionized water within 200 mL plastic vials, for 16 h at 25°C, after which the resulting steep water was collected. The leached electrolytes and pH values were determined with a digital conductivity meter (EMCEE Model 1152, India). Conductivity of the steep water was expressed as µS/cm/g seed (Wacu et al., 2015).

Moisture uptake

Thirty seeds of each of the bean variety were weighed, placed in perforated bags and cooked for 30 minutes. The bean seeds were dried using a blotting paper and re-weighed to determine the weight gain which reflects the moisture uptake during cooking (Wacu et al., 2015)..

Statistical analysis

The data obtained from this research were subjected to Analysis of variance using SPSS statistical software (version 20.0, SPSS Inc, Chicago, IL). The difference between mean values of parameters was investigated using Duncan's multiple range tests at 95% confidence level. All the experiments were conducted in five replications and the average value recorded.

RESULTS AND DISCUSSION

From the Analysis of Variance (ANOVA) table (Table 1), bean variety and maturity stage had significant ($P \leq 0.05$) effect on all the

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investigated parameters, apart from the hydration index of the bean seeds. In addition, the interaction of bean variety and maturity stage significantly ($P \leq 0.05$) influenced only the hydration capacity, swelling coefficient, swelling index, moisture update of the bean seeds.

Table 1a: ANOVA of effect of maturity stage and variety on the functional properties of bean seeds

Source	df	Bulk density	True density	Ec	pH	H_c	H_{coff}	H_i
V	2	1.2E-09*	7.3E-13*	8.5E-06*	0.1317^{ns}	1.4E-19*	3.3E-05*	0.9717^{ns}
M	2	8.71E-20*	4.09E-17*	5.38E-15*	5.45E-14*	3.02E-18*	1.56E-07*	0.43777^{ns}
V x M	4	0.09420^{ns}	0.12115^{ns}	0.36843^{ns}	0.94009^{ns}	1.62E-07*	0.72912^{ns}	0.41103^{ns}

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

Table 1b: ANOVA of effect of maturity stage and variety on the functional properties of bean seeds

Source	df	S_c	S_{coff}	S_i	Moisture uptake
V	2	1.3E-05*	3.1E-14*	8.4E-13*	3.5E-06*
M	2	5.46E-17*	8.32E-10*	4.38E-09*	1.66E-17*
V x M	4	0.05553^{ns}	0.00189*	9.14E-05*	0.0016*

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

The influenced of maturation and bean variety on the physico-functional properties of bean seeds are discussed below.

True and bulk densities of the bean flour

The flour bulk density and true density are presented in Figure 1. As illustrated in Figure 1, the flour bulk and true densities increased progressively as maturation of the bean seeds increase from 14 DAPA to 28 DAPA. In reference to Figure 1, *Iron* bean flour had the lowest true density among the three bean varieties studied in this research. This suggests that it will occupy greater space and will require more packaging material per unit weight, leading to high packaging cost (Padmashree et al. 1987; Oluwatooyin et al. 2002) when compared to *honey* and *butter-brown* bean flour. Higher bulk density is desirable for greater ease of dispersibility of flours (Padmasshree et al. 1987). In addition, bulk densities of flours are exploited in weanling food formulations, as low bulk density is an advantage in the formulation of complementary foods (Akpata and Akubor, 1999).

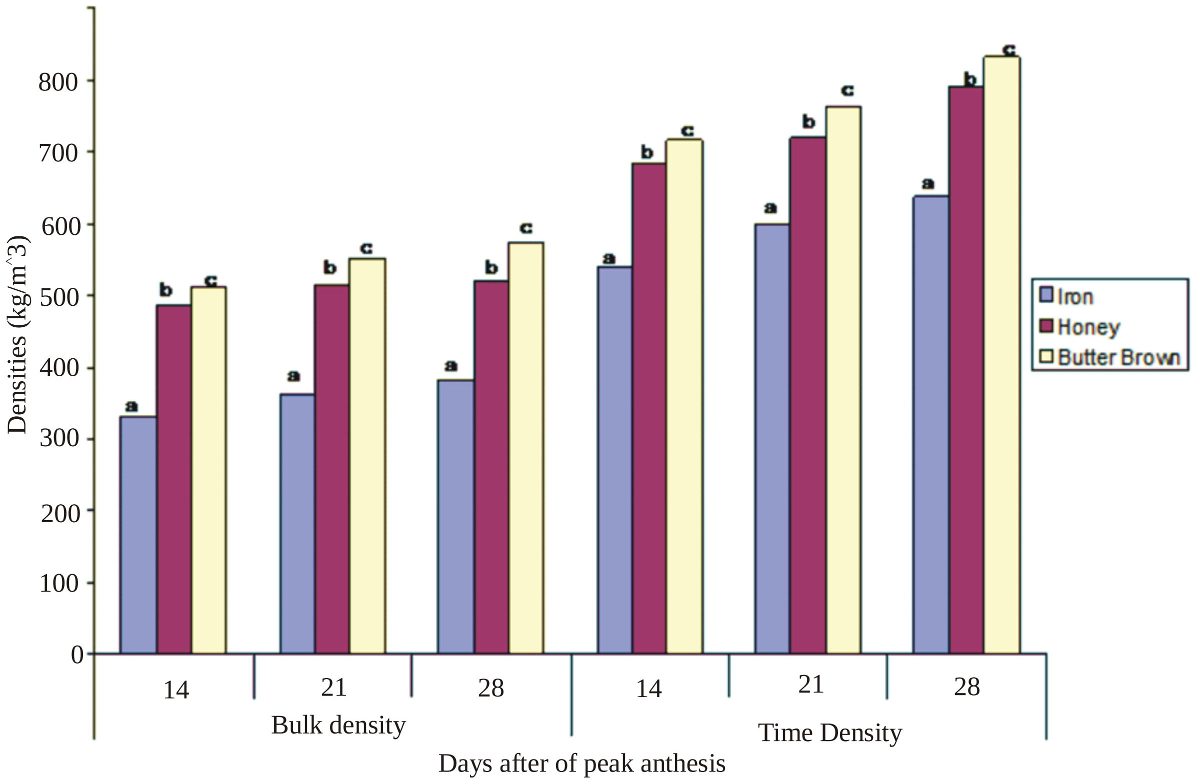

Figure 1: Influence maturity stage on bean flour bulk and true densities
Different letters on columns represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Functional properties

In reference to the results gotten from this research (Table 2), the functional properties of the bean seeds significantly increased with increase in maturation of the bean seeds, across the three bean varieties. The 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 the different bean seeds (Sefa-Dedah et al., 1979). 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). The results of this present study are consistent with previous studies (Daleen et al., 2006; Shimelis and Rakshit, 2005; Saha et al., 2009). Daleen et al. (2006) reported hydration coefficient between 1.73 and 1.81, for small white bean seeds; while (Saha et al., 2009) reported swelling capacity and swelling index of kidney bean cultivars in the range of 0.30–0.56 mL/seed and 0.91–1.39. The swelling capacity of seeds is a vital parameter of interest, the volume change of a processed product influences the acceptability of the product; making bean seeds with high swelling capacities more useful in the food processing industries.

Also hydration and swelling capacities of bean seeds are useful parameters to the food processing industry. Luse (1980) reported that bean seeds with short cooking time and high swelling capacity are more acceptable to consumers and processors. Akromah et al. (2015) reported that the swelling volume is desirable characteristic that influences acceptability of beans since high grain expansion during cooking is preferred. In this study, the low hydration and swelling coefficients obtained in the bean seeds at early stage of maturation (14 DAPA) could be due mostly due to the textural structure and chemical composition within the bean seeds making it less permeable to water thus preventing cotyledons from absorbing more water.

Table 2: Functional properties of the three bean varieties

Parameter	Variety	Maturity stage (DAPA)		
		14	21	28
Hydration capacity (g/seed)	*Iron*	^{a}±0.013	0.393^{b}±0.010	0.469^{c}±0.013
	Honey	0.108^{a}±0.005	0.198^{b}±0.005	0.253^{c}±0.013
	Butter Brown	0.101^{a}±0.005	0.185^{b}±0.004	0.244^{c}±0.011
Hydration coefficient (%)	*Iron*	1.856^{a}±0.060	1.983^{b}±0.030	2.043^{b}±0.048
	Honey	1.771^{a}±0.017	1.932^{b}±0.017	1.926^{b}±0.022
	Butter Brown	1.712^{a}±0.033	1.873^{b}±0.049	1.912^{b}±0.081
Hydration index	*Iron*	0.029^{a}±0.002	0.135^{a}±0.177	0.027^{a}±0.003
	Honey	0.026^{a}±0.001	0.031^{a}±0.001	0.109^{a}±0.148
	Butter Brown	0.024^{a}±0.001	0.029^{a}±0.002	0.109^{a}±0.148
Swelling capacity	*Iron*	0.200^{a}±0.017	0.400^{b}±0.033	0.533^{c}±0.033
(vol/seed)	*Honey*	0.210^{a}±0.024	0.417^{b}±0.019	0.550^{c}±0.042
	Butter Brown	0.233^{a}±0.017	0.433^{b}±0.054	0.567^{c}±0.020
Swelling coefficient (%)	*Iron*	1.400^{a}±0.012	1.667^{b}±0.032	1.740^{b}±0.038
	Honey	1.914^{a}±0.171	2.39^{b}±0.025	2.65^{b}±0.173
	Butter Brown	2.167^{a}±0.276	2.857^{b}±0.122	3.125^{b}±0.156
Swelling index	*Iron*	0.013^{a}±0.011	0.022^{b}±0.001	0.025^{c}±0.001
	Honey	0.031^{a}±0.005	0.046^{b}±0.002	0.053^{c}±0.005
	Butter Brown	0.038^{a}±0.009	0.062^{b}±0.004	0.071^{c}±0.005

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

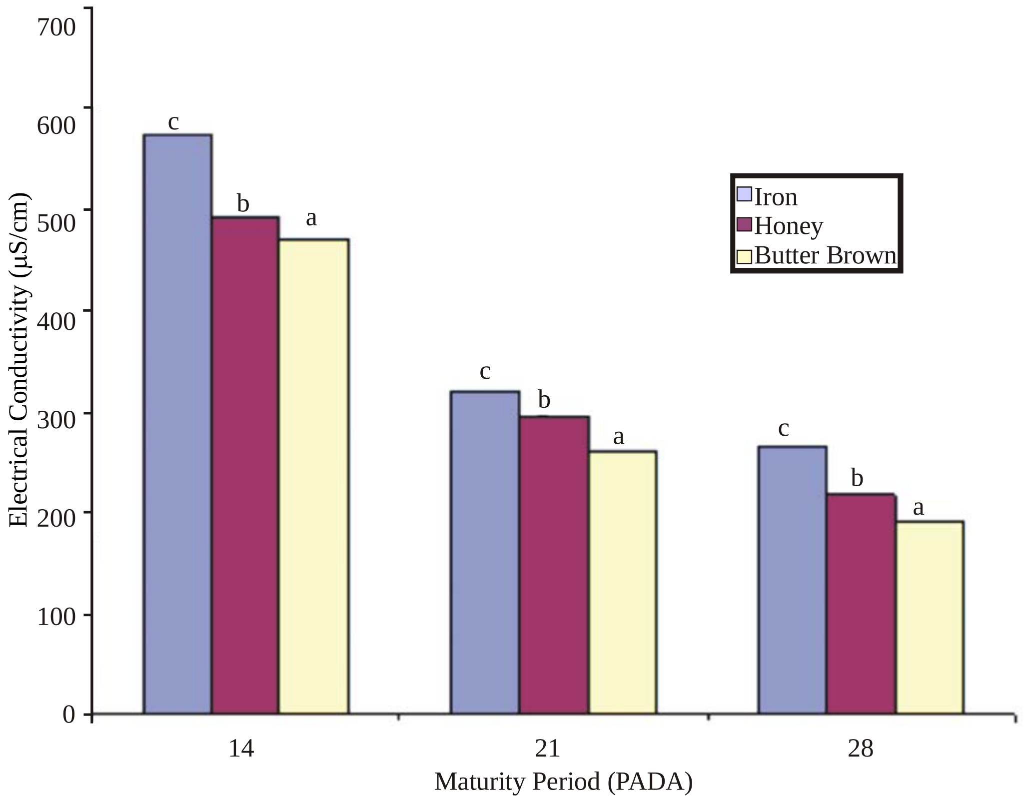

Figure 2a: Influence of maturity stage on the electrical conductivity of the bean seeds

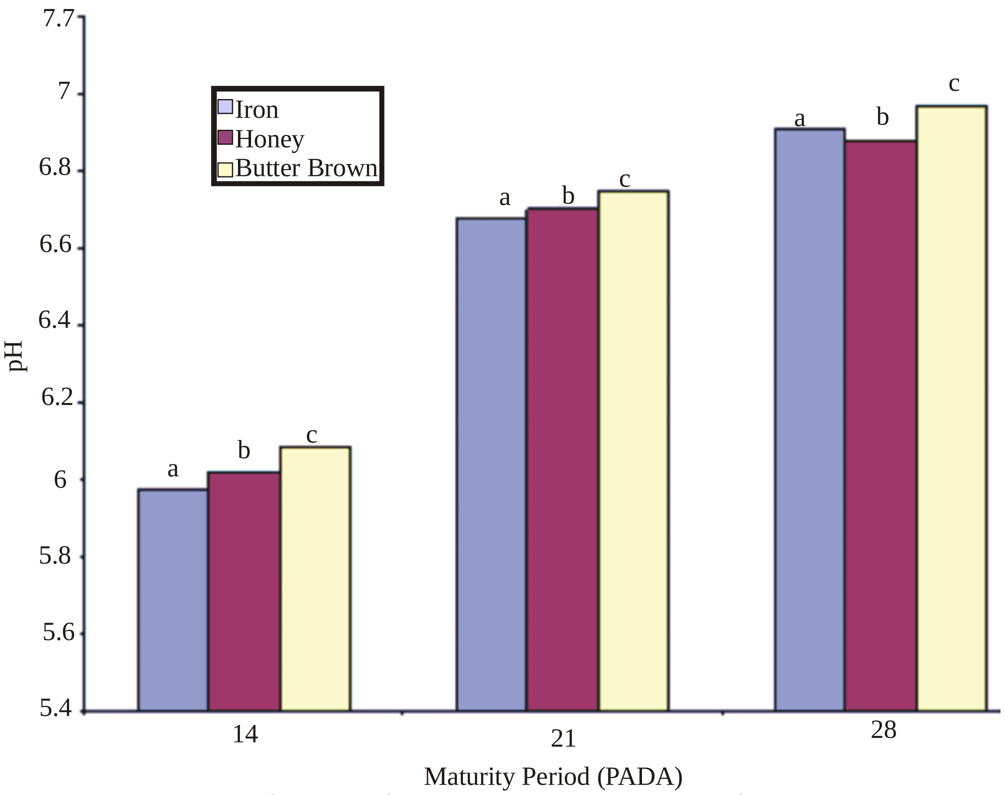

Figure 2b: Influence of maturity stage on the pH of the bean seeds

Different letters on columns represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

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Electrical conductivity is possible method for measuring viability and seedling vigour of crops. Seed vigour has a close relationship with the integrity of the cell membrane, and the electrical conductivity. Hence, an increase in the electrical conductivity leads to decrease in the seed germination potential. Pesis and Timothy (1983) reported that the germination of musk melon decreased from 94.4 to 41.6 % when the electrical conductivity increased from 128 to 287 µS/cm. Studies done on dry bean seeds of different varieties, showed significantly different electrical conductivity values (Hampton et al., 1992).

Moisture uptake

The rate of moisture uptake for the bean varieties during maturation are shown in Figure 3. Both bean varieties at 14 DAPA showed lower moisture uptake as compared to subsequent moisture uptake at 21 and 28 DAPA (Figure 3). The lower moisture uptake exhibited by the beans seeds at 14 DAPA when compared to the bean seeds at 21 DAPA and 28 DAPA, may be due to micro structural differences of the bean seeds as maturation progresses (Berrios et. al., 1999). In this present reported study, it was found that the moisture uptake was higher in *Iron* bean variety, when compared to *honey* and *butter brown* bean varieties, signifying that more the water absorbed by the *Iron* bean during cooking. Higher moisture uptake of bean seeds leads to shorter cooking time, and lesser energy (fuel). Cooking time is considered to be a function of permeability of seed coat, followed by the rate at which the hot water causes the gelatinization of starch (Williams and Nakkoul, 1985). The results of this study are expected to be useful in the food industries.

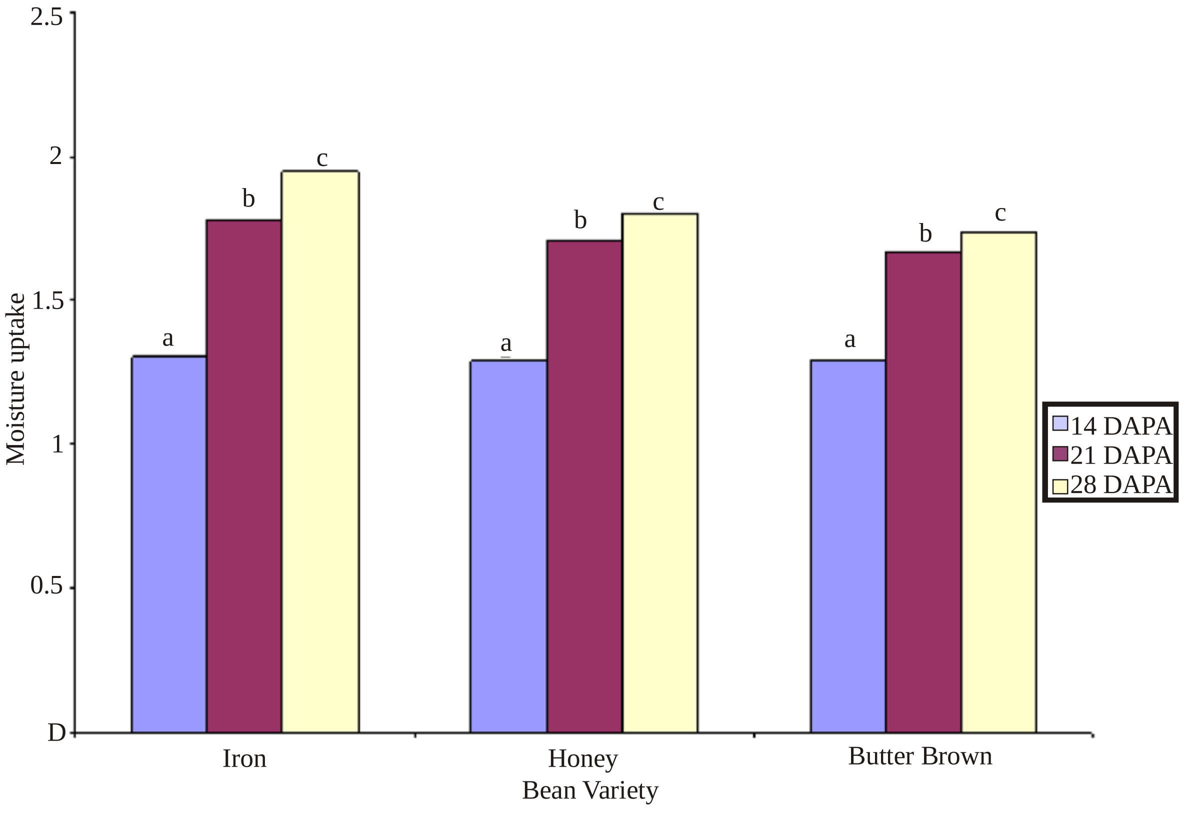

Figure 3: Influence maturity stage on the moisture uptake of the bean seeds
Different letters on columns represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

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CONCLUSION

This study was carried to provide information on the physico-functional properties of some Nigeria bean (*Phaseolus vulgaris* L.) varieties, as influenced by maturity period. The results of the study shown that maturity stage has significant ($P \leq 0.05$) effect on ten out of the eleven parameters investigated, depicting that the micro and macrostructure of the bean seeds varied significantly with maturation. The difference in flour true density among the varieties observed, suggests that the flours would occupied unequal space (in terms of packaging). Electrical conductively of the seeds shows that the seed vigour increases with an increased in maturation of the bean seeds. Moreover, some variations are needed during the design of processing and handling equipment. The results of this study are expected to be useful in the food industries.

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