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EFFECT OF VARIETY AND MOISTURE CONTENT ON AERODYNAMIC PROPERTIES OF FOUR NIGERIAN COWPEA (*Vigna unguiculata*) VARIETIES

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ABSTRACT

Knowledge of aerodynamic properties of a crop is important in developing handling, cleaning and processing equipment for the crop. Terminal velocity, drag coefficient and Reynolds number of four Nigerian cowpea varieties namely Ife 98-12, IT90K-277-2, Ife Brown and Drum were studied at moisture levels of 8.2, 12.2, 14.2 and 18.2% wet basis (w.b.), which are levels useful in the design of processing and handling equipment. The terminal velocities of the four varieties ranged from 13.35 to 14.47 m/s, the drag coefficient ranged from 0.446 to 0.454 and Reynolds number ranged from 4768 to 6447. The results showed that both variety moisture content and have significant effect ($P \leq 0.05$) on both terminal velocity and Reynolds number.

Keywords: Cowpea (*Vigna unguiculata*), aerodynamic properties, terminal velocity, drag coefficient, moisture content, varieties, Nigeria

INTRODUCTION

Airflow is used in handling and processing of agricultural products for conveying and separating the product from unwanted materials such as light gains, weed seeds and chaff. These processes known as pneumatic conveying and separation require the knowledge of aerodynamic properties of the product. These properties are terminal velocity and drag coefficient. Terminal velocity is the velocity of a body falling freely when the resistance drag force acting on it is equal to the weight of the body i.e. a point at which velocity is constant and acceleration is zero.

The terminal velocity of small particles like grains is frequently determined by using suspension or floating test and drop test. In suspension or floating test, the particle is suspended in an air stream and the air velocity at the point of suspension measured. This gives the terminal velocity of the particle. Drop test involves dropping the particle in front of a graduated wall or dropping tube and determining the time at different positions of fall. The terminal velocity is then calculated from the linear portion of the displacement-time graph of the motion (Carman, 1996). The drag coefficient of the particle can be calculated from its terminal velocity by using appropriate equation.

Cowpea, *Vigna unguiculata,* is a very important grain legume consumed in all parts of West Africa. Cowpea grains contain about 25% protein and 64% carbohydrate (Bressani, 1985; Singh, 2003), this makes it a cheap source of protein in the diet of both rural and urban population. Over 75% of world's cowpea production is from Africa and West Africa is the key producing zone. Nigeria is the largest producer and consumer of cowpea in West Africa and also in the world (FAOSTAT 2005; Coulibay and Lowerberg-DeBoer, 2003). Cowpea, due to its high protein content has the potential to be used in nutritional products for infants and children's food and to compensate for large proportion of carbohydrate often contained in African diets. However, a major constraint to such industrial use is the poor quality of cowpea available in the market (Taiwo, 1998; Lambot, 2003). They often contain impurities like foreign particles, stones, sand, chaff and defective grains due to traditional methods of handling and processing employed by many local farmers and processors. There is therefore the need for the development of handling and primary processing equipment for cowpea to improve the quality of cowpea available for industrial use as well as for human consumption. In order to design equipment for cleaning, handling, aeration, storing and processing of cowpea, there is a need to study its aerodynamic properties. Aerodynamic properties are also important in the selection and adjustment of appropriate machines for processing cowpea.

Different researchers have investigated the terminal velocities of different agricultural products. Carman (1996) investigated the terminal velocities of lentil seeds in the moisture range of 6.5 to 32.6% d.b. using drop tests. A seed of lentil was allowed to fall from the top of a dropping tube at various heights. The duration of fall was recorded and plotted as a function of distance of fall. The terminal velocity was then calculated as the slope of the linear portion of the distance-time curve. He concluded that the terminal velocity of lentil seeds increased linearly from 10.95 to 12.06 m/s as the moisture content increased from 6.5 to 32.6% d.b. Khostaghaza and Mehdizadeh (2006) investigated the aerodynamic properties of wheat kernel and straw materials. They measured the terminal velocity of Canadian variety of wheat kernel and straw materials by suspension tests in a vertical air stream. They concluded that mass and moisture content have significant effect on moisture content and that drag coefficient of wheat straw depended on node position. Gloria and O'Callaghan (1990) measured the aerodynamic properties of a wide range of grains and straws experimentally by finding the suspension velocities of the particles in an air stream. They reported that the range of grains found in normal sample at harvest corresponds to a range of terminal velocities rather than a single characteristics velocity. Irtwange and Igbeka (2003) determined the theoretical and experimental velocities of two Africa yam bean accessions (TSs 137 and TSs 138) at moisture content levels of 4, 8, 12, and 16% wet basis by using an aspirating column. They concluded that there was no statistically significant difference in the terminal velocities between accessions ($p \leq 0.05$) but there was a highly significant effect of moisture content and the method used to calculate terminal velocities. Rajabipour *et al*. (2006) investigated the terminal velocity of three wheat varieties at moisture contents of 8, 12, 14, 18 and 22% w.b. They concluded that by increasing moisture content, the terminal velocity of the three wheat varieties increased. Razavi *et al*. (2007) evaluated the terminal velocity of five varieties of pistachio nuts and their kernels as a function of moisture content. They concluded that the terminal velocity of pistachio and their kernels showed a linear increase with increasing moisture content. Olayanju *et al*. (2009) worked on some aerodynamic properties of two varieties of beniseed (Yandev 55 and E8) at moisture content range of 5.3 to 28.3% wet. Basis. Their results showed that the effect of moisture content was highly significant on the terminal velocity.

Therefore, the objective of this work was to determine the aerodynamic properties namely terminal velocity, drag coefficient and Reynolds number of four Nigerian cowpea varieties as affected by moisture content.

Theoretical Consideration

When a particle falls through an air stream, the force of gravity will cause it to accelerate until the drag force, F, exerted by the air balances the gravitational force, Mg. It will then fall at a constant velocity called terminal velocity (Mohsenin, 1986). The drag force, F, is given by (Gorial and O'Challaghan, 1990):

$$F = \frac{1}{2} C \rho A v_t^2 \tag{1}$$

An expression for the terminal velocity of the particle can be obtained by equating the drag force to the gravitational force, thus

$$F = Mg \tag{2}$$

$$\frac{1}{2} C \rho A v_t^2 = Mg \tag{3}$$

$$v_t^2 = \frac{2Mg}{C\rho A} \tag{4}$$

Therefore

$$v_{tt} = \sqrt{\frac{2Mg}{C\rho A}} \tag{5}$$

and the drag coefficient can be derived as

$$C = \frac{2Mg}{\rho v_t^2 A} \tag{6}$$

where C = drag coefficient,

M = mass of particles (kg),

g = gravitational acceleration (m/s^2),

ρ =air density in Kg/m^3,

v_t = terminal velocity (m/s),

A = projected area (m^2).

MATERIALS AND METHODS

Four varieties of cowpea namely Ife 98-12, IT90K-277-2, Ife Brown and Drum were obtained from the Institute of Agricultural Research and Training (IAR &D), Ibadan. The initial moisture content of the grains was determined by oven drying method using ASAE 1998 standard. Calculated amount of distilled water was added to the grains to bring them to the desired moisture contents of 8.2, 12.2, 14.2, and 18.2% w.b. using equation (7) as described by Akinoso *et al.* (2006).

$$Q = {A(b-a)}\big/{(100-b)} \tag{7}$$

where

A=initial mass of the sample, g

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

b= final (desired) moisture content of

sample % w.b.

Q= mass of water added to be added, g

Each sample of cowpea varieties was sealed in a separate polythene bag. The samples were kept at 5^{0}C in a refrigerator for a week to enable the water to distribute uniformly.

Aerodynamic properties

Terminal velocities were determined experimentally using a vertical wind tunnel (Fig. 1). The wind tunnel was developed at the Federal Institute of Industrial Research, Oshodi, Lagos. A grain was placed on a mesh screen at the bottom of the vertical wind tunnel. Input air was adjusted until the grain began to float. The velocity at which the grain became suspended was measured. Ten replicates were taken for each moisture content level (Joshi *et al*., 1993; Aydin and Ozcan, 2002; Polat *et al*., 2006). This was repeated for the four varieties. The drag coefficient was calculated from the measured terminal velocity using Equation (6). Reynolds

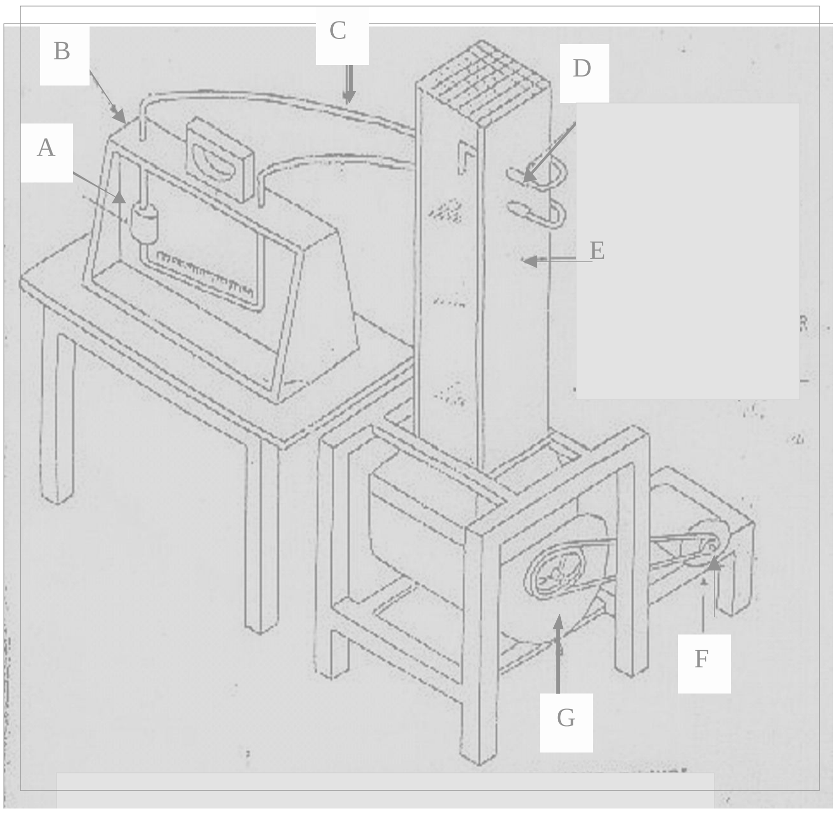

Figure 1: Isometric View of the Terminal Velocity Test Equipment

A – Manometer; B – Manometer Box; C – Rubber Hose; D – Pitot Tube; E – Wind Duct; F – Electric Motor; G – Blower

$$R_e = \frac{V_t d_p \rho}{\mu} \qquad (13)$$

Where

R_e =Reynolds number, dimensionless

d_p =geometric mean diameter, m

ρ =density of air, kgm^{-3}

μ =kinematic viscosity of air $kgsm^{-1}$

Individual grain mass

The mass of ten randomly selected grains from each variety was determined by an electronic beam balance reading to 0.001g.

RESULTS AND DISCUSSION

The summary of the aerodynamic properties of the four varieties are presented in Table 1. Tables 2-3 show the summary of analysis of variance (ANOVA) for terminal velocities and Reynolds number respectively.

The terminal velocities of the four varieties increased from 13.80 to 14.30, 13.35 to 13.83, 13.72 to 14.04 and 14.15 to14.47 m/s respectively within the moisture content range. They all appear to increase linearly with moisture content as shown in Fig. 2.

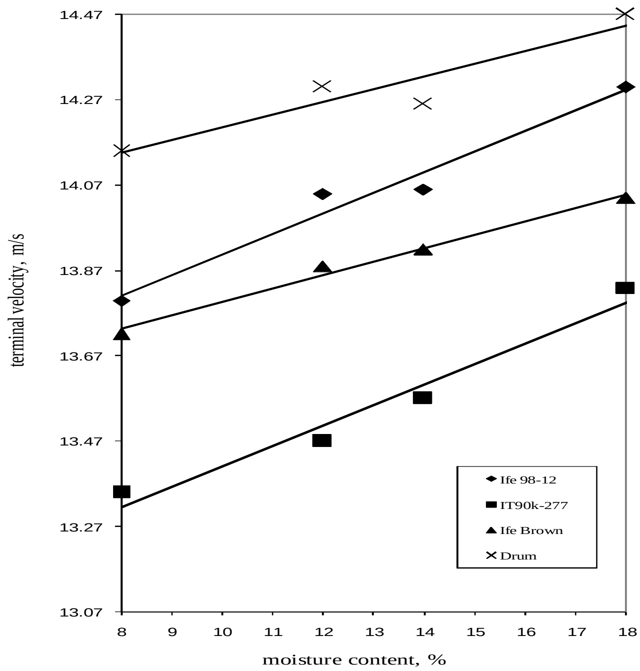

Fig: 2 Effect of moisture content on terminal velocities of cowpea varieties

Table 1: Aerodynamic properties of four cowpea varieties

Variety	Moisture content, %	Average mass, g	Terminal velocity, m/s	Drag coefficient	Reynolds number
Ife 98-12	8.2	0.193	13.80	0.447	4879
	12.2	0.195	14.05	0.452	5641
	14.2	0.198	14.06	0.450	5891
	18.2	0.210	14.30	0.453	6011
IT90K-277-2	8.2	0.163	13.35	0.449	4786
	12.2	0.168	13.47	0.448	5083
	14.2	0.177	13.57	0.452	4998
	18.2	0.186	13.83	0.450	5394
Ife Brown	8.2	0.146	13.72	0.446	4768
	12.2	0.156	13.88	0.448	5060
	14.2	0.158	13.92	0.450	5092
	18.2	0.169	14.04	0.454	5355
Drum	8.2	0.223	14.15	0.449	6192
	12.2	0.235	14.30	0.450	6286
	14.2	0.239	14.26	0.450	6130
	18.2	0.247	14.47	0.449	6447

Table 2: Summary of ANOVA for terminal velocities of four cowpea varieties at 5% level of significance.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Variety	3	11.64	3.88	14.37*
Moisture content	3	3.33	1.11	4.11*
Interaction	9	0.25	0.03	0.11NS
Error	144	38.39	0.27	

Table 3: Summary of ANOVA for Reynolds number for the four cowpea varieties at 5% level of significance

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Variety	3	3.88 x 107	1.29 x 107	672.27*
Moisture content	3	8.42 x 106	2.81 x 106	146.00*
Interaction	9	3.63 x 106	4.04 x 105	21.01*
Error	144	2.77 x 106	1.92 x 104	

significant difference NS = non significant difference

This is similar to observations made by other researchers for some other agricultural materials like wheat (Khoshtaghaza and Mehdizadeh, 2006,) African yam bean (Irtwange and Igbeka, 2003,) and beniseed (Tunde-Akintunde and Akintunde, 2007). The relationship between terminal velocity and moisture content can be represented by the following equations:

Ife 98-12	$V_t = 13.43 + 0.048M_C$	r = 0.98
IT90K-277-2	$V_t = 12.93 + 0.048\ M_C$	r = 0.98
Ife Brown	$V_t = 13.48 + 0.032\ M_C$	r = 0.99
Drum	$V_t = 13.91 + 0.030\ M_C$	r = 0.94

Where, V_t = terminal velocity, M_C = moisture content r= coefficient of correlation.

Comparing the terminal velocities of the four varieties, IT90K-277-2 has the lowest terminal velocities which range from 13.35 – 13.83 m/s while Drum has the highest terminal velocities which range from 14.15 – 14.47m/s. This may be due to the fact that IT90K-277-2 has the lowest individual grain mass which ranged from 0.163 – 0.186g while Drum has the highest individual grain mass which ranged from 0.223 – 0.247g.

The drag coefficients of the four varieties ranged from 0.446 to 0.454 within the moisture content range. This shows that they are closer to that of a sphere. There is no definite change in drag coefficient as the moisture content increased from 8.2 to 18.2% w.b. for the four varieties as shown in Table 1. Also the Reynolds number also increased from 4879 to 6011, 4786 to 5394, 4768 to5355 and 6192 to 6447 respectively for the four varieties as the moisture content increased from 8.2 to 18.2% w.b. The relationship between the Reynolds number and the moisture content can be represented by the following regression equations:

Ife 98-12	Re = 4128 + 113.89 M_C	r=0.92
IT90K-277-2	Re = 4327 + 56.83 M_C	r=0.94
Ife Brown	Re = 4327 + 57.06 M_C	r=0.99
Drum	Re = 5984 + 0.65 M_C	r=0.65

There is highly correlated relationship between Reynolds number and terminal velocity as shown in Figs 2 to5.

Analyses of variance show that moisture content and variety have significant effects on terminal velocities ($P \leq 0.05$). The interaction between variety and moisture content however was not significant on terminal velocity at 5% level of significance. The effect of variety and moisture content as well as their interaction is also significant on Reynolds number ($P \leq 0.05$) as shown in Tables 2 and 3.

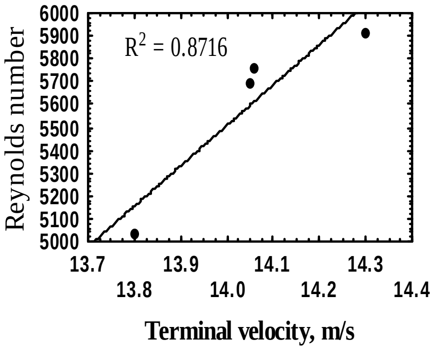

Fig. 3. Terminal velocity Vs Reynolds number for Ife 98-12

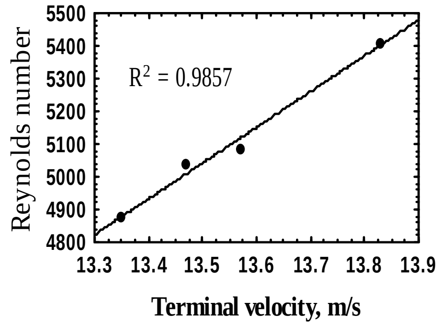

Fig.4. Terminal velocity Vs Reynolds number for IT90K-277-2

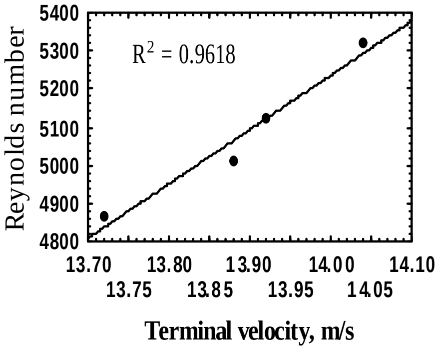

Fig.5. Terminal velocity Vs Reynolds number for Ife brown

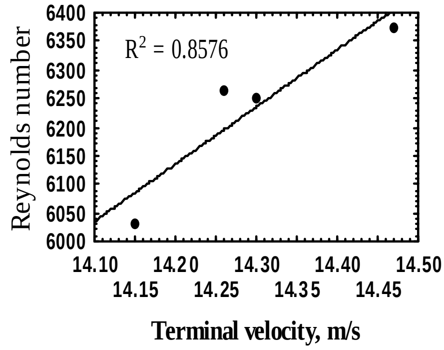

Fig.6. Terminal velocity Vs Reynolds number for Drum

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. The terminal velocities and Reynolds number of the four varieties of cowpea increased linearly as the moisture content increased from 8.2 to 18.2% w.b.

2. IT90K-277-2 had the lowest terminal velocity of the four varieties and it ranged from 13.35 to 13.83 m/s and Drum had the highest terminal velocity and it ranged from 14.15 to 14.47 m/s within the moisture content levels of 8.2 to 18.2% w.b.

3. Terminal velocities differ significantly ($P \leq 0.05$) among the four varieties of cowpea as such different air velocities will be needed for cleaning and conveying the four varieties of cowpea.

4. The drag coefficients of the four varieties of cowpea appeared to be constant within the moisture content levels considered.

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