Terminal Velocity Of Popcorn (Zea Mays Everta) As Affected By Moisture Content

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***Abstract*—Due to difficulties in operation, processing, production, utilization and drying of agricultural produce, there is to study approximate range of velocities required to lift and separate seeds from contaminants and also study the forces and resulting motion of object through the air. The objective of this study is to determine the effect of moisture on the terminal velocity and some physical properties of popcorn at the different moisture content. Materials used for this study include wind tunnel, measuring cylinder, electric oven, envelopes, polythene bags, distilled water and standard methods for determination of moisture content and terminal velocity was adopted. The terminal velocity obtained increased from 6.88 to 7.82m/s as the moisture content increases from 20 to 60% wet basis respectively however, the analysis of variance showed that there is no significant difference within the terminal velocities at various moisture content. The increase in terminal velocity as a result of increase in moisture content explain the fact that there is an equivalent increase in moisture content across the air path which otherwise causes a tremendous increase in the friction on the edges of popcorn seed in motion and this tend to increase the seed terminal velocity of the popcorn seeds. These findings however will aid the cleaning, sorting and grading techniques of popcorn seeds and also provide information for design of equipment and facilities for handling, processing and storing of agricultural produce**

Keywords— popcorn, moisture content, terminal velocity

I. INTRODUCTION

Popcorn (*Zea mays everta*) is one of the world's favorite snack foods, In the US, Americans consume as much as 18 billion quarts of popcorn each year, which equates to 56 quarts per person. Some nutritionists call it a perfect snack food because it is a whole grain, a good source of fiber and low in fat. Pressure builds inside the kernel and a small explosion (or "pop") is the end result. Popcorn was not only commonly made at home, but it was also sold at general stores, concession stands, carnivals, and circuses. Although several method of popping corn had been developed, the first commercial popcorn machine was invented in Chicago. The popularity of street popcorn vendors grew at approximately the same time that movies burst onto the scene. The roaming popcorn vendors could often be found near the crowds, especially outside of theaters. This coincidence gave birth to the tradition of popcorn being a favorite movie snack [1].

There are various techniques for popping corn. Along with prepackaged popcorn, which is generally intended to be prepared in a microwave oven, microwave for cooking is a type of oven that cooks or heats food very quickly; there are small home appliances for popping corn. These methods require the use of minimally processed popping corn [2]. Depending on how it is prepared and cooked, some consider popcorn to be a health food, while others caution against it for a variety of reasons. Popcorn can also have non-food application, ranging from holiday decorations to packaging materials. Demand for popcorn has remained steady throughout years with a peak in the 1990s. Sales increased with the introduction of microwave popcorn in the 1980s and microwave popcorn accounted for 72 percent of sales in the 1999s. Iowa was the number one producing popcorn state in 1940s. Today the industry produces approximately 9 million pounds of corn in 25 states. Popcorn is grown by less than one percent of U.S. farmers on one percent of the harvested acres. The majority of popcorn is grown by farmers with over 100 acres, so most popcorn is mechanically harvested. However, the numbers of farms and acres dropped by over one-third from 2002 to 2007, but the production increased by 9 percent over the same time period. Iowa is very similar to the rest of the country with respect to popcorn production. Iowa had a decrease, less than one percent of the farms and harvested crop land is devoted to popcorn [3].

Popcorn comes in many different varieties which include sweet corn, field corn, regular popcorn, rainbow blend popcorn, medium white hulless popcorn, baby white popcorn and midnight blue hulless popcorn. Popcorn is available in many flavors such as caramel, plain salted, tomato cheese, dill pickle, salt and vinegar cheese, white cheddar, holiday corn and white popcorn. Popcorn flavour is enhanced to individual tastes with the addition salt and butter. There is no end to the uses of popcorn. During the great depression popcorn was one of the few snack foods that could be afforded by all, it was fairly inexpensive at 5-10 cents a bag and became popular. Nutritionally, it is one of the best all-around snack foods, providing 67% as much protein, 110% as much iron and as much calcium as an equal amount of beef. The nutritional content of popcorn is presented in Table 1.

Table 1: Nutritional value of popcorn per 100g

Values	Per 100G Serving (1/10 OF THE PACK)
Energy	1,598 KJ (382 Kcal)
Carbohydrates	78g
Dietary fiber	15g
Fat	4g
Protein	12g
Thiamine (vitamin B1)	0.2 mg (17%)
Riboflavin (vitamin B2)	0.3 mg (25%)
Iron	2.7 mg (21%)

Due to difficulties in operation, processing, production, utilization and drying of agricultural produce, there is need for research that will enable food product engineers to predict an approximate range of velocities required to lift and separate seeds from contaminants, this will provide essential data for equipment manufacture in the construction of equipment for processes like grading, sorting and cleaning of agricultural seeds, this process is termed aerodynamics which is the study of forces and the resulting motion of object through the air. The air velocity and the energy required for movement of grains in the air stream are important design criteria for modern cleaners. The design should be based on knowledge of the suspension velocity of the material in this capacity; the best material (maize, cowpea, soybean) is placed in a wind tunnel, that is, vertical air stream at certain air velocities to determine the terminal velocity of each material in raising it out of some specific mass loaded in the wind tunnel. The terminal velocity at which the particles are suspended stationary in vertical air stream can be determined by using different methods. These methods are free- fall, vertical air tunnel and elutriator method [4], [5].. Thus, the major objective of this study is to determine the terminal velocity as affected by moisture content.

II. MATERIALS AND METHODS

A. *Materials*

The major materials used for this research include: wind tunnel, regular popcorn, measuring cylinder, micrometer screw gauge, electric oven, refrigerator, envelopes, polythene bags, distilled water

Wind tunnel: used to study the effect of air moving past solid object. A wind tunnel; consists of a closed tubular passage with the object under test mounted in the middle. A powerful fan system moves air past the object, the fan must have straightening vanes to smooth the air flow. The test object is instrumented with a sensitive balance to measure the forces generated by air flow, or the airflow may have smoke or other substances injected to make the flow lines around the object visible, full-scale aircraft or vehicle are sometimes tested in large wind tunnels, but these facilities are expensive to operate and some of their functions have been taken over by computer modeling. In addition to vehicles, wind tunnels are used to study the airflow around large structure such as bridge or office building (Plate 1)

Plate 1: Wind Tunnel

Hand held digital anemometer: The components of the machines are; duct, screen, vane, fan [centrifugal] electric motor and control switch. The anemometer was designed in Thies Clima, Germany and has a least count of 0.1m sec^{-1} (Plate 2)

Plate 2: Handheld Anemometer

B. Sample Procurement and Preparation

Different varieties of 1kg of popcorn seeds was obtained from Bodija International Market (BIM), Ibadan, Oyo State, Nigeria. The seeds were manually cleaned to remove all foreign materials and broken seeds. Moisture is a natural constituent of all agricultural products and for the purposes of processing, storage and utilization, it is often necessary to reduce the level of moisture in an agricultural produce. Electric oven drying method was used to determine the moisture content of the corn in accordance with ASAE standard methods. In determining the moisture content, samples were placed in the oven at 130 ± 2°C i.e. 105°C for 24 hours. This was replicated 5 times to ensure good accuracy and the mean and standard deviation was calculated and recorded. Equation (1) was used for computation of moisture content.

$$MC_{\text{wet bases}} = \frac{\text{Wwp}}{\text{Wwp}} = \frac{\text{Ww}}{\text{Wwp}} \quad (1)$$

Where: Wwp is the weight of wet product (g), Wdp is the weight of dry product (g) and Ww is the initial weight of the grain

Moreover, to achieve desired moisture contents levels of 20, 30, 40, 50 and 60% wb, the popcorn was conditioned by adding desired quality of distilled water, kept in sealed polythene bag and refrigerated at 5°C for 24hrs. The popcorn samples were allowed to equilibrate at room temperature for 2hrs to determine the actual moisture content present in the popcorn prior to experiments for determination of its properties. Equations (2) and (3) were used to determine the quantity of water added to the corn [6]:

$$B = \frac{A\,(100-a)}{(100-b)} \quad (2)$$

$$Q = \frac{A\,(b-a)}{(100-b)} \quad (3)$$

Where: A is the initial mass of samples (g), B is the final mass of samples after drying (g), a is the initial moisture content of samples (%wb), b is the desired (or final) moisture content of samples (%wb) and Q is the mass of water to be added (g)

Determination of Terminal velocity

Terminal velocity is the velocity of a rising air current that will suspend a given particle. It is also the velocity at which the net gravitational acceleration force (F_G) is equal to resisting upward drag force (F_D) when an object is in free fall [7]. The terminal velocity of grain at different moisture content were measured using a cylindrical air column in which the material was suspended in the air stream [8]. The air column was 28mm in diameter. Relative operating of a regulating value provided at blower output end was used to control the airflow rate. In the beginning, the blower output was set at minimum. For each experiment, a sample was dropped into the air stream from the top of the air column. Then airflow rate was gradually increased till the grain mass gets suspended in the air stream. The determination of terminal velocity of popcorn sample was done on wind tunnel. The air velocity which kept the grain suspension was recorded by a digital Anemometer [9].

Terminal velocity equation was obtained as;

$$V_t = \frac{2mg}{\rho C_d A} \quad (4)$$

Where: m is the mass of the object [g], g is the gravitational acceleration [m/s], C_d is the drag co-efficient, ρ is the density [kg/m^3], A is the projected area [m^2] and V_t is the terminal velocity [m/s]

III. RESULTS AND DISCUSSIONS

The effect of moisture content on the terminal velocity of popcorn was studied. The summary of the results obtained is presented in Table 2 below:

Table 2: Effect of moisture content on Terminal Velocity (m/s)

No of observation	Moisture content (%wb)				
	20	**30**	**40**	**50**	**60**
1	6.9	7.0	7.3	7.4	7.9
2	6.8	7.1	7.2	7.5	7.8
3	7.0	7.0	7.3	7.4	7.8
4	6.9	6.9	7.2	7.5	7.9
5	6.8	7.0	7.1	7.4	7.7
Mean	**6.88**	**7.00**	**7.22**	**7.44**	**7.82**
Standard deviation	5.6×10^{-4}	4.0×10^{-4}	5.7×10^{-4}	2.4×10^{-4}	5.6×10^{-4}

The terminal velocity increased from 6.88 to 7.82m/s as the moisture content ranged from 20 to 60% respectively (Figure 1). The terminal velocity was significantly different at all moisture levels. The results are in tandem with melon seeds reported by [10], [11].

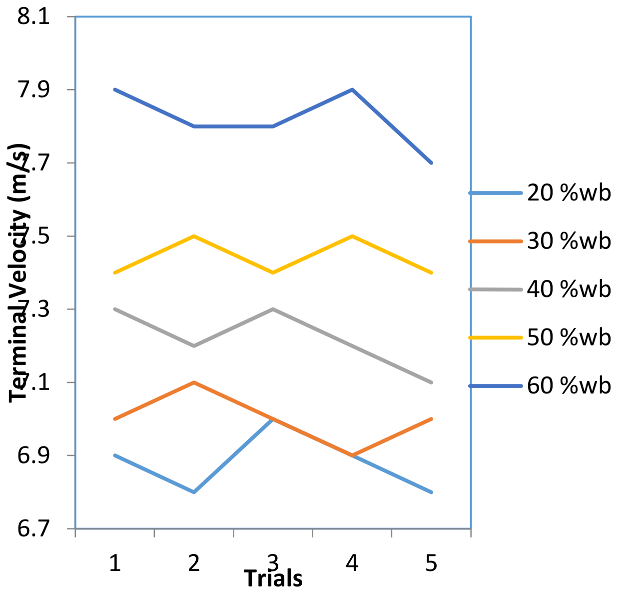

Figure 1: Effect of moisture content on terminal velocity of popcorn

It was also observed from Table 3 that there is no significance difference in the terminal velocities of the popcorn at various moisture contents. Though, there is increase in moisture content across the air path and due to friction on the edges of the popcorn seed in motion results to increase in terminal velocity.

TABLE 3: ANALYSIS OF VARIANCE

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	207.66	4	51.9	0.24	0.91	2.76
Within Groups	5258.25	25	210			
Total	5465.91	29				

IV. CONCLUSION

The effect of moisture content on terminal velocities of popcorn was evaluated. Moisture content used for the evaluation ranged from 20 to 60% wb., respective terminal velocity obtained increased with an increase in moisture content from 6.88 to 7.82m/s. This explains the fact that an increase in moisture content across the air path causes a tremendous increase in the friction on the edges of popcorn seed in motion and this tend to increase the seed terminal velocity. These findings however will aid the cleaning, sorting and grading techniques of popcorn seeds and also provide information for design of equipment and facilities for handling, processing and storing of agricultural produce.

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