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Compression Loading Behaviour of some Quality Protein Maize (QPM) Varieties

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***Abstract*—**The compressive strength of three varieties (TZE COMP 5-W, ART/98/SW1, and Suwan-1-SR-Y) of quality protein maize (QPM) commonly grown in Nigeria was study using a Universal Testing Machine (Model 3369). Three clean and healthy maize grain samples with same approximate dimensions were carefully selected and tested. The grain was loaded in two axes (lengthwise and breadthwise). Each seed was positioned in between the compression plates of the UTM. The gauge length was reduced to a minimum to prevent buckling during compression loading. The average of the three best values of the compressive strength and other properties were recorded as the final values for the respective properties. The compressive load at maximum compressive stress for the three varieties TZE COMP 5-W, ART/98/SW1-Y and SUWAN 1-SR-Y were 169.75, 209.74 and 96 N respectively while the compressive extension at maximum compressive stress for the three varieties TZE COMP 5-W, ART/98/SW1-Y and SUWAN 1-SR-Y were 1.52, 1.57 and 1.16 mm respectively lengthwise. The compressive load at break were 145.20, 101.43 and 48.13 N (lengthwise), 69.00, 30.44 and 85.67 N (breadthwise) for TZE COMP 5-W, ART 98/SWI-Y and SUWAN 1-SR-Y respectively. However, the study revealed that the TZE COMP 5-W required more force to separate the particles followed by ART/98/SW1-Y variety while SUWAN 1-SR-Y has the least.

Keywords—*QPM, Compression, lengthwise, breadthwise and Varieties*

I. INTRODUCTION

Maize accounts for 15% of the world's proteins and 19% of the calories derived from food crops [1]. The most important cereals grown in Nigeria are sorghum, millet, rice, maize and wheat [2]. Out of these cereals, maize remains the most popularly grown and consumed in all the ecological zones of the country. Western Nigeria generally produced about 50% of Nigeria green maize, the remaining 50% being split between the North, the east and the south [3]. There are several varieties of maize which are used as food for human consumption. Sometimes they are classified as various subspecies related to the amount of starch each has. These include flour (*amylacea*), Popcorn (*everta*), Dent maize (*indentata*), Flint maize (*indurata*) and Sweet corn (*rugosa*). Quality Protein Maize (dent/flint) contains nearly twice as much usable protein as other maize grown in the tropics. The utilization potential is high especially for breakfast menu, livestock industries and for lactating/nursing mothers, pregnant women and weaning babies will also find it beneficial. Other additional attributes include high *Ogi* (maize starch) yield, better storability and higher crude fibre [4]. Although Quality Protein Maize (dent/flint) has been introduced to farmers, but there is need to generate data for engineers and food scientist who are involve in designing processing machine and processing methods for maize in order to ensure food security and enhance development of mini industries. Agricultural produce is subjected to various physical treatments involving mechanical, thermal, electrical, optical and sonic techniques and devices from the field to the consumer; therefore, it is essential to understand the physical laws governing the response of the crop so that the machine, processes and handling operation can be designed for maximum efficiency and highest quality of the end product [5]. Therefore, these physical properties constitute an essential engineering data in the design of machine, structures, processes and control, in analyzing the performance and the efficiency of a machine. Data concerning the physical and mechanical properties of agricultural food materials are of importance to plant breeders, engineers, machine manufactures, food scientists, processors and consumers. Those properties are useful in postharvest unit operations for the design of cleaning, grading, sorting, transportation, handling, aeration, sizing, storing, size reduction, packaging and other processing equipment [6]. The main component of corn kernels is starch granules; these have a complex hierarchical structure consisting of polysaccharide macromolecules that are partially arranged in ordered conformations as single and double helices and entangled to form supra- and sub-molecular structures [7]. A knowledge of the compression behaviour of maize is important in understanding the mechanical properties of the maize. However, the aim of this study was to provide information on the strength properties of some high quality protein maize seeds commonly grown in Nigeria.

II. RELATED WORK

Some physical and mechanical properties of corn seeds were determined by [8] in which surface area and volume increased as the moisture content increased. The rupture energy of the grains increased in magnitude with an increase in moisture content, while rupture force was decreasing. [9] conducted a study to evaluate the physical properties that affect equipment design, processing, storage and transportation of high quality protein maize (SWAM 1) seeds. [10] investigated the interrelations between moisture content and mechanical properties of dry and wet native starches of wheat, maize, and potato. Uniaxial compression test was conducted to determine the reaction of powder in a cylindrical probe to vertical load. Mechanical behaviour of the material was found to be changing with increasing moisture content. [11] stated that the behaviour of the corn kernel during compressive loading is one of its textual properties and that the processing of corn for food and feed requires various types of mechanical treatment such as milling, extruding and flake preparation depend on external forces. [12] confined uniaxial compression tests on the granular wheat, results indicated that the parameter ranged from 0.034 to 0.197, with a mean value of 0.08 for the test wheat. Because the material is rapidly compacted in the initial cycle, the compaction curve is steeper and nearly 80% of the total deformation occurred at the initial loading stage. Values of the modulus of elasticity ranged from 25.4 to 44.6 MPa. The modulus of elasticity of wheat was variable according to the different maximum stress applied. Some researchers had investigated the properties of some grain considering the internal frictional angle and bulk density of the grain [13], [14], [15] and [16], also, the frictional angle between concrete/steel, these are also required for the design of silos [17],[18]. Other researchers had worked on compressive force properties of some crops [19],[20] and [21].

III. METHODOLOGY

Material selection

Three varieties of maize- TZE COMP 5-W, ART/98/SW1, and Suwan-1-SR-Y obtained from the Institute of Agricultural Research and Training, Moor Plantation, Ibadan were used for the experimentation. These varieties are quality protein maize (QPM), they contain nearly twice as much usable protein as other maize grown in the tropics.

Preparation of materials

The moisture content of the maize sample was first determined. About 450 g maize seed was weighed and put in an oven at a set temperature of 100^oC to dry to a constant weight for 24 hours overnight [22]. The mass of sample was determined after oven dry using electric weighing balance having a sensitivity of 0.01 g. The difference in weight was assumed to be due to the removal of moisture. Three replications were carried out and the average value was reported.

Determination of strength properties

The compressive strength of the kernel was determined using a Universal Testing Machine (UTM, Model 3369 with Bluehill Software, Instron, USA) equipped with 50 KN load cell with a cross-head speed of 2 mm/min according to standard ASTM D-3410 (1995). The anvil height was adjusted to 9.48 mm. The test was carried out by loading the maize grain between the two plates and then applying a force to the grain by moving the crossheads

Figure 1. Universal Testing Machine

together. Three clean and healthy maize grain samples with same approximate dimensions were carefully selected and tested. The grain was loaded in two axes (lengthwise and breadthwise). Each seed was positioned in between the compression plates of the UTM. The gauge length was reduced to a minimum to prevent buckling during compression loading. The average of the three best values of the compressive strength and other properties were recorded as the final values for the respective properties.

IV. RESULTS AND DISCUSSION

The compressive strength properties of three varieties (SUWAN-I-SR-Y, ART98/SWI and TZE COMP 5-W) of maize were obtained at the moisture contents 11.7%, 10.9% and 12.2% respectively. The mean values of Stress-Strain properties- maximum compressive stress (MPa), compressive strain at maximum compressive stress (mm/mm), energy at maximum compressive stress (J), compressive load at maximum compressive stress (N), compressive extension at maximum compressive stress (mm), compressive stress at break (standard) (MPa), compressive load at break (standard) (N), compressive strain at break (standard) (mm/mm), load at maximum compressive stress (N), extension at maximum compressive stress (mm), compressive extension at break (standard) (mm), load at break (standard) (N), extension at break (standard) (mm), energy at break (standard) (J), compressive stress at yield (zero slope) (MPa) and compressive load at yield (zero slope) (N) obtained for lengthwise and breadthwise orientation of seeds in each cases were presented in Table 1. Relationships between compressive stress and compressive strain obtained in direct shear testing for lengthwise and breadthwise for each kernel of maize varieties (TZE COMP 5-W, ART/98/SW1-Y and SUWAN 1-SR-Y) are show in Figures 1,2, and 3. The Figures (2, 3, and 4) showed the plots of the compressive stress and compressive strain of the specimens for each variety when considered at both lengthwise and breadthwise orientations. The compressive load at maximum compressive stress for the three varieties TZE COMP 5-W, ART/98/SW1-Y and SUWAN 1-SR-Y were 169.75, 209.74 and 96 N respectively while the compressive extension at maximum compressive stress for the three varieties TZE COMP 5-W, ART/98/SW1-Y and SUWAN 1-SR-Y were 1.52, 1.57 and 1.16 mm respectively lengthwise. The values obtained for TZE COMP 5-W were 0.727 MPa (lengthwise), 0.541 MPa (breadthwise) maximum compressive stress, 0.1599 mm/mm (lengthwise), 0.0883 mm/mm (breadthwise)compressive strain at maximum compressive stress, compressive load at maximum compressive stress 169.7459 N (lengthwise), 115.8694 N (breadthwise), Compressive load at Break (Standard) 145.2026 N (lengthwise), 68.9954 N (breadthwise). However, the energy exerted at break (standard) was 0.0943 J (lengthwise), 0.0488 J (breadthwise). This implies that the bonding force among the molecules for TZE COMP 5-W variety is concentrating more lengthwise. In the case of ART/98/SW1-Y, the values obtained lengthwise were higher than those obtained for TZE COMP 5-W variety except for the Compressive load at Break (Standard) but, the breadthwise values were smaller in values. Maximum compressive stress 0.9794 MPa (lengthwise), 0.4728 MPa (breadthwise), compressive strain at maximum compressive stress 0.1653 mm/mm (lengthwise), 0.0596 mm/mm (breadthwise), compressive load at maximum compressive stress 209.74 N (lengthwise), 101.2603 N (breadthwise), Compressive load at Break (Standard) 101.43 N (lengthwise), 30.4365 N (breadthwise). Energy at break (standard) was 0.1171 J (lengthwise), 0.0205 J (breadthwise) for ART/98/SW1-Y. From all these values more energy (0.1171 J) is required to compress ART/98/SW1-Y variety lengthwise than the other two varieties. SUWAN 1-SR-Y variety has maximum compressive stress 0.4507 MPa (lengthwise), 0.6243 MPa (breadthwise), compressive strain at maximum compressive stress 0.1218 mm/mm (lengthwise), 0.0666 mm/mm (breadthwise), compressive load at maximum compressive stress 96.531 N (lengthwise), 133.7011 N (breadthwise), Compressive load at Break (Standard) 48.134 N (lengthwise), 85.6894 N (breadthwise). Energy at break (standard) was 0.0566 J (lengthwise), 0.0421 J (breadthwise). The observations for SUWAN 1-SR-Y took a different dimension because higher values were obtained in the breadthwise orientation except for the energy at break 0.0566 J (lengthwise). The values obtained in this study were not far from the mean values 174.8 N and 1.756 mm, presented by [23] for force at peak and deformation at peak respectively of maize grain investigated. Least force is required to break the Suwan-1-SR-Y variety. In another study [24] Suwan-1-SR-Y has the largest grain sizes and yielded the highest flour out of the three varieties. Hence, this could be as the result of the least force required to break the grain. [12] reported that values of the modulus of elasticity ranged from 25.4 to 44.6 MPa for uniaxial compression tests on the granular wheat. [25] studied the Mechanical Properties of Native Maize, Wheat, and Potato Starches and found that Cohesion of dry materials varied from 0.04 kPa for maize starch at 10 kPa of consolidation stress to 0.26 kPa. These results were lower to those obtained in this work probably the fact that grain was examined in this research.

V. CONCLUSION

This study focused on the compressive strength of some quality protein maize varieties. However, the study revealed that the TZE COMP 5-W required more force to separate the particles followed by ART/98/SW1-Y variety while SUWAN 1-SR-Y has the least. It further implies that more force could be required in the processing of TZE COMP 5-W and ART/98/SW1-Y, especially where size reduction is being involve. However, further study should focus more on the engineering properties of the QPM.

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Table 1: Stress-strain properties for lengthwise and breadthwise orientation of maize kernels varieties

	TZE COMP 5-W				ART 98/SWI-Y				SUWAN 1-SR-Y			
	Lengthwise		Breadthwise		Lengthwise		Breadthwise		Lengthwise		Breadthwise	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Maximum Compressive stress (MPa)	0.7926	0.1619	0.5410	0.5956	0.9794	0.1798	0.4728	0.2583	0.4507	0.1810	0.6243	0.5616
Compressive strain at Maximum Compressive stress (mm/mm)	0.1599	0.0891	0.0883	0.0466	0.1653	0.0394	0.0596	0.0294	0.1218	0.0446	0.0666	0.0200
Energy at Maximum Compressive stress (J)	0.0823	0.0335	0.0288	0.0215	0.0900	0.0214	0.0154	0.0066	0.0513	0.0329	0.0321	0.0298
Compressive load at Maximum Compressive stress (N)	169.7459	34.6652	115.8694	127.5598	209.7400	38.4989	101.2603	55.3177	96.5310	38.7568	133.7011	120.2641
Compressive extension at Maximum Compressive stress (mm)	1.5159	0.8449	0.8372	0.4417	1.5668	0.3738	0.5647	0.2784	1.1548	0.4227	0.6313	0.1898
Compressive stress at Break (Standard) (MPa)	0.6780	0.1839	0.3223	0.5411	0.4736	0.6029	0.1421	0.5078	0.2248	0.3819	0.4001	0.6986
Compressive load at Break (Standard) (N)	145.2026	39.3832	68.9954	115.8790	101.4300	129.1200	30.4365	108.7476	48.1340	81.7925	85.6894	149.6056
Compressive strain at Break (Standard) (mm/mm)	0.1685	0.0882	0.1078	0.0526	0.1858	0.0448	0.0753	0.0334	0.1296	0.0425	0.0812	0.0262
Load at Maximum Compressive stress (N)	-169.7459	34.6652	-115.8694	127.5598	-209.7362	38.4989	-101.2603	55.3177	-96.5310	38.7568	-133.7011	120.2641
Extension at Maximum Compressive stress (mm)	-1.5159	0.8449	-0.8372	0.4417	-1.5668	0.3739	-0.5647	0.2784	-1.1548	0.4227	-0.6313	0.1898
Compressive extension at Break (Standard) (mm)	1.5975	0.8358	1.0222	0.4990	1.7610	0.4246	0.7136	0.3169	1.2289	0.4030	0.7702	0.2483
Load at Break (Standard) (N)	-145.2026	39.3832	-68.9954	115.8790	-101.4294	129.1155	-30.4365	108.7476	-48.1340	81.7925	-85.6894	149.6056
Extension at Break (Standard) (mm)	-1.5975	0.8358	-1.0222	0.4990	-1.7610	0.4246	-0.7136	0.3169	-1.2289	0.4030	-0.7702	0.2483
Energy at Break (Standard) (J)	0.0943	0.0316	0.0488	0.0476	0.1171	0.0214	0.0205	0.0187	0.0566	0.0343	0.0421	0.0374
Compressive stress at Yield (Zero Slope) (MPa)	0.2791	0.3690	0.1204	0.0605	0.7485	0.5756	0.2818	0.4168	0.2108	0.2466	0.2796	0.3841
Compressive load at Yield (Zero Slope) (N)	59.7646	79.0154	25.7746	12.9650	160.2941	123.2747	60.3496	89.2654	45.1502	52.8186	59.8857	82.2543

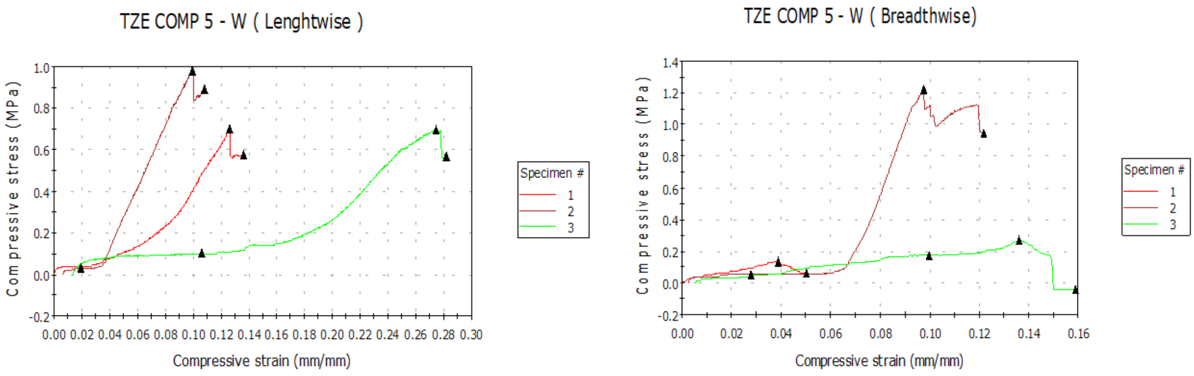

Figure 1: Compressive stress-strain relation for lengthwise and breadthwise orientation of maize kernels for TZE COMP 5-W

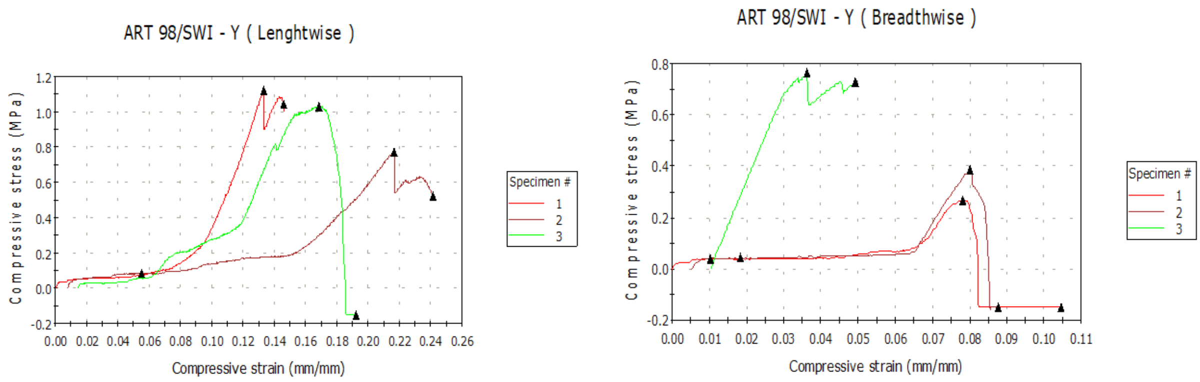

Figure 2: Compressive stress-strain relation for lengthwise and breadthwise orientation of maize kernels for ART 98/SWI-Y

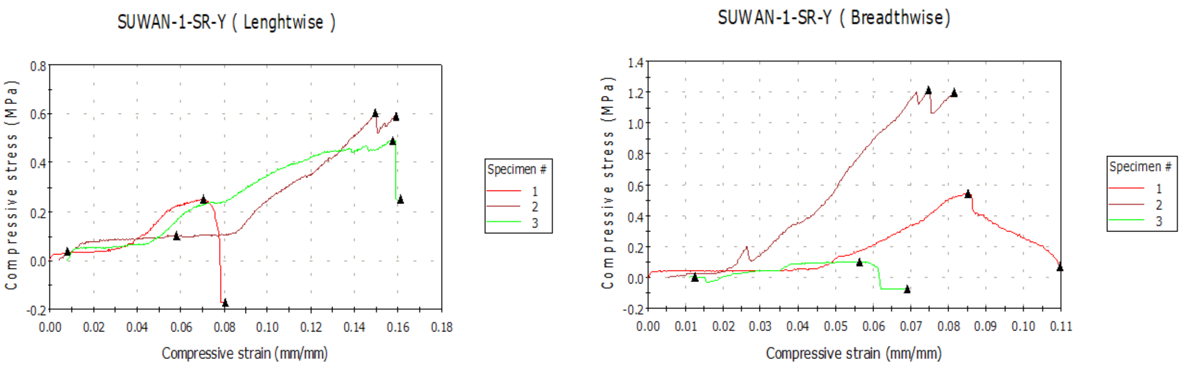

Figure 3: Compressive stress-strain relation for lengthwise and breadthwise orientation of maize kernels for SUWAN 1-SR-Y

