



ORIGINAL RESEARCH ARTICLE

**STRESS RELAXATION BEHAVIOR OF DIFFERENT VARIETIES OF POTATO TUBERS UNDER COMPRESSIVE MECHANICAL LOADING**

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**ABSTRACT**

Potatoes tubers obtain several mechanical injuries during its harvesting, handling and storage and the knowledge of the mechanical properties of potatoes is very important for improving these operations. The stress relaxation of three varieties of Benue State-grown potato tubers was determined using the universal testing machine to study the behavior of the named varieties; orange potato, purple potato and white potato tubers under loading. The potato tubers were cut into cubes of 2700 mm<sup>3</sup> and the stress relaxation was observed under the application of compressive force. It was observed that the compressive stress at total relaxation across the three varieties of potato ranged from 0.040-0.071 MPa with orange potato having the highest value of 0.071 MPa while white potato had the least value of 0.040 MPa. The compressive strain at total relaxation for the three varieties of potato tubers ranged from 0.00010 to 0.00011 mm/mm. The compressive load at total relaxation for the three varieties of potato ranged from 15.937 to 28.293 N. The compressive extension at total relaxation for the three varieties of potato tubers ranged from 0.0015 to 0.0020 mm. The load at total relaxation for the three varieties of potato tubers ranged from 15.937 to 28.293 N. Extension at total relaxation for the three varieties of potato tubers ranged from 0.0015 to 0.0020 mm. The maximum compressive stress for the three varieties of potato tubers ranged from 0.133 to 0.188 MPa. The compressive strain at maximum compressive stress for the three varieties of potato tubers ranged from 0.0598 to 0.0601 mm/mm. The compressive load at maximum compressive stress for the three varieties of potato tubers ranged from 53.274 to 75.170 N. The extension at maximum compressive stress for the three varieties of potato tubers ranged from 1.196 to 1.202 mm. Load at maximum compressive stress for the three varieties of potato tubers ranged from 53.27 to 75.17 N. ANOVA and Duncan test at 95% confidence level revealed there was no significant difference across the stress relaxation of the three varieties of potato tubers investigated. The data generated on the three varieties of potatoes indicate that it is safe if the various potatoes varieties are packaged and transported together, and that this will not cause any mechanical damage to the potatoes. It can be concluded that the various varieties of Benue grown potato can use the same post harvest processing and handling machines. These data are also important for maximum efficiency in designing equipment for further processing of potatoes and the reduction of its mechanical damage during postharvest operations such as transportation, packaging and storage of potato tubers.

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## 1.0 Introduction

Sweet potato (*Ipomoea batatas* L. Lam.), is an important economic crop, grown in nearly every corner of the globe, most widely consumed and versatile crop. In 2023, the world produced over 440 million metric tons of potatoes, making it the third most important staple crop after rice and wheat (USDA, 2024). China is the largest potato producer, followed by India and Russia (FAO, 2016) and also ranked the 2<sup>nd</sup> largest cultivated root crop (7.9 million ha) after cassava worldwide (Makos, 2016). Sweet potato roots have high nutritional value and sensory versatility in terms of taste, texture, and flesh colour (white, cream, yellow, orange, purple). The varieties with high dry matter (>25%), white-cream flesh colour, and mealy firm texture after cooking are preferred by consumers in the tropics (Ray, 2017). The purple-fleshed sweet potato varieties with attractive colour and high anthocyanin content are the specialty type in Asia. The International Potato Centre (CIP) holds the largest sweet potato gene bank in the world with more than 6,500 wild, traditional and improved varieties. According to FAO (2006) statistics, West African Sweet potato production stood at 2,516 million metric tons. Sweet potato is high in nutritive value, outranking most carbohydrate foods in vitamins, minerals, protein and energy content (Onuh *et al.*, 2004). Sweet potato serves as a staple food (fleshy roots and tender leaves), snack food, weaning food, animal feed, as well as raw material for industrial starch and alcohol. It is processed into diverse products (Udensi, 2000).

Some of the root and tuber crops cultivated by farmers in the country include cassava, yam and sweet potato. The global, ranking of sweet potato-producing countries showed Nigeria to be the largest producer in Africa, and the second largest producer in the world after China in 2014, (FAO, 2015). It requires fewer inputs and less labour than other crops, is more productive, and is adaptable to marginal growing conditions (drought and poor soils). Harvesting, handling and storage of potatoes produce several mechanical injuries therefore the study of mechanical properties is very important for improving the technology of these processes (Omale and Omobowale, 2018). Storage processes produce stress effect and bring about physiological changes and water loss, affecting the mechanical properties. According to Mohsenin(1986) and Negar (2019), mechanical properties in agricultural products are due to external and internal forces. External forces affect fruits or vegetables when they are subjected to several static and dynamic loads causing mechanical injuries, while internal forces may be a result of physical changes, such as variations in temperature and moisture content, or as a result of chemical and biological changes. Different varieties of potatoes are cultivated in Benue State and during harvest season, these different varieties are sometimes packaged and transported differently by some farmers while other farmers package and transport them together to the market or processing industries. The Benue State potato farmers are not sure of which method is proper for packaging and transporting their harvested potatoes. Hence, this study was conducted to investigate the mechanical properties of the various potato varieties grown in Benue State so as to provide the Benue Farmers with data on their engineering properties relevant for transportation and packaging of products.

## 2. Materials and Methods

### 2.1 Materials

The three varieties of Benue-grown potato tubers (orange potato, purple potato, and white potato) used for this study were procured directly from a farm at Yaikyo, Makurdi, Benue State, Nigeria and transported in perforated cartons to the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria, for experimentation.

The three varieties of potatoes used are shown on Figures 1, 2 and 3 respectively while the major apparatus used was the universal testing machine shown in Figure 4.

### 2.2 Methods

Each of the samples was cut into cubes of ten replications with dimensions of approximately 30 mm by 30 mm by 30 mm. The specimen was fixed up to the jigs of the Universal Testing Machine (Figure 4) and the load balanced on the specimen by clicking on the load cell soft key which displayed zero. The extension was set to zero and the extensometer was allowed to balance for the test to begin. The crossed head moved at the specified rate of 1.0 mm/min until the test was stopped. As the end of the test conditions were met, the screen returned to the beginning of the test screen. The extensometer was balanced on the specimen by pulling the

spring clips back. After the specimen was stretched, the readings were computed automatically by the computer and this procedure was repeated for all the three varieties of potatoes.



**Figure 1: Purple Sweet Potato**



**Figure 2: Orange Sweet Potato**



**Figure 3: White Sweet Potato**



**Figure 4: Universal testing machine**

### **3. Results and Discussion**

#### **3.1 Results**

The experimental results data obtained from this study are shown in Table I.

**Table I:** Mean value of the mechanical properties of the three varieties of potatoes grown in Benue State

Parameters	Variety	N	Mean	Std. Deviation	Minimum	Maximum
COMPRESSIVE STRESS AT TOTAL RELAXATION (MPa)	ORANGE POTATOES	10	0.0707	0.0462	0.0279	0.1631
	PURPLE POTATOES	10	0.0564	0.0449	0.0046	0.1560
	WHITE POTATOES	10	0.0398	0.0404	0.0075	0.1394
COMPRESSIVE STRAIN AT TOTAL RELAXATION (mm/mm)	ORANGE POTATOES	10	0.0001	0.0000	0.0000	0.0001
	PURPLE POTATOES	10	0.0001	0.0000	0.0001	0.0001
	WHITE POTATOES	10	0.0001	0.0001	0.0000	0.0001
COMPRESSIVE LOAD AT TOTAL RELAXATION (N)	ORANGE POTATOES	10	28.2934	18.4738	11.1531	65.2471
	PURPLE POTATOES	10	22.5391	17.9497	1.8443	62.4001
	WHITE POTATOES	10	15.9371	16.1421	3.0062	55.7729
COMPRESSIVE EXTENSION TOTAL RELAXATION (mm)	ORANGE POTATOES	10	0.0017	0.0006	0.0003	0.0023
	PURPLE POTATOES	10	0.0020	0.0004	0.0014	0.0024
	WHITE POTATOES	10	0.0015	0.0009	0.0002	0.0025
LOAD AT TOTAL RELAXATION (N)	ORANGE POTATOES	10	28.2934	18.4738	11.1531	65.2471
	PURPLE POTATOES	10	22.5391	17.9497	1.8443	62.4001
	WHITE POTATOES	10	15.9371	16.1421	3.0062	55.7729
EXTENSION AT TOTAL RELAXATION (mm)	ORANGE POTATOES	10	0.0017	0.0006	0.0003	0.0023
	PURPLE POTATOES	10	0.0020	0.0004	0.0014	0.0024
	WHITE POTATOES	10	0.0015	0.0009	0.0002	0.0025
MAXIMUM COMPRESSIVE STRESS (MPa)	ORANGE POTATOES	10	0.1879	0.1238	0.0660	0.4010
	PURPLE POTATOES	10	0.1670	0.1151	0.0712	0.3924
	WHITE POTATOES	10	0.1332	0.1032	0.0543	0.3887
COMPRESSIVE STRAIN AT MAXIMUM COMPRESSIVE STRESS (mm/mm)	ORANGE POTATOES	10	0.0601	0.0000	0.0600	0.0601

	PURPLE POTATOES	10	0.0599	0.0005	0.0585	0.0601
	WHITE POTATOES	10	0.0598	0.0006	0.0582	0.0601
COMPRESSIVE LOAD AT MAXIMUM	ORANGE POTATOES	10	75.1704	49.5288	26.3870	160.3815
COMPRESSIVE STRESS (N)	PURPLE POTATOES	10	66.8140	46.0210	28.4648	156.9669
	WHITE POTATOES	10	53.2736	41.2770	21.7152	155.4623
COMPRESSIVE EXTENSION AT	ORANGE POTATOES	10	1.2017	0.0007	1.2000	1.2023
MAXIMUM COMPRESSIVE STRESS	PURPLE POTATOES	10	1.1988	0.0101	1.1701	1.2024
(mm)	WHITE POTATOES	10	1.1955	0.0124	1.1630	1.2024
LOAD AT MAXIMUM COMPRESSIVE	ORANGE POTATOES	10	75.1704	49.5288	26.3870	160.3815
STRESS (N)	PURPLE POTATOES	10	66.8140	46.0210	28.4648	156.967
	WHITE POTATOES	10	53.2736	41.2770	21.7152	155.4623
EXTENSION AT MAXIMUM	ORANGE POTATOES	10	1.2017	0.0007	1.2000	1.2023
COMPRESSIVE STRESS (mm)	PURPLE POTATOES	10	1.1988	0.0101	1.1701	1.2024
	WHITE POTATOES	10	1.1955	0.0124	1.1630	1.2024

### 3.2 Discussion of Results

The compressive properties of different potato varieties (Orange, Purple, and White) were evaluated under total relaxation and maximum compressive stress conditions. The results highlight variations in mechanical behavior, which could have implications for storage, processing, and handling.

#### 3.2.1 Compressive Stress at Total Relaxation

Orange potatoes exhibited the highest mean compressive stress at total relaxation (0.0707 MPa), followed by purple potatoes (0.0564 MPa) and white potatoes (0.0398 MPa). The higher stress in orange potatoes suggests greater resistance to deformation, possibly due to differences in cell structure or moisture content. The standard deviation values indicate variability in stress distribution among the samples, with white potatoes showing the least variation.

#### 3.2.2 Compressive Strain at Total Relaxation

The mean compressive strain at total relaxation was relatively uniform across all varieties, with minimal differences. This suggests that despite variations in stress, the degree of strain upon relaxation remained within a narrow range, indicating similar structural responses after compression.

#### 3.2.3 Compressive Load at Total Relaxation

Orange potatoes required the highest load (28.29 N) to reach total relaxation, while white potatoes required the lowest (15.94 N). This trend aligns with the compressive stress results, reinforcing the observation that orange potatoes exhibit higher mechanical strength. The greater load-bearing capacity of orange potatoes could be advantageous in handling and transportation, reducing susceptibility to mechanical damage.

### **3.2.4 Compressive Extension at Total Relaxation**

Purple potatoes exhibited the highest mean extension (0.0020 mm), followed by orange (0.0017 mm) and white potatoes (0.0015 mm). The variations in extension values may be attributed to differences in cell wall elasticity and moisture content, with purple potatoes being slightly more extensible before full relaxation.

### **3.2.5 Maximum Compressive Stress**

At maximum compressive stress, orange potatoes demonstrated the highest mean value (0.1879 MPa), while white potatoes had the lowest (0.1332 MPa). This indicates that orange potatoes can withstand greater compressive forces before failure, making them mechanically stronger. The differences in stress resistance could be linked to genetic and compositional differences among the varieties.

### **3.2.6 Compressive Strain at Maximum Stress**

The mean compressive strain at maximum stress remained nearly constant across all varieties, with orange potatoes having a slightly higher value (0.0601 mm/mm) compared to white potatoes (0.0598 mm/mm). The small variations suggest that all three varieties exhibit similar deformation behavior at peak stress.

### **3.2.7 Compressive Load at Maximum Stress**

The highest compressive load was observed in orange potatoes (75.17 N), followed by purple potatoes (66.81 N) and white potatoes (53.27 N). These results are consistent with the compressive stress findings, indicating that orange potatoes require a significantly higher force to reach their maximum stress threshold. This property may make them more resistant to mechanical damage during storage and transportation.

### **3.2.8 Compressive Extension at Maximum Stress**

The extension at maximum compressive stress was slightly higher in orange potatoes (1.2017 mm) compared to purple (1.1988 mm) and white potatoes (1.1955 mm). Although the differences are minor, they suggest that orange potatoes undergo slightly greater elongation before failure, possibly due to higher turgor pressure or structural differences.

### **3.2.9 Statistical Analysis**

Analysis of variance and Duncan test were carried out on the result data at a 95% confidence level using SPSS 2021 packaged (Version 20). It revealed that the compression stress, strain, extension at the total relaxation among all other properties investigated are not significantly different across the three varieties of potato tubers (orange potato, purple potato and white potato) as shown in Table 2 and Figure 5 (a, b, c) displays the graphical results of the compression relaxation test / creep test of the three varieties of potatoes investigated.

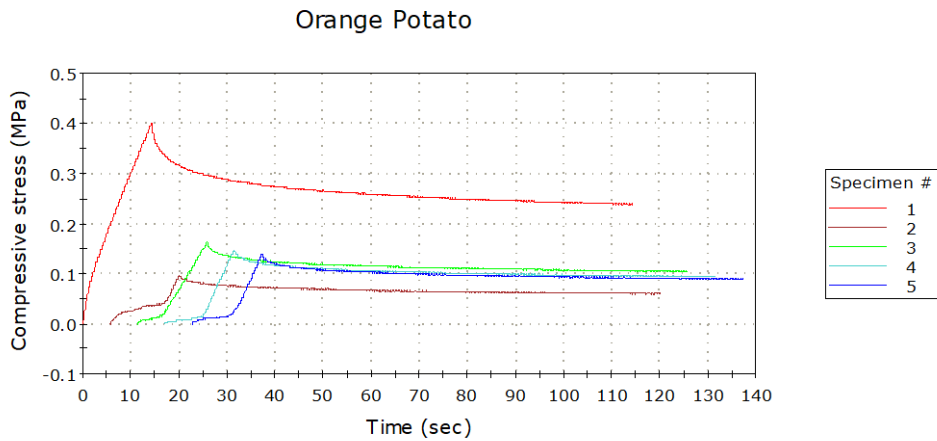
The result shows that the stress relaxation of the three varieties of Benue State grown potatoes were not significantly different as affected by compressive force, The report in this study is the opposite in the case of yam as reported by Omale *et al.* (2021) in their study that investigated the stress relaxation of three varieties of Benue State grown yam tubers as affected by compressive force.



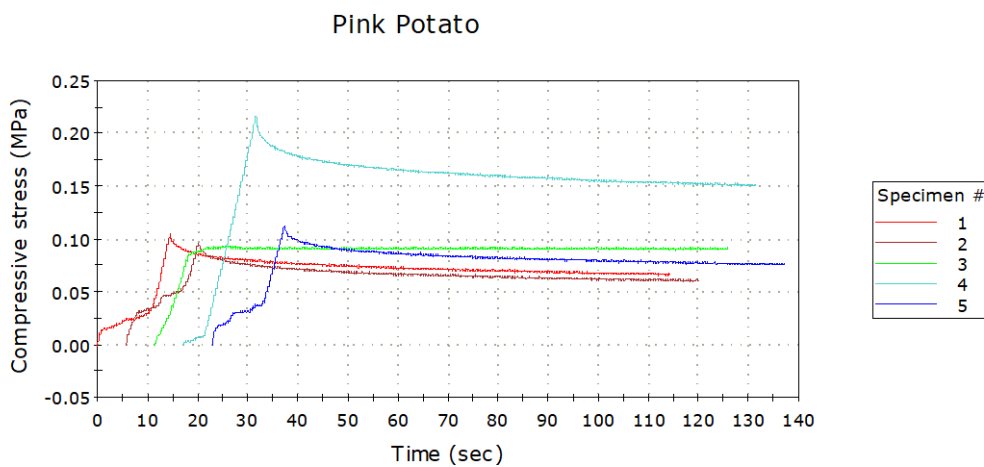
**Table 2: Analysis of Variance**

		Sum of Squares	Df	Mean Square	F	Sig.
Compressive Stress at Total Relaxation (MPa)	Between Groups	.005	2	.002	1.241	.305 <sup>NS</sup>
	Within Groups	.052	27	.002		
	Total	.057	29			
Compressive Strain at Total Relaxation (mm/mm)	Between Groups	.000	2	.000	1.509	.239 <sup>NS</sup>
	Within Groups	.000	27	.000		
	Total	.000	29			
Compressive Load at Total Relaxation (N)	Between Groups	764.597	2	382.299	1.241	.305 <sup>NS</sup>
	Within Groups	8316.350	27	308.013		
	Total	9080.947	29			
Compressive Extension at Total Relaxation (mm)	Between Groups	.000	2	.000	1.643	.212 <sup>NS</sup>
	Within Groups	.000	27	.000		
	Total	.000	29			
Load At Total Relaxation (N)	Between Groups	764.597	2	382.299	1.241	.305 <sup>NS</sup>
	Within Groups	8316.350	27	308.013		
	Total	9080.947	29			
Extension at Total Relaxation (mm)	Between Groups	.000	2	.000	1.643	.212 <sup>NS</sup>
	Within Groups	.000	27	.000		
	Total	.000	29			
Maximum Compressive Stress (MPa)	Between Groups	.015	2	.008	.584	.565 <sup>NS</sup>
	Within Groups	.353	27	.013		
	Total	.368	29			
Compressive Strain at Maximum Compressive Stress (mm/mm)	Between Groups	.000	2	.000	1.128	.339 <sup>NS</sup>
	Within Groups	.000	27	.000		
	Total	.000	29			
Compressive Load at Maximum Compressive Stress (N)	Between Groups	2442.139	2	1221.069	.584	.565 <sup>NS</sup>
	Within Groups	56473.444	27	2091.609		
	Total	58915.583	29			
Compressive Extension at Maximum Compressive Stress (mm)	Between Groups	.000	2	.000	1.139	.335 <sup>NS</sup>
	Within Groups	.002	27	.000		
	Total	.002	29			
Load At Maximum Compressive Stress (N)	Between Groups	2442.139	2	1221.069	.584	.565 <sup>NS</sup>
	Within Groups	56473.444	27	2091.609		
	Total	58915.583	29			
Extension at Maximum Compressive Stress (mm)	Between Groups	.000	2	.000	1.139	.335 <sup>NS</sup>
	Within Groups	.002	27	.000		
	Total	.002	29			

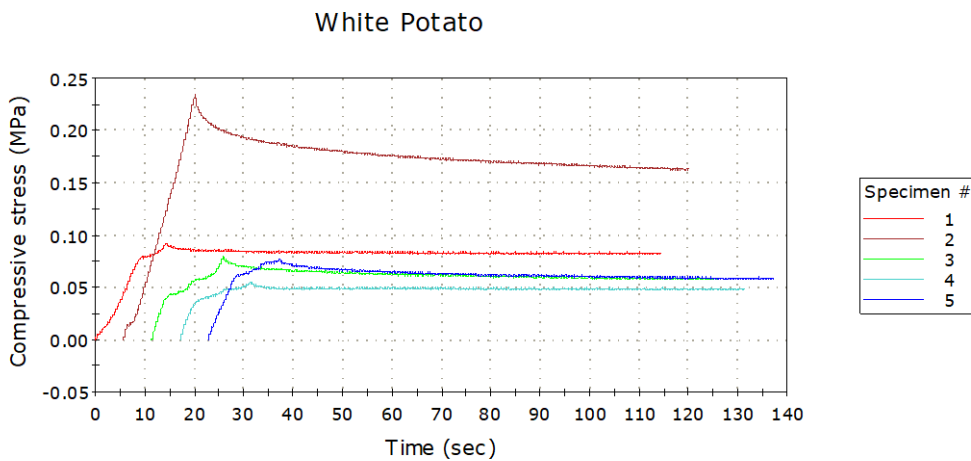
**Note:** Sig. values with a superscript (NS) show there's no significant difference at P>0.05



**Figure 5 (a):** Compression Relaxation Test / Creep Test on the Orange variety of potatoes



**Figure 5 (b):** Compression Relaxation Test / Creep Test on the Pink variety of potatoes



**Figure 5 (c):** Compression Relaxation Test / Creep Test on the white variety of potatoes

#### 4. Conclusion

The compression test of three varieties of Benue State-grown potato tubers (Orange, Purple, and White) was conducted using a universal testing machine. The results indicate that orange potatoes generally exhibit the highest mechanical strength, followed by Purple, while White potatoes have the lowest compressive strength. This suggests that orange potatoes are more resistant to mechanical damage, making them more suitable for extended storage and transportation. The compressive stress relaxation of White potatoes was found to be lower compared to orange and purple varieties. Orange potatoes had the highest compressive stress



relaxation, followed by Purple and then White. The compressive stress at total relaxation ranged from 0.040–0.071 MPa, with orange potatoes having the highest value (0.071 MPa) and White potatoes the lowest (0.040 MPa). Similarly, the compressive strain at total relaxation ranged from 0.00010 to 0.00011 mm/mm, while the compressive load at total relaxation varied between 15.937 and 28.293 N. The compressive extension at total relaxation was between 0.0015 and 0.0020 mm. At maximum compressive stress, values ranged from 0.133 to 0.188 MPa, with compressive strain between 0.0598 and 0.0601 mm/mm. The compressive load at maximum stress varied from 53.274 to 75.170 N, while extension at maximum stress ranged from 1.196 to 1.202 mm. The ANOVA results revealed no significant difference in compressive stress relaxation among the three varieties. Further analysis using Duncan's test at a 95% confidence level (SPSS 2021, Version 20) confirmed that there was no statistically significant difference in the mechanical properties of the three potato varieties. These findings suggest that Benue State farmers can package and transport all three varieties together without concern for differential mechanical damage. Additionally, the design of postharvest handling and processing equipment can be standardized for all three varieties. The data generated in this study will help farmers and industry stakeholders understand the engineering properties of Benue State-grown potatoes, facilitating better handling, transportation, and processing decisions.

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