Journal of Tropical Crop Science Vol. 9 No. 1, February 2022
www.j-tropical-crops.com

Investigation of Vibration Technique To Control Physical Properties of Yam Tubers (*Dioscorea rotundata* Poir.) During Storage

Kifilideen L. Osanyinpeju*[A], Adewole A. Aderinlewo[A], Olawale U. Dairo[A], Olayide R. Adetunji[B], Emmanuel S.A. Ajisegiri[A]

[A] Agricultural and Bioresources Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta, Ogun State, Nigeria
[B] Mechanical Engineering Department, College of Engineering, Federal University of Agriculture Abeokuta, Ogun State, Nigeria

*Corresponding author; email: amkifilideenosanyinpeju@gmail.com

Abstract

Yam tubers loss weight during storage and prolonged storage can reduce tuber quality and quantity. This study investigated the application of vibration technique for the control of physical properties of yam tubers during storage. Measurements were conducted on the physical properties of the tubers: weight loss, shrinkage of the middle diameter, shrinkage of the length, top and bottom diameter, on 108 tubers treated and 32 tubers untreated (control). The factors of the experimental design were three levels of vibration frequencies, i.e. low (1 – 5 Hz), medium (60 – 100 Hz) and high (150 – 200 Hz), amplitudes of low (5 mm), medium (10 mm), and high (20 mm), and durations of low (5 minutes), medium (10 minutes) and high (15 minutes). Tuber weights were classified as small (0.1 – 2.9 kg) and large (3.0 – 5.0 kg). The tubers were stored for ten weeks after vibration, and their physical properties were measured every week during the storage period. Our study demonstrated that as the frequency, amplitude, and duration of vibration increase, the physical properties of yam tubers decrease significantly in both tuber classes. The study shows that mechanical vibration can slow down the changes of the physical properties of yam tuber during storage.

Keywords: yam tuber, mechanical vibration, tuber quality

Introduction

Tubers are living organisms after they have been harvested, so they response to abiotic and biotic stresses. Abiotic stresses include water, salt, drought, temperature, humidity, heat, cold, windy pressures, and ultraviolet radiation, and mechanical stimulus such as touch, rub, brush, bend, press, stretch, some multiplex effects induced by sound, electric or magnetic field. Biotic stresses are mainly arises from infection or attacks by bacteria, fungi, viruses, nematodes and insects (Ganfwar et al., 2014; Thao et al, 2015; Vivek et al., 2016).

Control of dormancy is related to three groups of plant growth regulators, abscisic acid (ABA), gibberellins (GA), and cytokinins (Arteca, 1996). The phytohormones are naturally occurring synthesis chemicals that play critical roles in regulating plant growth, including in yams. Phytohormones regulate or influence a range of cellular or physiological processes including growth, development (cell division, cell enlargement, cell differentiation) and movement (tropisms). During the harvest period of yam tuber which occur at the period of dry season, there is secretion of abscisic acid at low concentration (Davies, 2010) which make the yam tubers to go dormant (Awologbi and Hamadina, 2015), metabolically quiescent/all metabolic activities stopped or cease in physiological, respiration, biochemical changes (Sorth, 2015). The action of the phytohormone helps the tubers to survive through the period of the water stress and extreme cold winter conditions (Cheema, 2010).

In the south Nigeria, during the raining season in February, the environmental condition is favourable for yam tuber sprouting. According to Cheema (2010) and Wickam (2019) the sprouting also relate to the release of gibberellins which break yam tuber dormancy. Once the dormancy is broken, sprouting continues and resulting in rapid carbohydrate metabolism and utilization, and at the same time causing senescence and increase the prone to pathogenic invasion (Adeyemi, 2009). In West Africa, planting of the yam tuber begins in the humid forest February and April (Ile et al., 2016), and depending on the variety, yams can be harvested in August to November (Tortoe et al., 2015). According to Suttle (2004), ABA plays important roles in the regulation of yam tuber dormancy.

The time or inhibition of sprouting during the life cycle of yam can be carried out by manipulating the physical environment. This study investigated the application of vibration techniques on the physical properties of yam tubers (*Dioscorea rotundata*) during storage.

Materials and Methods

Experimental Study Location

The experiment was carried out at Federal University of Agriculture, Alabata, Abeokuta, Ogun State, Nigeria (70N, 30 E).

Materials

A developed rigid mechanical vibrator of adjustable frequency and amplitude was used to vibrate the yam tubers. A tachometer was used to set the frequency of the vibration. The digital weighing machine was used to measure the weight of the yam tuber every week of storage, weight of yam sprout and root of the yam tuber after storage. The flexible tape rule was used to measure the length of the sprout and root of the yam tuber and the longitudinal length of the yam tuber, and he steel rule was used to measure the length of the root of the yam tubers. A total of 140 white tuber yams were measured for their weight loss, tuber diameter, and shrinkage after storage.

Experimental Designs, Analysis and Procedures

Vibration parameters examined were frequency, amplitude and duration of vibration. Measurements were conducted on the weight, diameter and length of the yam tubers. The yam tubers were classified into small (0.1 kg – 2.9 kg) and large (3.0 kg – 5.0 kg).

The factors considered for the experimental design were frequency, amplitude and duration of the vibration, which were tested on the two weight classes of the yam tuber (described above). The range of frequencies of vibration design for the yam vibration was from 1 to 200 Hz. The selection of the frequency range for the yam vibration was based on the possible and achievable frequency range reported for mechanical vibrator. Nitinkumar et al. (2014) reported that the frequency range of mechanical vibrator (using eccentric and connecting link, scotch yoke, cam and follower or rotating unbalance mass mechanism) falls between 0 – 200 Hz while maximum displacement achievable is 25 mm. Based on this, it was designed to operate the vibration at the frequency range of 1 – 200 Hz and amplitude range of 0 to 20 mm. Also, a low, medium and very high frequency were considered. Thirty two replications of yam tuber were taken as control experiments which were not set exposed to vibration treatment. One hundred and eight tubers were subjected to vibration and remaining thirty-two tubers were set as control. The vibration was carried out from 20/01/2020 to 24/01/2020. For each treatment, the timing of vibration was continuous until the time of vibration lapse.

The factors of the experimental design examined were three levels of frequencies (low (1 – 5 Hz), medium (60 – 100) Hz and high (150 – 200 Hz)), amplitudes oflow (5 mm), medium (10 mm) and high (20 mm) and times of low (5 minutes), medium (10 minutes) and high (15 minutes) with weight of yam tuber of two levels of small (0.1 – 2.9 kg) and big (3.0 – 5.0 kg). After the vibration treatment, the tubers were stored at the Agricultural and Bioresources Engineering processing laboratory of Agricultural Engineering Department at Federal University of Agriculture, Abeokuta, for ten weeks (25/01/2020 to 29/03/2020). The physical properties of the yam tubers and sprouting were monitored and recorded every week for a 10-week storage period. The variety of yam tube used for the experiment was white yam (*Dioscorea rotundata*). The yam tubers were selected based on easy accessibility. The yam tubers were carried stored in a laboratory wood benches with temperatures ranging from 24.2 to 32.6ºC.

Evaluation and Measurement of the Yam Tuber Response

Measurement of weight loss

The weight of each tuber was measured and recorded using a digital balance each week over the duration of study. Weight loss of the yam tuber is calculated based on the weight of the yam tuber in the first day of storage minus the weight of the yam tuber after 10 days of storage.

Shrinkage length of the yam tuber was measured and recorded every week throughout the storage period. The shrinkage length for each yam tuber for the whole period of storage was determined by subtracting the measured length of yam tuber at the

10th week of storage from the 1st week of storage period. The length the tuber was measured using a flexible tape rule.

The top diameter of each yam tuber was measured and recorded every week throughout of the storage period. The shrinkage diameter of the top part of the yam tuber was determined by removing the measured top diameter at the 10th week of storage from the 1st week of storage period. The top diameter was measured using micrometer screw gauge.

Tuber shrinkage was measured in the mid-part and bottom-part of the tubers by measuring their diameter weekly. The swollen value diameter of the middle part of the yam tuber was determined by removing the measuredmiddle diameter at the first week of storage from the 10th week of storage period. The shrinkage diameter of the bottom part of the yam tuber was determined by removing the measured bottom diameter at the 10th week of storage from the 1st week of storage period. The top and the bottom diameter was measured using micrometer screw gauge.

Results and Discussions

Weight Loss of the Yam Tubers

It was observed during the experimental studied that weight loss of the yam tubers occurred during storage. The maximum weight loss recorded at the end of storage period was 1000 g which was obtained from the control (Table 1). According to Ravi and Balogopalan (1996), Bibah (2014) sprouting and respiration are the main factors that contribute to weight loss in yam tuber.

The effects of the frequency, amplitude and time of vibration on the mean of the weight loss of the yam tuber at the end of storage period are presented in Table 1. The higher the frequency, the less weight loss occurring in both small and large tuber groups (Table 1). Similar results were reported by Lawal et al. (2011) and Imeh et. al. (2012). Lawal et. al. (2011) studied the effects of gamma irradiation at different doses on the yam tubers and reported that the untreated control had the highest weight loss while the tubers irradiated at 80-180 Gy had significantly reduced weight loss. In addition, increasing dose of the gamma irradiation progressively decreased the weight loss of the yam tubers (Imeh et. al., 2012)

Similar to the effects of frequency, vibration amplitude affected weight loss of the yam tubers; the highest weight loss occurred in the control, followed by tubers treated with low, medium and high amplitude ($p < 0.05$, Table 1); and this trend of weight loss occurred in both tuber classes. With the duration of vibration treatment, the result demonstrated that as the time of vibration increases the weight loss of the yam tuber decreases in both tuber glasses (Table 1). Our results agrees with the report of Adegoke and Odebade (2017), Ibrahim et al. (1987) and Schmutterer et al. (1980).

Shrinkage Length of the Yam Tubers

The length of the yam tuber was decreasing over time throughout the storage period. At high frequency, high amplitude and longtime duration the length of the yam tuber did not change throughout the period of storage for both yam tuber classes. This indicates that mechanical vibration can prevent the shrinkage of the yam tuber over time during storage. The maximum value of shrinkage length of the yam tuber recorded at the end of the storage period is 10.5 cm, which was obtained from the control (Table 2).

Table 2 displays result of the effect of the frequency, amplitude and duration of vibration on the shrinkage length of the yam tuber for both tuber classes. The highest length shrinkage occurred in control, followed by low, medium and high frequency, for both tuber groups. The highest magnitude of shrinkage length of the yam tuber occurred at control (7.42 cm), followed by low amplitude (2.64 cm), medium (2.01 cm) and high amplitude (1.28 cm) for the small tuber group, and a similar trend occurred in the large tuber group (Table 2; $p < 0.05$). The result revealed that as the amplitude of vibration increases, the shrinkage length of the yam tuber decreases for both tuber groups. With regards to the effects of duration of the vibration on shrinkage length, similar trends occurred, i.e. as the duration of vibration increases, the shrinkage in tuber length decreases for both tuber groups.

Shrinkage of the Top Diameter of the Yam Tubers After Storage

Tuber shrinkage is one of the main character that changes in tuber yam during storage (Joshua and Hillary, 2019). It was observed that the top diameter of the yam tuber was decreasing over time throughout the storage period, both for the control and the treated tubers. Mechanical vibration significantly prevent the shrinkage of the top diameter of a yam tuber over time during storage period. The maximum value of shrinkage top diameter of the yam tuber recorded at the end of the storage period is 4.1 cm, which was obtained from the control (Table 3). As the frequency of vibration increases, the shrinkage of the top diameter of the yam tuber decreases in both

Table 1. The effects of frequency, amplitude, and time of vibration on the weight loss of the yam tuber

	Weight loss (g) of the yam tubers	
	Small tubers (0.1 – 2.9 kg)	Large tubers (3.0 – 5.0 kg)
Control	600.00 ± 36.83	660.71 ± 31.13
Vibration frequency		
Low (1 – 5 Hz)	305.56 ± 16.09	277.78 ± 11.66
Medium (60 – 100 Hz)	88.88 ± 11.50	116.67 ± 11.50
High (150 – 200 Hz)	50.00 ± 10.42	61.10 ± 9.16
Vibration amplitude		
Low (5 mm)	183.33 ± 16.18	200.00 ± 14.95
Medium (10 mm)	155.55 ± 17.23	144.44 ± 15.04
High (20 mm)	105.56 ± 12.11	111.11 ± 11.32
Vibration duration		
Short (3 minutes)	250.00 ± 13.83	261.11 ± 13.78
Medium (10 minutes)	111.11 ± 14.51	116.67 ± 11.38
Long (15 minutes)	83.33 ± 12.95	77.77 ± 10.56

Note: values are means ± standard deviation

Table 2. The effects of frequency, amplitude and duration of vibration on the shrinkage length of theyam tubers

	Shrinkage length (cm) of the yam tubers	
	Small tubers (0.1 – 2.9 kg)	Large tubers (3.0 – 5.0 kg)
Control (untreated)	7.42± 0.12	6.36 ±0.21
Vibration frequency		
Low (1-5 Hz)	3.90± 0.19	4.30 ±0.22
Medium (60-100 Hz)	1.22 ±0.13	0.83 ±0.07
High (150-200 Hz)	0.81 ±0.08	0.74 ±0.07
Vibration amplitude		
Low (5 mm)	2.64± 0.25	2.51± 0.25
Medium (10 mm)	2.01± 0.19	1.84± 0.21
High (20 mm)	1.28± 0.13	1.52 ±0.18
Vibration duration		
Short (3 minutes)	3.17± 0.20	3.27± 0.28
Medium (10 minutes)	1.61± 0.21	1.38± 0.14
Long (15 minutes)	1.15 ±0.12	1.22± 0.13

Note: values are means ± standard deviation

tuber groups (Table 3). With regards to the effects of amplitude on the shrinkage of the top diameter tuber, similar trends occurred, i.e. as the amplitude of vibration increases, the shrinkage of the top diameter of the yam tuber decreases. For the effect of vibration duration, the highest shrinkage of the top diameter tubers occurred in control (3.14 cm), followed by low (1.76 cm), medium (0.91 cm) and high frequency (0.66 cm) for the small tubers group. The responses of the large tubers was similar to those of the small tubers (Table 3).

Diameter of the Middle Part of Yam Tubers After Storage

It was observed that at high vibration frequency, high amplitude and long duration of vibration, the middle diameter of the yam tuber did not change throughout the period of storage, for both yam tuber classes. Therefore, the mechanical vibration can prevent the middle diameter of a yam tuber not to changein size over time during storage period. The maximum of swollen value of the middle diameter of the yam tuber

Table 3. The effects of frequency, amplitude, and duration of vibration on the shrinkage of the top diameter of the yam tubers

	Shrinkage top diameter (cm) of the yam tubers	
	Small tubers (0.1 – 2.9 kg)	Large tubers (3.0 – 5.0 kg)
Control	3.14 ± 0.13	3.39 ± 0.25
Vibration frequency		
Low (1 – 5 Hz)	2.24 ± 0.08	2.23 ± 0.08
Medium (60 – 100 Hz)	0.65 ± 0.07	0.78 ± 0.09
High (150 – 200 Hz)	0.44 ± 0.05	0.37 ± 0.09
Vibration amplitude		
Low (5 mm)	1.43 ± 0.11	1.40 ± 0.12
Medium (10 mm)	1.11 ± 0.11	1.16 ± 0.12
High (20 mm)	0.79 ± 0.08	0.82 ± 0.09
Vibration duration		
Short (3 minutes)	1.76 ± 0.11	1.58 ± 0.12
Medium (10 minutes)	0.91 ± 0.10	1.16 ± 0.13
Long (15 minutes)	0.66 ± 0.08	0.64 ± 0.07

Note: values are means ± standard deviation

recorded at the end of the storage period is 4.7 cm which was obtained from the control.

Table 4 displays result of the effect of the frequency, amplitude and duration of vibration on the mean of the swollen value of the middle diameter of both yam tuber classes. The highest value of the middle diameter of the yam tuber occurs at control (3.72 cm), followed by low (2.53 cm), medium (0.68 cm) and high frequency (0.56 cm) for small yam tubers. A similar trend occurred with the large tubers.

The highest loss of the middle diameter of the yam tuber occurred at control (3.72 cm) followed by low amplitude (1.63 cm), medium (1.23 cm), and high amplitude (0.91 cm) for the small yam tubers. A similar trend occurred in the large tuber class. The result revealed that as the amplitude of vibration increases, the changes in the middle diameter of the yam tuber decreases. Similar trends occurred with the amplitude and duration of vibration (Table 4).

According to the analysis of variance, there were significance difference ($p < 0.05$) between the low, medium and high levels of frequency, amplitude and time of vibration in affecting the middle diameter of the yam tubers of both classes. There was no significance difference between the two tuber classes with regard to the middle diameter of the yam tubers.

Shrinkage of the Bottom Diameter of the Yam Tubers After Storage

It was observed that the bottom diameter of the yam tubers decrease with time throughout the storage period. At high frequency, high amplitude and high time there was little change in the bottom diameter of the yam tubers of both classes.

The maximum value of shrinkage bottom diameter of the yam tuber recorded at the end of the storage period is 4.5 cm which was obtained from the control (Table 5). The highest shrinkage of the bottom diameter of the yam tuber occurred in control tubers (3.62 cm), followed tubers treated with by low vibration frequency (2.45 cm), medium frequency (0.99 cm), and lastly high frequency (0.48 cm) for the small tuber group. A similar trend occurred in the large tuber class. The result revealed that as the amplitude of vibration increases, the changes in the bottom diameter of the yam tuber decreases. Similar trends occurred with the amplitude and duration of vibration (Table 5).

Table 4. The effects of frequency, amplitude, and time of vibration on the shrinkage of the middle diameter of the yam tubers

	Shrinkage in the middle diameter (cm) of the yam tubers	
	Small tuber (0.1 – 2.9 kg)	Large tubers (3.0 – 5.0 kg)
Control	3.72 ± 0.06	4.04 ± 0.05
Vibration frequency		
Low (1 – 5 Hz)	2.53 ± 0.09	2.64 ± 0.11
Medium (60 – 100 Hz)	0.68 ± 0.07	0.79 ± 0.07
High (150 – 200 Hz)	0.56 ± 0.07	0.48 ± 0.04
Vibration amplitude		
Low (5 mm)	1.63 ± 0.13	1.67 ± 0.13
Medium (10 mm)	1.23 ± 0.12	1.32 ± 0.13
High (20 mm)	0.91 ± 0.09	0.92 ± 0.11
Vibration duration		
Short (3 minutes)	2.00 ± 0.13	1.99 ± 0.14
Medium (10 minutes)	0.99 ± 0.11	1.21 ± 0.12
Long (15 minutes)	0.78 ± 0.08	0.71 ± 0.09

Note: values are means ± standard deviation

Table 5. The effects of frequency, amplitude, and duration of vibration on the shrinkage of bottom diameter of the yam tubers

	Shrinkage in the bottom diameter (cm) of the yam tubers	
	Small tubers (0.1 – 2.9 kg)	Large tubers (3.0 – 5.0 kg)
Control	3.62 ± 0.16	3.90 ± 0.21
Vibration frequency		
Low (1 – 5 Hz)	2.45 ± 0.09	2.36 ± 0.09
Medium (60 – 100 Hz)	0.99 ± 0.09	0.73 ± 0.05
High (150 – 200 Hz)	0.48 ± 0.03	0.46 ± 0.03
Vibration amplitude		
Low (5 mm)	1.59 ± 0.12	1.39 ± 0.12
Medium (10 mm)	1.43 ± 0.12	1.24 ± 0.11
High (20 mm)	0.90 + 0.09	0.92 ± 0.08
Vibration duration		
Short (3 minutes)	2.00 ± 0.12	1.68 ± 0.13
Medium (10 minutes)	1.11 ± 0.11	1.19 ± 0.10
Long (15 minutes)	0.81 ± 0.08	0.68 ± 0.06

Note: values are means ± standard deviation

Figure 1 (A) showed the yam tubers in the first week, the fifth week (B) and the seventh week of storage.

Discussion

Weight loss, shrinkage of length and diameter of the yam tubers occurred during storage. It was found that the increase in the frequency, amplitude and duration of vibration decreased the weight loss, shrinkage length, shrinkage top and bottom diameter and the swell value of middle diameter.

There were significance differences between the low, medium and high levels of frequency, amplitude and duration of vibration for each of physical properties of the yam tubers examined for both groups of yam tuber, and both groups demonstrated similar trends (Figure 4, 4, and 6).

The vibration affects the particles of the yam tubers. It is suggested that at high frequency, amplitude and long duration time would lead to stress to the yam tubers which can lead to secretion of abscisic acid (ABA), the type of hormone that responsible for the inhibition of yam tubers. It is possible that the higher the magnitude of vibration the higher the secretion of the abscisic acid (ABA); which lead to the increase in duration of the dormancy of the yam tubers. Figure 2 (A) presented the view of the unsprouted, slightly and highly sprouted yam tuber at week 10 of the storage, while Figure 2 (B) shown closer view of the unsprouted, slightly and highly sprouted yam tuber on week 10 of storage.

It is important to understand the physical properties of yam tubers and the optimal treatments for the tubers after harvest, and the postharvest handling including transportation and storage, and how these factors affect the quality of the tubers. According to Joshua and Hillary (2019), yam cultivars have different properties and sensitivity to mechanical damages. Further studies should be conducted to other yam cultivars.

Figure 2. Unsprouted, slightly and highly sprouted yam tuber (A), and a closer view of the unsprouted, slightly and highly sprouted yam tuber on the 10th week of storage (B).

Conclusion

The study investigated the vibration technique to control physical properties of yam tubers during storage in the South West Nigeria. The frequency, amplitude, and duration of vibration increased the weight loss, and the middle diameter. The shrinkage of the length, top and bottom diameter of the white yam tuber decrease for both small (0.1 – 2.9 kg) and large (3.0 - 5.0 kg) yam tubers. There were significant difference between the low, medium and high levels of frequency, amplitude and duration of vibration for each of physical properties of both tuber classes. The study has shown that mechanical vibration can slow down the changes of the physical properties of yam tuber during storage.

References

Abewoy, D. (2021). Review on Postharvest Handling Practices of Root and Tuber Crops. *International Journal of Plant Breeding and Crop Science* **8**, 992 – 1000.

Adegoke, G.O., and Odebade, A.O. (2017). Control of browning of yam (Dioscorea rotundata) and sweet potato (*Ipomoea batatas*) using African cardamon (*Aframomum danielli*), turmeric (*Curcuma longa*)and clova (*Syzygium aromaticum*). *Journal of Food Industry* **1**, 52 – 58.

Adeyemi, H. R. Y. (2009). "Comparative Assessment of Some Biochemical Characteristics of Dormant and Sprouting Cultivars of Yam (*Dioscorea spp*.)" [Thesis]. 109 pp. University of Ilorin, Ilorin.

Arteca, R.N. (1996). "Plant Growth Substances: Principles and Applications". 59 pp. Chapman and Hall, New York.

Aschner, M., Guilarte T.R.J., Schneider, S., and Zheng, W. (2007). Manganese: recent advances in understanding its transport and neurotoxicity. *Toxicology and Applied Pharmacology,* **221**, 131 – 147.

Awologbin, E., and Hamadinan, E.I. (2015). Early induction of sprouting on seed tubers of yam (*Dioscorea* spp.) soon after tuber initiation in a hydroponics system. *Experimental Agriculture* **52**, 405 – 417.

Bibah, L. (2014). "Evaluation of the Efficacy of Three Organic Extract in Controlling Storage Rot in Sweet Potato". [Thesis]. 79 pp. Horticulture, Agriculture, Kwame Nkrumah University of Science and Technology, Ghana.

Cheema, M. U. A. (2010). "Dormancy and Sprout Control in Root and Tuber Crops". [Thesis]. 276 pp. Resources Institute, University of Greenwich, United Kingdom.

Davies, P.J. (2010). "The Plant Hormones: Their Nature, Occurrence, and Functions". 59 pp. Department of PlantBiology, Cornell University, Ithaca, New York.

Ganfwar, S., Singh, V.P., Tripathi, D.K., Chauhan, D.K., Prasad, S.M., and Maurya, J.N. (2014). Plant responses to metal stress: the emerging role of plant growth hormones in toxicity alleviation. *Emerging Technologies and Management of Crop Stress Tolerance* **2**, 215 – 248.

Ibrahim, M.H., Williams, J.O., and Abiodun, M.O. (1987). Assessment of parts of neem tree for yam tuber storage. *Nigeria Stored Product Research Institute* **4**, 37 – 41.

Ile, E.I., Craufurd, P.Q., Battey, N.H., and Asiedu, R. (2006). Phases of dormancy in yam tubers (*Dioscorea rotundata*). *Annals of Botany* **97**, 497 – 504.

Imeh, J., Onimisi, M.Y., and Jonah, S.A. (2012). Effect of irradiation on sprouting of water yam (*Dioscorea alata*) using different doses of gamma radiation. *American Journal of Chemistry* **2**, 137 – 141.

Joshua, I., and Hillary, U. (2019). Effects of storage on physical and viscoelastic properties of yam tubers. *Direct Research Journal of Agriculture and Food Science* **7**, 181-191. DOI: https://doi.org/10.5281/zenodo.3262306

Kevers, C., Ovono, P.O., and Dommes, J. (2010). Effects of storage conditions on sprouting of microtubers of yam (*Dioscorea cayenensis – D. rotundata*). *Comptes Rendus Biologies* **333**, 28 – 34.

Lawal, A.O., Akueche, E.C., Anjorin, S.T., Anyanwu, C.E., Harcourt, B.I., Shonowo, O.A., Ogunsola, A., Olasehinde, T.O., and Adesanmi, C.A. (2011). Effects of gamma irradiation on the sprouting, nutritional and phytochemical composition of Meccakusha yam tubers in Abuja, Nigeria. *Journal of Agriculture and Biological Sciences* **2,** 203 – 207.

Nitinkumar, A., Ruiwale, V.V., Nimbalkar, S., and Rao, P. (2014). Design and testing of unbalanced massmechanical vibration exciter. *International Journal of Research in Engineering and Technology* **3**, 107 – 112.

Ravi, V., Aked, J., and Balagopalam, C. (1996). Review ontropical tuber crops: II physiological disorders in freshly stored roots and tubers. *Critical Review in Food Science and Nutrition* **36**, 711 – 731.

Schmutterer, H., Ascher, K.R.S., and Rembold, H. (1980). Natural pesticides from the neem tree *In "*Proceedings of the First Neem Conference". 30 pp. Rottach Egern, German Agency for Technical Cooperation (GTZ). Eadhborn FRG, Germany

Sorth, S., Kone, F.M.T., Binate, S., Dabonne S., and Kouame, L.P. (2015). Nutritional composition and enzyme activities changes occurring in water yam (*Dioscorea alata*) "Brazo" during the post-harvest storage. *International Journal of Food and Nutritional Sciences* **4**, 6 – 12.

Suttle, J.C. (2004). Physiological regulation of potato tuber dormancy. *American Journal of Potato Research* **81**, 253 – 262.

Thao, N.P., Khan, I.R., Thu, N.B.A., Hoang, X.L.T., Asgher, M., Khan, N.A., and Tran, L.P. (2015). Role of ethylene and its cross talk with other signaling molecules in plant responses to heavy metal stress. *Plant Physiology: American Society of Plant Biologists* **169**, 73 – 84.

Tortoe, C., Dowuona, S., and Dziedzoave, N.T. (2015). Determination of sprout control treatment using seven key yam (*Dioscorea* spp.) varieties of farmers in Ghana. *World Journal of Agricultural Research* **3**, 20 – 23.

Vivek, V., Pratibha, R., and Prakash, P.K. (2016). Plant hormone mediated regulation of stress responses. *BMC Plant Biology* **16**, 86 – 96.

Wickham, L.D. (2019). Successful manipulation of the growth cycle of yam (*Dioscorea spp.*) for year– round production for food security and climate change. *Tropical Agriculture* **96**, 27 – 39.