Pathogenicity of fungi associated with yam rot disease of *Dioscorea alata* and their effect on tuber quality

[1,2] Abdulmujib, Y. G. and [2]Aduramigba-Modupe, A. O.*

[1] King Saud University, College of Food and Agriculture, Plant Protection Department;
[2] University of Ibadan, Faculty of Agriculture, Crop Protection and Environmental Biology

ABSTRACT

Many pathogens have been reported to be associated with tuber rots of yam. These reduce the yield and economic value of the crop. A diagnostic probe, including visual and microscopy parameters, was carried out to determine the pathogenicity of fungi associated with tuber rot in *Dioscorea alata* and their effect on yam nutritive value. Thirty-two yam tubers were obtained from the International Institute of Tropical Agriculture (IITA) yam barn in Ibadan. Yam tubers showing various symptoms were selected, and pieces of the diseased portion were taken for isolation using standard procedures. The pathogenicity of the fungal isolates was tested using a tuber inoculation assay. *Aspergillus niger, Aspergillus flavus, Rhizopus stolonifer,* and *lasiodiplodia theobromae* were isolated from rotted yam and they were found to be pathogenic on yam. *Aspergillus niger* and *Lasiodiplodia theobromae* were the most pathogenic among the fungi isolates with 49.91 % and 38.2 % rot severity respectively. The proximate analysis result showed an appreciable reduction in the nutritional composition of infected water yam. The percentage of dry matter composition (88.39 %) was lowest in yam tuber infected by *Rhizopus* sp., this was followed by yam tuber infected by *Aspergillus niger*. *A. niger* and *L. theobromae* also affected the quality and nutrient composition of yam. The study highlights the significant impact of fungal pathogens on tuber rot in *Dioscorea alata* (water yam), with *Aspergillus niger* and *Lasiodiplodia theobromae* being the most pathogenic. This study showed that these fungi are not only responsible for rot in yam tubers but can also cause a significant decrease in the nutritional composition and quality of yam tubers. Therefore, understanding the impact of these pathogens is crucial for developing effective management strategies to protect crop yield and economic value.

Key words: *Aspergillus niger*, *Lasiodiplodia theobromae*, Proximate analysis, Tuber quality, Yam rot

Corresponding author: fyaduramigba@yahoo.com

INTRODUCTION

Yams (*Dioscorea* spp.) are members of the Dioscoreaceae family. It is a tuber crop that is one of the world's most essential staple foods, especially in the tropics and subtropics (Okigbo and Ogbonna, 2006). It is impossible to overstate the importance of yams in the food economy of most West African countries. It is one of the most important sources of nutritional energy produced in the tropics. After harvest and storage, the average profit per seed yam was projected to be over US$13 000 per hectare harvested, and over 70% of Nigerians farm yams as a primary source of income (IITA, 2013, Wumbei *et al.*, 2022).

There are hundreds of *Dioscorea spp,* both wild and domesticated. *D. rotundata,* white yam, is the most important species, particularly in the dominant yam production zones of West and Central Africa. Like the yellow yam, *D. cayenensis*, is native to West Africa. The second most farmed species, *D. alata*, is the world's most extensively spread species, having originated in Asia. West and Central Africa account for roughly 94% of global yam production (FAOSTAT, 2021). Wumbei *et al.* (2022), with Nigeria being the leading producer (IITA, 2007; Azeteh *et al.*, 2019). Even the United Nations has expressed worry over post-harvest storage losses, stating that further reduction of post-harvest food losses in developing countries should be addressed. This is necessary as food losses after harvest are a major source of food insecurity in Africa (AMCOST, 2006; Totobesola *et al.*, 2022).

Several ways for storing yams after harvesting have been developed. Despite its shortcomings, however, the traditional yam barn remains the most popular yam storage method among farmers. Although losses of up to 50% of fresh matter are possible (Amusa *et al.*, 2003; Nyadanu *et al.*, 2014). Mechanical damage and poor handling during and after harvest are the main reasons for yam tuber loss during storage. Physiological changes within the tuber, as well as microorganism-caused storage rots, are also significant factors. Weight loss, mechanical damage, discoloration, and shriveling are all signs of yam tuber loss during storage, rendering it unfit for ingestion.

Postharvest losses account for roughly 40% of valuable yam stock (Awuah and Akrasi, 2007; Olayemi *et al.,* 2012; Stathers *et al.,* 2020), and rots caused by microbial infection diminish table quality and make healthy tubers unpalatable to consumers (Amusa, 1999). In the tropics, where the temperature and humidity are high, microbial infestation and the spread of rots are severe. *Aspergillus flavus*, *A. niger*, *A. tamari*, *Botryodiplodia theobromae*, *Cladosporium herbarium*, *C. sphaerospermum*, and *Cylindrocarpon radiocola* are the representative fungal (Aduramigba *et al.*, 2010) and bacterial pathogens implicated in the development and spread of rots., Representative spoilage bacteria include *Corynebacterium* spp., *Serratia* spp., and *Erwinia* spp. (Okigbo, 2004).

Diseases are responsible for 25% of yam post-harvest losses in storage (Ikotun, 1989), which could ultimately amount to about 80 % annually (Mabou *et al.*, 2020). Insects, nematodes, and poor handling allow fungal infections to enter tubers through wounds (Amusa *et al.*, 2003). Known to be quite common and highly pathogenic are the three common genera of *Lasiodiplodia*, *Fusarium*, and *Penicillium* (Noon, 1978, Adeniji *et al.*, 2020). *Fusarium* species, the most frequent of which are *Fusarium oxysporium* and *Fusarium solanii*, produce the rots (Nwankiti, and Arene, 1978). *Penicillium oxalicum*, one of the well-studied rot-associated fungi, can grow on top of the bark, whereas *Lasiodiplodia theobromae*, the most prevalent, was the first parasitic fungus related to tuber rot (Aderiye and Ogundana 1984).

Yams are highly prized food crops that are high in carbs, vitamins, and dietary fibers (Ekefan *et al.*, 1999; Ogaraku and Usman, 2008), as well as in therapeutic qualities for the treatment of diabetes and hypercholesterolemia (Okigbo and Ogbonna, 2006). Yam can be eaten boiled, fried, or roasted, and in yam pastes and a few confectioneries. Yam is also grown in Nigeria as a variety of staples that are processed into intermediate end products for direct intake by animals (Okaka *et al.*, 1991), as well as basic ingredients for snacks and flour. Yam is rich in alkaloid content that confers special medicinal properties on yam. Yam produces antioxidants that may assist in inflammation reduction (Bantilan, 2019). Rots degrade the quality of yam tubers, rendering them undesirable to customers (Raphael *et al.*, 2015.). In Nigeria, yam storage losses are high, largely due to rot, as a result, demand for yam tubers has consistently outstripped supply (FAO, 1998). In Nigeria, more than half of the yam tubers grown and harvested are lost in storage.

It is therefore necessary to confirm the current prevalence of fungi associated with yam tuber rot and to determine their effect on nutritional quality. Therefore, this work aimed to identify the pathogens that are associated with the tuber rot of water yam during storage and establish their impact on the nutrient composition of tubers.

MATERIALS AND METHODS

Source of yam tubers

Thirty-two yam tubers showing symptoms of both dry and soft rot were obtained from the International Institute of Tropical Agriculture, Ibadan, Nigeria, and the tubers were taken to the Pathology Laboratory of the University of Ibadan, Nigeria, for isolation and identification of associated myco-pathogens.

Examination of yam tubers for classification of rot

Rot was hand felt, visualized under a stereo microscope for detailed examination, and categorized as dry or soft rot. Soft rots are observed as squashy and ramified by the fungal mycelium. Dry rots are categorized when infected tissues are hard, disfigured, and with various colorations (Amusa *et al*., 2003). Percentage rot severity was estimated as the proportion (by weight) of the rotted portion to the whole tuber without the rot portion, using the following equation:

$$\%\ Rot\ severity = \frac{Weight\ of\ Rotted\ portion}{Weight\ of\ whole\ tuber} \times 100$$

Isolation and identification of fungi

The part of the yam tissue showing different symptoms (5-7 mm) was cut out with a sterile sharp knife and placed on small plastic bowls. A small slice of yam tissue, encompassing the expanding boundary of rot and neighboring healthy tissue, was cut and surface-sterilized with 1.5% sodium hypochlorite. Each surface-sterilized sample was rinsed in three changes of sterile distilled water and allowed to air dry before being transferred onto the already prepared Potato Dextrose Agar plates for inoculation under the inoculating chamber. On each plate, three peeled sections were arranged with an equal distance between them and were incubated at 28 °C for 5-7 days. The identification of isolates was done by examining them macroscopically and microscopically. The colony characteristics, spores, mycelium, and conidia were observed. The fungal pathogen was identified using the illustration chart of Barnet and Hunter (1998).

Pathogenicity test

Healthy whole yam tubers were collected, and the initial weight of each tuber was determined. The yam tubers were rinsed with distilled water and surface sterilized for one minute using a 1% sodium hypochlorite solution. Sterilized whole yam tubers were inoculated according to the method described by Sangoyomi (2004). A 6 mm diameter cork borer was driven to a depth of about 10 mm into the yam tubers to create wounds on the yam. Agar blocks of mycelium from the culture of the isolate were deposited into the wound and covered with the tissue that was removed with the aid of the cork borer. The inoculated tubers were enclosed in a polythene bag, few drops of sterile distilled water were introduced into the bag to increase the relative humidity of the environment. The bags were kept and watched for 14 days. At the end of the inoculation period, inoculated tubers were sliced at the points of inoculation and assessed for the presence or absence of rots. Mycelia and spores from the tuber were surface-scraped onto prepared PDA, and the different fungi that were re-isolated were compared with the original isolates.

Proximate analysis

Proximate composition analysis (AOAC, 2005) was conducted to determine the Moisture Content, Crude Protein, Crude Fat, Ash Content, and Crude Fiber to establish the nutritive components of healthy yam and rotten yam tuber. Data collected were subjected to analysis of variance, while means were separated using Duncan's Multiple Range Test at a 5% significance level.

RESULTS AND DISCUSSION

Fungi identified from infected yam samples

Four fungi species were identified from infected yam tuber samples. The fungal isolates were *Aspergillus niger, Aspergillus flavus, Rhizopus stolonifer, and Lasiodiplodia theobromae*. The morphological and cultural characteristics of the fungi were observed. The culture of *A. flavus* was yellowish to light green. *Aspergillus niger* had a dark-greyish mycelial growth. *Rhizopus* formed a white woolly mycelium, and *L. theobromae* grew as a spongy white culture at three days old, but gradually turned black (Table 1). Their frequency of occurrence is presented in Figure 1.

Table 1. Cultural and microscopic characteristics of fungal isolates

Fungal isolates	Colony description	Body view under the microscope
Aspergillus niger	Colonies are blackish brown in the culture plate	Conidiophores are rough-like and non-septate, and arise from a thick-walled foot cell
Aspergillus flavus	Brownish green color surrounded by a hallow	Conidiophore is non-septate and arises from a thick-walled foot cell. Conidiophores are smooth and colorless
Rhizopus stolonifera	The whitish woolly appearance that grows rapidly	Sporangiophore extends from an elongated stolon and ends with a spherical, black-colored sporangium
Lasiodiplodia theobromae	The culture was spongy white at 3 days old, but gradually turned black	Conidia are dark brown with longitudinal striation, with an observation central septum

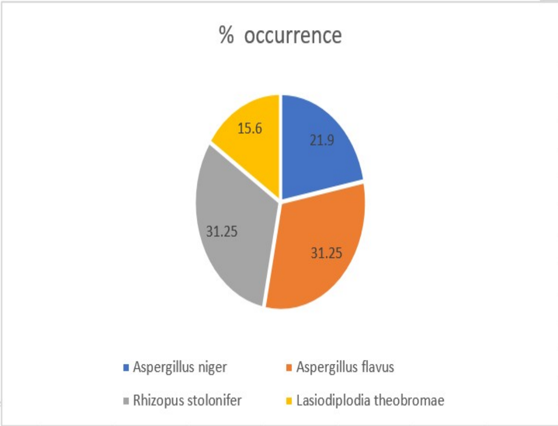

Figure 1: Frequency of occurrence of fungi isolated from infected yam tubers

Pathogenicity of the isolates on yam tubers

The result of the pathogenicity test showed that, at room temperature and high relative humidity, all tested fungi were pathogenic on *Dioscorea alata* (Tables 2 and 3). The rot symptoms caused by *A. niger* were soft and pinkish. *Aspergillus flavus* caused brownish soft rot symptoms, *R. stolonifer* caused pinkish-brown soft rot symptoms, and *Lasiodiplodia theobromae* caused soft rot with a dirty black color. *Aspergillus niger* and *Lasiodiplodia theobromae* were the most pathogenic among the fungi isolated. They reduced tuber weight by 22.5% and 17.5%, respectively. This was followed by *A. flavus,* causing a weight reduction of 12.5%. The least pathogenic isolate was *R. stolonifer* with only a 10% reduction in tuber weight (Table 4).

Table 2. Effect of inoculated fungi on yam tuber rot at room temperature

Fungi	Size of rot (cm)
Aspergillus niger	2.7 ± 0.16 a
Aspergillus flavus	1.9 ± 0.09 bc
Rhizopus stolonifer	1.7 ± 0.04 c
Lasiodiplodia theobromae	2.1 ± 0.05 b
Control	No visible rot

Real means ± standard error of real means (Tukey's HSD where $p \leq 0.05$). Means within the same column followed by the same letters are not significantly different at $p \leq 0.05$.

Table 3. The severity of damage caused by fungi isolate on healthy yam tubers

Fungi	Damage (%)
Aspergillus niger	49.91
Aspergillus flavus	30.2
Rhizopus stolonifer	29.31
Lasiodiplodia theobromae	38.2
Control	0.0

Table 4. Effect of isolated fungi on the weight of yam tubers

Fungi	Weight reduction (%)
Aspergillus niger	22.5
Aspergillus flavus	12.5
Rhizopus stolonifer	10.0
Lasiodiplodia theobromae	17.5
Control	0.0

Proximate analysis

The proximate analysis showed that uninoculated, healthy yam had the highest percentage for all compositional nutrients and dry matter measured in this study. The percentage composition of dry matter was lowest in yam tuber inoculated with *R. stolonifer,* with 88.39%; yam tuber inoculated with *A. flavus* had the highest percentage composition of dry matter. The result of the nutritional composition analysis is presented in Table 5. The current study revealed that active storage rot of yams is caused by *Aspergillus niger, Aspergillus flavus, Rhizopus stolonifer, and Lasiodiplodia theobromae*. These fungal isolates have been previously associated with tuber rots of yams in storage (Gwa *et al*., 2018; Mabou *et al*., 2020). All the fungi isolates were able to cause the same symptoms that were observed on the diseased yam from which they were isolated. This observation was corroborated by the work of Gwa *et al.* (2017), who also isolated fungi from yams in Nigeria. This shows that these fungi are important agents in post-harvest losses of yam during storage.

Fewer fungal species were isolated in the current study compared to the report of Ogunleye and Ayansola, (2014). This may be a result of the differences in storage methods used for the sources from which the two sets were collected. The yams used in this study were collected from the yam barn of IITA, while the yams used by Ogunleye and Ayansola, (2014) were collected from an open market store. This implies that the storage method for yams may be a factor in incidents of storage infection. Also, the yams collected for the current study were stored yams, with reduced moisture content (due to storage duration), compared to freshly harvested yams. This may also be a reason for the lower number of microflora encountered in the study. Low moisture content has been suggested as a requirement for storage when long-term holding is intended (Fauziah *et al*., 2020). Thus, it could be suggested that the moisture content of yams should be reduced before subjecting them to long-term storage. Also, further work is required to establish the correlation between moisture content and the number of fungal organisms associated with the rot of yam tubers in storage.

Table 5. Proximate composition of healthy and infected yam tubers

Treatment	%CP	%ASH	%EE	%CF	%DM
Control	4.55±0.05a	4.00±0.03a	0.50±0.05a	1.50±0.03a	90.12±0.39a
Rhizopus stolonifer	3.50±0.02c	3.00±0.04b	0.30±0.05a	1.00±0.03b	88.39±0.41b
Aspergillus flavus	2.45±0.04b	3.00±0.02b	0.40±0.04a	1.00±0.01b	90.06±0.25b
Lasiodiplodia theobromae	2.46±0.04b	2.00±0.02b	0.30±0.01a	1.10±0.02b	89.91±0.32b
Aspergillus niger	3.52±0.03c	3.00±0.03b	0.40±0.02a	1.20±0.02b	89.54±0.22b

Means followed by the same letter within a column are not significantly different at $p \leq 0.05$ using Duncan's multiple range test; numbers of replicates = 3. (CP=Crude protein, EE=ether extract, CF=Crude fibre, DM=Dry matter)

The organism associated with the rot of water yam in this study were *Aspergillus niger, Aspergillus flavus, Rhizopus spp., and Lasiodiplodia theobromae*. These fungi have been associated with post-harvest rots (Okigbo, 2004; Adeniji *et al*., 2020). *Aspergillus flavus* and *Rhizopus stolonifera* have the highest frequency of occurrence, and this is in line with the previous works of Ogunleye and Ayansola (2014). The pathogenicity capacity of fungal isolates significantly differed ($p \leq 0.05$) after re-inoculation of healthy yam tubers (Table 2). *Aspergillus niger* showed the highest pathogenicity, followed by *Lasiodiplodia theobromae* causing lesions ranging from 2.7 to 2.1 cm in diameter 14 days after inoculation. Rot in storage, most likely, begins in the soil and proceeds during storage. Microorganisms enter yams through natural holes and wounds that occur during harvesting and transportation from the field to the storage barn (Gao *et al*., 2023).

The proximate composition result showed that the crude protein, crude fibre, and dry matter components of the yam tubers are affected by the isolates. Significant reduction is observed in the infected yams except for the ether extract. The proximate composition of the current study reveals that the nutritional composition of yam can be compromised upon infection, and this effect continues during storage. Similar outcomes have been previously noted, particularly in the work of Eneogwe *et al* (2022). Rot severity varied depending on the isolated myco-pathogens. Fungi were found to be responsible for more than 60% of all yam tuber rots in Nigeria, according to Ikotun (1989), and about thirty distinct fungi were isolated from preserved yams. These findings were comparable to those of Agbejule *et al* (2017), Shiriki *et al* (2015) and Amusa and Baiyewu (1999), who identified *Aspergillus, Penicillium*, and *Rhizopus* as rot pathogens associated with stored and marketed yam tubers from Southwestern Nigeria's tropical forest zone. These findings corroborate those of Adeniji (1970), and Ikotun (1989) who identified *Aspergillus niger* and *Lasidioplodia theobromae* as the cause of severe yam degradation in Nigeria.

CONCLUSION

Aspergillus niger, Aspergillus flavus, Rhizopus spp., and Lasiodiplodia theobromae were identified as rot-associated pathogens in this study, the pathogens invade yam tissues, causing decolorization and lesions along the site of infection. These infections significantly impaired the quality and nutrient composition of yams. It is, therefore, essential to develop safe and accessible control measures specific to these rot pathogens. Also, understanding the pathogenicity of these fungi and implementing effective control measures are crucial for maintaining yam tuber quality.

REFERENCES

Adeniji, A., Taiga, A. and Ayodele, M. S. 2020. Comparative studies on the susceptibility of three tubers of Dioscorea species to dry rot in Anyigba, Kogi State. *International Annals of Science*, 8(1): 70-74.

Adeniji, M. O. 1970. Fungi associated with storage decay of Yam in Nigeria. *Phytopathology*, 60(4): 590-592.

Aderiye, B. I., and Ogundana, S. K. 1984. Survival of *Botryodiplodia theobromae* in yam tissues. In *Tropical root crops: production and uses in Africa: proceedings of the Second Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held in Douala, Cameroon, 14-19 Aug. 1983*. IDRC, Ottawa, ON, CA.

Agbejule, A. A., Aduramigba-Modupe A. O. and Sangoyomi, T. E. 2017. Evaluation of plant extracts for the control of post-harvest fungal spoilage of yam tubers

(*Dioscorea rotundata* Poir.) *African Journal of Root and Tuber Crops* V13 (1): 20 – 28.

AMCOST 2006. Technologies to reduce post-harvest food loss The African Ministerial Council on Science and Technology (AMCOST) of the African Union (AU), Pretoria, South Africa, From http://www.nepadst.org/platforms/foodloss.shtml.

Amusa, N. A., Adegbite, A. A., Muhammed, S. and Baiyewu, R. A. (2003). Yam diseases and their management in Nigeria. *African Journal of Biotechnology*, 2(12): 497-502.

Amusa, N. A., and Baiyewu, R. A. 1999. Storage and market disease of yam tubers in southwestern Nigeria. *Ogun Journal of Agriculture Research*, 11: 211-225.

AOAC. 2005. Official methods of analysis of the Association of Analytical Chemists International. *OfficialMethods: Gaithersburg, MD, USA.*

Awuah, R. T. and Akrasi, K. O. 2007. Suppression of tuber rot of yam caused by *Aspergillus niger* with a Yam Rhizobacterium. In *Proceedings of the 8th African Crop Science Society Conference* (8: 875-879).

Azeteh, I. N., Hanna, R., Sakwe, P. N., Njukeng, A. P. and Kumar, P. L. 2019. Yam (*Dioscorea* spp.) production trends in Cameroon: A review. *Afr. J. Agric. Res*, 14(26): 1097-1110.

Bantilan, C. 2019. Nutrition. 11 health and nutrition benefits of yams. *Healthline Media, Inc.: New York, NY, USA.*

Barnett, H. and Hunter, B. 1998. Illustrated genera of imperfect fungi. 4th Edition, 2nd printing. *American Phytopathological society press,* St. Paul, Minnesota. 218 pp.

Ekefan, E. J., Simon, S. A., Nwankiti, A. O., and Peter, J. C. 1999. Effect of intercropping on the incidence of foliar anthracnose and tuber yield of susceptible *Dioscorea alata*; yam in Nigeria. *J. Plant Protec. in the Tropics*, 12(2): 80-90.

Eneogwe, G. O., Ibrahim I. E. and Obuye, F. 2022. Proximate Composition, Levels of Some Essential Mineral Elements and Anti-Nutritional Components of Some Yam Species Found in Minna, Niger State. *Biology, Medicine, and Natural Product Chemistry*, 12(1): 9-16.

FAOSTAT. 2021. Food and Agriculture Organization of the United Nations. FAOSTAT Statistical Database. Rome. Available at: https://fao.org/faostat/en/#compare (assessed October 15, 2022).

Fauziah, F., Mas' udah, S., Hapsari, L. and Nurfadilah, S., 2020. Biochemical composition and nutritional value of fresh tuber of water yam (Dioscorea alata L.) local accessions from East Java, Indonesia. *AGRIVITA, Journal of Agricultural Science*, 42(2): 255-271.

Food and Agriculture Organisation. (1998). FAOSTAT Agriculture Database – Agriculture Production crops Primary, Fao@www.fao.org.

Frank, C. O. and Kingsley, C. A., 2014. Role of Fungal rots in post-harvest storage losses in some Nigerian varieties of Dioscorea species. *British Microbiology Research Journal*, 4(3):.343-350.

Gao, J., Hu, X., Xiao, R., Luo, F., Tang, Y., Luo, J., and Guo, M. 2023. The microbiome and typical pathogen multiplication, qualities changes of baoxing yam at different storage temperatures. *LWT*, *188*, 115402.

Gwa, V. I., Ekefan, E. J. and Nwankiti, A. O. 2017. Antifungal Potency of Some Plant Extracts in the Control of White Yam (*Dioscorea rotundata* Poir) Tuber Rot. *Adv Biotech and Micro*, 7(1): 555703.

Gwa, V. I., Nwankiti, A. O. and Hamzat, O. T. H. 2018. Antimicrobial activity of five plant extracts and synthetic fungicide in the management of postharvest pathogens of yam (*Dioscorea rotundata* Poir) in storage. *Acad. J. Agric. Res*, 6(6): 165-175.

IITA 2007. Yam. Research Review. International Institute of Tropical Agriculture, Ibadan, Nigeria. Pp.1-4.

IITA 2013. Healthy yam seed production. IITA Publications.

Ikotun, T. 1989. Diseases of Yam tubers. *Int. J. Trops plants Dis.* 7: 1 – 21.

Mabou, L. C. N., Sameza, M. L., Tchameni, S. N., Eke, P., Toghueo, R. M. K., Albertini, A., and Boyom, F. F. (2020). Molecular Identification of Fungal Pathogens Associated with Post-harvest Yam Tubers Rot in Mbam et Kim Division (Cameroon) with Emphasis on *Penicillium monomenatosum* (Frisvad, Filt. & Wicklow) as a First Report. *American Journal of Microbiological Research*, *8*(2), 73-78.

Noon, R. A. (1978). Storage and market diseases of yams. *Tropical Science*. 20(3): 177-188

Nwankiti, A. O., and Arene, O. B. (1978). Diseases of yam in Nigeria. *Pans*, *24*(4), 486-494.

Nyadanu, D., Dabah, H., and Agyekum, A. D. (2014). Resistance to post-harvest microbial rot in yam: integration of genotype and storage methods. *African Crop Science Journal*, *22*(2), 89-95.

Ogaraku, A. O., and Usman, H. O. (2008). Storage Rot of Some Yams (*Dioscorea* spp) in Keffi and Environs, Nasarawa State, Nigeria. *Patnsuk J*, *4*(2), 22-27.

Ogunleye, A. O., and Ayansola, O. T. (2014). Studies of some isolated rot-causing mycoflora of yams. *Am. J. Microbiol. Biotechnol*, *1*(1), 9-20.

Okaka, J. C., Okorie, P. A. and Ozo, O. N. 1991. Quality evaluation of sun-dried yam chips. *Tropical science*, 31(3): 265-275.

Okigbo, R. N. 2004. A review of biological control methods for post-harvest yams (*Dioscorea* spp.) in storage in South-Eastern Nigeria. *Current Applied Science and Technology*, 4(1): 207-215.

Okigbo, R. N. and Ogbonnaya, U. O. 2006. Antifungal effects of two tropical plant leaf extracts (*Ocimum gratissimum* and *Aframomum melegueta*) on postharvest yam (*Dioscorea* spp.) rot. *African Journal of Biotechnology*, 5: 727-731.

Olayemi, F. F., Adegbola, J. A., Bamishaiye, E. I. and Awagu, E. F. 2012. Assessment of post harvest losses of some selected crops in eight local government areas of rivers state, Nigeria. *Asian journal of rural development*, 2(1): 13-23.

Raphael, O. N., Ebere, E. C., Kingsley, A. C., Chidiebere, I. R., Chidi, O. B., Nsikak, A. S. and Confidence, I. A. 2015. Control of white yam (Dioscorea rotundata) rot pathogen using peel extract of water yam (Dioscorea alata). *Advances in Applied Science Research*, 6(10): 7-13.

Sangoyomi, T. E. 2004. Post-Harvest Fungal Deterioration of Yam (*Dioscorea rotundata*. Poir) and Its Control. PhD Thesis, IITA, Ibadan, Nigeria, 179 p.

Shiriki, D., Ubwa, S. T. and Shambe, T. 2015. Isolation of nine microorganisms from rotten Dioscorea rotundata (white yam) and antimicrobial sensitivity test with five plant extracts. *Food and Nutrition Sciences*, 6(10): 825.

Stathers, T., Holcroft, D., Kitinoja, L., Mvumi, B. M., English, A., Omotilewa, O. and Torero, M. 2020. A scoping review of interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia. *Nature Sustainability*, 3(10): 821-835.

Totobesola, M., Delve, R., Nkundimana, J. D. A., Cini, L., Gianfelici, F., Mvumi, B. and Rolle, R. S. 2022. A holistic approach to food loss reduction in Africa: food loss analysis, integrated capacity development and policy implications. *Food Security*, 14(6): 1401-1415.

Wumbei, A., Kengirir, S., Gautiei, N., Kwodanga, J. K., Joseph, D. F. and Galani, Y. J. A. 2022. State of the art of yam production. In: Kaushi P, editor. Advances in root and vegetable research. IntechOpen. DOI: https://doi.org/10.5772/intechopen.106504.