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Influence of Fertilizer on the Colour and Starch Properties of Yam (*Dioscorea* spp) Tuber

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Authors' contributions

This work was carried out in collaboration among all authors. Author AF designed the study, performed the data collection, statistical analysis, managed literature searches and wrote the draft of the manuscript. Author AB designed the study, supervised the study and made reviews and corrections in the manuscript. Author OB designed and supervised the study. All authors read and approved the final manuscript.

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ABSTRACT

Yam is a tuber crop grown for food security, cultural value and income generation. Due to its high nutrient-demanding nature, soil fertility is required for its cultivation. fertilizer is a crucial agronomic factor in yam production, Still, yam farmers are skeptical about fertilizer usage because of their fear of it exerting poor qualities on yam tubers. Limited information on the effect of fertilizer on yam tuber quality is available.

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Four varieties each of *Dioscorea rotundata* (TDr9518544, Danacha, Hembakwase and Ojuiyawo) and *Dioscorea alata* (TDa291, TDa0200012, TDa0000194 and TDa9801176) were cultivated under non-fertilization, manure fertilizer (4.5t ha-^{1} poultry manure) and NPK fertilizer (90, 50 and 75 Kg N, P, K ha^{-1}). The field experiment was conducted in the International Institute of Tropical Agriculture, Ibadan, Nigeria, in the 2017 and 2018 cropping seasons. The harvested tubers were evaluated for colour indices (L, a*, b* and browning index) and starch properties (starch yield, amylose and amylopectin, starch granule size and shape). Data obtained was subjected to analysis of variance using Statistical Analysis System software (SAS) package and means were separated using Duncan multiple range test with a probability of $p \le 0.05$.

Fertilizer did not cause browning or any significant change in the colour indices of the tuber flesh. starch yield (18.83 to 28.3%), increase in amylose was observed in *D. rotundata* in the order; manure>NPK>control with manure having 92.66% and NPK 40.2% increase. Fertilizer had no significant effect on the granule size and shapes of the starches.

Hence, fertilizer, especially manure and NPK, should be used to cultivate yam on nutrient-depleted soil without detrimental tuber colour and starch.

Keywords: Yam; fertilizer; starch; colour.

1. INTRODUCTION

Yam belongs to the genus *Dioscorea*. It is a multi-species plant which bear tubers annually. Only six of the diverse species are economically important in terms of food and medicine (Padhan and Panda 2011). The white yam *(Dioscorea rotundata*) and water yam (*Dioscorea alata*) are the most widely cultivated species with more economic value in West Africa (Norman and Tongoona 2011). Yam is a major starchy staple with high economic, nutritional and cultural importance for millions of people in the tropics (Asiedu and Sartie 2010). It plays a significant role in ensuring food security in sub-Saharan Africa where a growing population is a vital issue (O'Sullivan 2010). Yam tuber is the major part of the plant that is consumed. It can be boiled, fried or roasted. Boiled yam is pounded into a sticky and elastic dough usually eaten with vegetable soup (Baah et al. 2009). Also, fresh tubers are processed into flour which is prepared in boiling water to form a thick paste and eaten with soup (Akinwande et al. 2014). Aside from being a staple food source, yam starch is an important component of yam tuber which is used for arrays of food and industrial applications (Otegbayo 2014).

Yam starch makes up 60-80% of the dry matter of yam tuber (on a dry basis) and has been identified as a key factor in determining the physicochemical, rheological and textural characteristics of food products derived from different yam species (Zhu 2015). Starch has been utilized as a food ingredient in the food industry to regulate the structure and texture of a variety of food products (Astuti et al. 2018).

Despite the diverse forms of yam utilization, its productivity in West Africa is unfortunately going low and has remained stagnant over decades (Alabi et al. 2019). The low productivity is ascribed to soil infertility due to shortened fallowed periods (Adegbenro et al. 2013) as this method is being threatened by the increase in demand of land for non-agricultural purposes and land degradation. This has called for alternative ways of improving and maintaining soil fertility to enhance yam productivity.

Among the diverse ways of restoring *D. alata* and maintaining soil fertility for crop improvement and yield is using fertilizer, a common external source of nutrients for crop production among farmers (Ogboru and Ayeni 2015). Diby et al. (2009) illustrated the significance of soil fertility for yam production when varieties grown under no fertilizer and fertilizer conditions were compared. Unfortunately, yam farmers are skeptical about the adoption of its usage because of the belief that it exerts negative effects on the tuber such as browning of the surface of the tuber flesh when cut, poor textural properties of yam product which is influenced by the starch content of the tuber.

Several research efforts have been geared toward improving yam tuber yield with the use of inorganic and organic fertilizers (Akom et al. 2015, Tiama et al. 2018). However, there has not been an indept study on the effect of fertilizer on the quality of yam tuber colour and starch. It is possible to have an increase in tuber yield with subsequent decrease in its tuber quality. This study aimed at evaluating the effect of NPK and poultry manure on the colour of yam tuber and the quality of its starch.

2. MATERIAL AND METHODS

2.1 Planting Material and Sample Preparation

Four varieties of *Dioscorea rotundata* (TDr9518544, Danacha, Hembakwase and Ojuiyawo) and four varieties of *Dioscorea alata* (TDa291, TD0200012, TDa0000194 and TDa9801176) were planted and harvested in 2017 and 2018 cropping seasons (April to January) at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Three different fertilizer applications (Chemical fertilizer, (N:P:K= 90:50:75 kg ha^{-1}) poultry manure of 4.5 t ha^{-1} and no fertilizer as control).

Two tubers from each replication of the variety were used. To prevent variation in composition along the tuber sections (anisotropic effect), about 5 cm each of proximal and distal ends of the tubers were cut off and the middle portions left of all tubers were used.

2.2 Starch Extraction and Starch Yield Determination

Peeled yam tubers (100 g) were grated and homogenized in a food blender with 10 ml of water for 15 sec then it was sieved using a sieve (180 µm mesh screen) and 3 L of water. It was left to settle and the supernatant was decanted leaving the slurry. Soluble impurities were removed by further stirring of the starch with distilled water, settling and decantation of the supernatant. This procedure was repeated till the supernatant was like the distilled water in clarity. The resulting starch slurry was air-dried at room temperature, milled and packed into ziplock bags. Starch yield was calculated as the percentage of dried starch to the weight of the grated tuber.

2.3 Colour Indices

Three tubers each of variety and replication were used to determine the colour. Colour of the tuber flesh was determined using a Konica Minolta Chroma meter (CR-400 Konica Minolta, INC Japan). The device was calibrated with a reference white porcelain tile (L* = 86.2, a* = 0.31 and b* = 0.32) before the determinations. Colour of the tuber flesh was described in L* a* b* notation, where L* is a measure of lightness, a* defines components on the red-green axis and b* defines components on the yellow-blue axis. All determinations were done in triplicates.

For the determination of the browning index, the L*a*b* values of the flesh of freshly peeled yam tuber at 0 min (L_0). Measurement was taken again after 30 min (L_1). All determinations were done in triplicates. From the data obtained, the browning index (BI) was calculated using the formula of Hunt (Babajide et al. 2006).

$$BI=(100-L_1) - (100-L_0) \qquad (2.1)$$

2.4 Starch Properties of Tuber

2.4.1 Determination of amylose and amylopectin

The determination of the amylose content of yam starch samples was carried out by modifying the method of (Kaufman et al. 2015). Yam starch of 5 mg was weighed in eppendorf tube and 1 ml of 90% DMSO (dimethyl sulfoxide) was added to it. The solution was heated for 1 h at 95 ºC to? completely disperse the starch (vortexed at 0,5,30,45 and 60 min). Aliquot of 100 µL of starch solution was pipetted into microplate and 100 µL of iodine was added to it after which it was stirred for 2 min using a thermoshaker (1000 rpm). Starch- iodine solution of 20 µL was pipetted into new microplate and 180 µL of deionised water was added to each well in the microplate. It was stirred on a thermoshaker for 1 min. The concentration of amylose in the starch sample was then read on a microplate reader (Chromate 4300 Awareness Technology INC) at 620 nm and 505 nm. Calibration curve was obtained with a standard amylose solution (amylose: A0512 amylose from potato). A regression equation was determined for the standard curve on each plate analyzed using both the absorbance value at 620 nm and the Diff ABS (ABS620 − ABS510). Amylose and amylopectin was then calculated using the formulae in equations 2.2 and 2.3, respectively.

$$\% \text{ Amylose} = \frac{\text{Absorbance} - \text{Intercept}}{\text{slope}} \qquad (2.2)$$

$$\% \text{ Amylopectin} = 100 - \% \text{ amylose} \qquad (2.3)$$

2.4.2 Determination of starch granule morphology

The size and shape of starch granules were obtained from extracted yam starch samples. A small amount of starch powder was scooped with a spatula onto a clean micro-slide (75 x 25 mm). A drop of diluted safranin solution was added and distributed thinly on the slide and covered with a slip. Starch granules were observed under a light microscope (Olympus DP12 BX 51, U-PMTVC, Japan) and sizes were determined by measuring the granule diameter with an ocular micrometer fixed to the lens of the microscope. The actual sizes of the granules were calculated by multiplying their mean diameters by a factor of 2.5 µm (i. e. the factor for objective magnification that was used) which was calculated earlier using the parallax obtained between a stage micrometer and the calibrations of the eyepiece. A minimum of 50 granules were selected randomly and measured for each replicate of a variety. The observation was done under x 400 magnification.

2.5 Statistical Analysis

Data obtained were analyzed using Statistical Analysis System software (SAS) package (version 9.4 of SAS institute INC, 2012). Analysis of variance (ANOVA) was done by the General Linear Model (GLM) procedure and means were separated using Duncan multiple range test with a probability of $p \leq 0.05$

3. RESULTS AND DISCUSSION

3.1 Colour of Yam Tuber

The results for the colour of the tuber flesh is presented in Table 1. The L* value, which is an indication of lightness or whiteness, ranged between 72.86 to 84. The whiteness of tuber flesh was not significantly affected by fertilizer treatments TDa0200012 treated with NPK which was whiter than the same that was treated with manure and without fertilizer. The variety in particular had the least L* value among all varieties.

The greenness and redness (a*) of all the varieties was not significantly affected by fertilizer treatment except the untreated TDa0000194 which differed significantly, having positive a* while the same treated with NPK and manure had negative a* values. Also, the untreated and manure treated TDa291 had higher negative value than the same treated with NPK.

Fertilizer treatments had significant effect on the blueness and yellowness (b*) of the tuber flesh of *Dioscorea alata* varieties. The untreated TDa0200012 had significantly lower b* value than other treatments. Also, TDa291 treated with NPK was significantly higher in yellowness than the same with other treatments. Fertilizer treatments had no significant effect on the browning index of the yam varieties.

Colour of food is one of the first parameters of quality assessed by consumers thereby making it a vital factor for food acceptability (Leon et al. 2006).

Food colours are influenced by chemical biochemical, microbial and physical changes that occur during growth, maturation, postharvest handling and processing (Panka et al. 2013). The insignificant effect of fertilizer on the browning index indicated that fertilizer did not increase the phenolic compounds that are associated with oxidative browning. This implies that fertilizer treatment did not increase the susceptibility of yam tuber flesh to browning.

3.2 Properties of Yam Tuber Starch

The properties of the yam starch are presented in Table 2. The results obtained for starch yield ranged from 18.83 to 28.3%. NPK and manure treatments showed no significant effect on the starch yield of the tubers except Hembakwase having a reduction in starch yield concerning fertilizer application; the control > Manure> NPK in starch yield.

According to (Duan et al. 2019), N fertilizer rate of 75 kg/ha increased the starch yield of sweet potato tuber. This report cannot be generalized for this study due to different varietal responses to fertilizer treatment. However, (Danso et al. 2018) reported a decrease in starch content of false horn plantain flour with NPK and Poultry manure fertilizer treatment. Starch is an amylaceous product extracted from edible parts of plants, especially roots and rhizomes (Andrade et al. 2017).

The rheological and textural quality of yam food products is highly dependent on yam starch due to its high percentage in yam composition on a dry basis (Otegbayo et al. 2011). Yam starches could be as texture improvers, thickeners, colloidal stabilizers, gelling agents or volume and water retention agents in the food industry (Kaur et al. 2007).

Table 1. Colour of the yam tuber flesh

Yam variety	L*			a*			b*			Browning index		
	NF	MN	CF	NF	MN	CF	NF	MN	CF	NF	MN	CF
TDr9518544	83.95a	83.46a	84.06a	-1.04a	-0.58a	-1.27a	28.58a	26.46a	30.30a	1.68a	0.09a	1.00a
Danacha	84.76a	82.35a	84.45a	0.01a	-0.02a	-0.74a	18.48a	23.31a	22.70a	-0.82a	-0.57a	0.54a
Hembakwase	83.03a	83.26a	83.44a	-1.02a	-1.77a	-1.69a	32.07a	35.37a	35.37a	-0.59a	0.44a	0.33a
Ojuiyawo	82.13a	82.73a	82.05a	-1.54a	-2.18a	-0.70a	36.85a	37.22a	36.50a	0.20a	-0.97a	-0.2a
TDa0000194	80.40a	80.57a	83.08a	1.21a	-0.3ab	-1.91b	27.09a	26.06a	27.09a	2.06a	0.29a	1.03a
TDa0200012	73.89ab	72.86b	77.4aa	9.79a	8.79a	4.54a	24.63a	28.64a	29.60a	2.97a	2.51a	2.24a
TDa291	84.74a	84.44a	83.36a	-0.24a	-0.80ab	-1.39b	17.34b	16.78b	22.96a	0.95a	0.66a	1.34a
TDa9801176	76.43a	77.21a	77.43a	5.83a	4.63a	2.67a	28.22a	26.52a	29.46a	2.47a	1.57a	2.51a

Value s are means of at least three determinations (n=3). means in each row with different superscripts is significantly different (p ≤ 0.05). NF:No fertilizer(Control); MN: manure; CF: chemical fertilizer (NPK)

Table 2. The properties of yam starch

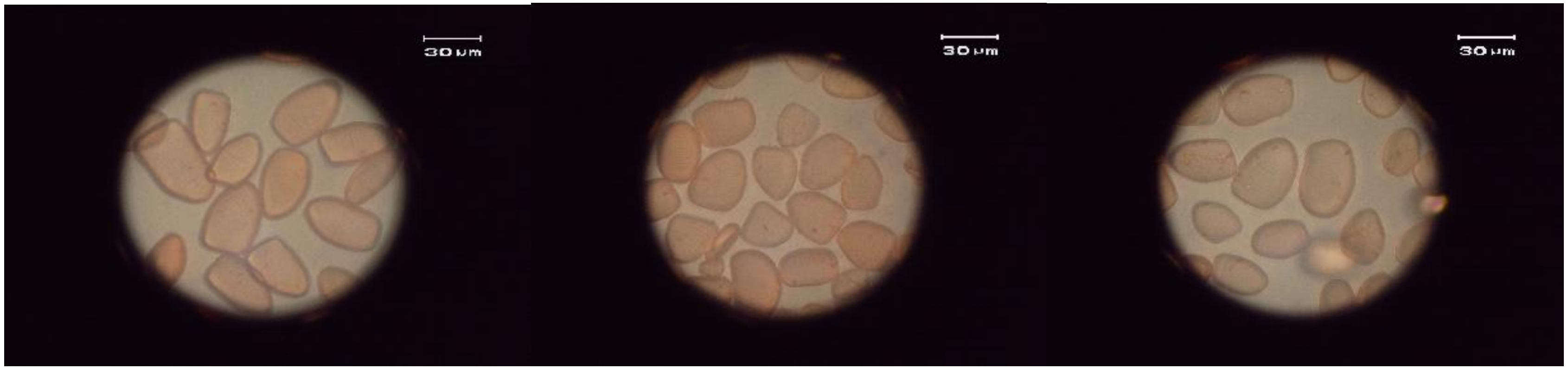
Yam variety	Starch yield (%)			Amylose (%)			Amylopectin (%)			Granule		
	NF	MN	CF	NF	MN	CF	NF	MN	CF	NF	MN	CF
TDr9518544	27.35a	26.64a	22.78a	22.07a	35.59a	30.89a	77.93a	64.41a	69.11a	38.10a	38.08a	37.42a
Danacha	26.55a	27.65a	24.25a	19.36b	40.41a	25.42b	80.64a	59.59b	74.58a	45.07a	44.33a	42.65a
Hembakwase	26.91a	24.00b	19.95c	24.57a	39.83a	28.27a	75.43a	60.17a	71.73a	42.23a	37.80a	36.60a
Ojuiyawo	21.65a	24.33a	20.50a	16.88b	43.84a	31.66ab	83.12a	56.16b	68.34ab	38.40a	38.05a	37.43a
TDa0000194	24.41a	24.84a	23.03a	41.23a	15.98a	29.51a	58.77a	84.02a	70.49a	40.43a	44.10a	42.68a
TDa0200012	22.26a	21.04a	18.83a	59.58a	20.32b	28.36b	40.42b	79.68a	71.64a	38.43a	39.58a	40.6a
TDa291	28.53b	27.08a	23.30a	48.52a	16.25b	22.24b	51.48b	83.75a	77.76a	39.45a	41.30a	40.83a
TDa9801176	23.09a	21.14a	19.86a	50.52a	27.05b	32.33ab	53.52b	74.28a	70.50ab	38.15a	38.12a	39.73a

Value s are means of at least three determinations (n=3). means in each row with different superscripts is significantly different (p ≤ 0.05). NF:No fertilizer(Control); MN: manure; CF: chemical fertilizer (NPK)

Table 3. Granular shapes of yam starches

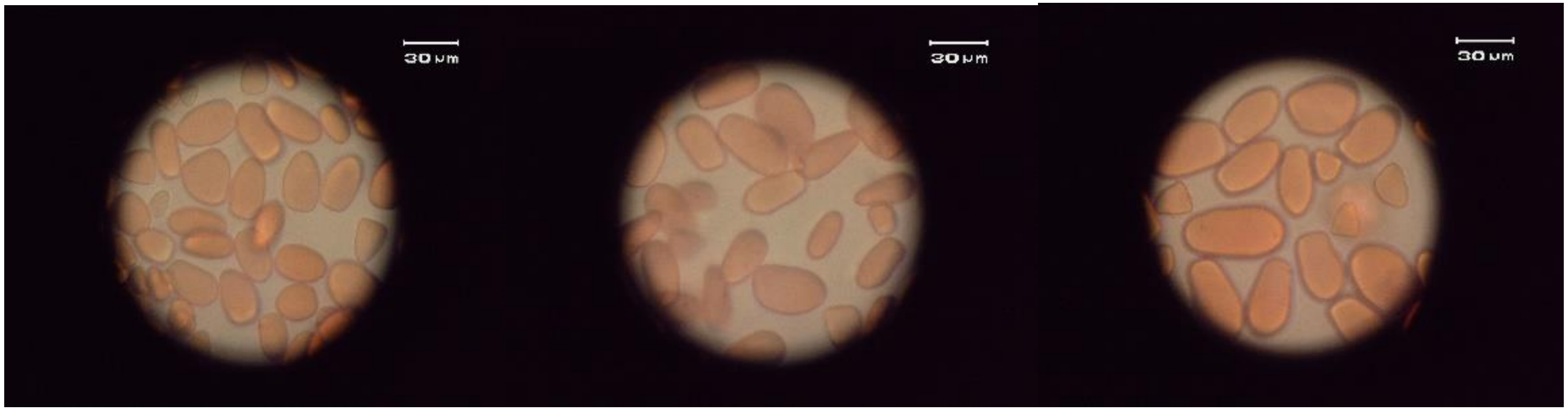
Yam Variety	Granule size		
	NF	**MN**	**CF**
TDr9518544	Oval triangular and polygonal	Oblong, triangular and polygonal	Oblong triangular and polygonal
Danacha	Oval and oblong	Oval and oblong	Oval and polygonal
Hembakwase	Oval and triangular	Oval and triangular	Oblong, triangular and polygonal
Ojuiyawo	Oval and triangular	Oblong and triangular	Oblong, triangular and polygonal
TDa0000194	Oval, oblong and triangular	Oval, oblong and triangular	Oval, oblong and triangular
TDa0200012	Oblong, triangular and polygonal	Oblong and Triangular	Oblong, triangular
TDa291	Oblong and triangular	Oblong and triangular	Oblong and triangular
TDa9801176	Oblong, triangular and polygonal	Oblong, triangular and polygonal	Oblong, triangular and polygonal

Note: NF: No fertilizer (Control); MN: manure; CF: chemical fertilizer (NPK)



Hembakwase (control) Hembakwase (manure) Hembakwase (NPK)

Plate 1. Photomicrographs of *Dioscorea rotundata* starch granule (mg × 40, scale bar=30 μm)



TDa0000194 (control) TDa0000194 (manure) TDa0000194 (NPK)

Plate 2. Photomicrographs of *Dioscorea alata* starch granule (mg × 40, scale bar=30 µm

The amylose and amylopectin content of yam starches ranged between 15.98 to 59.88% (amylose) and 40.41 to 84.43% (for amylopectin). Fertilizer had a significant effect ($P = 0.05$) on the amylose and amylopectin content of yam starch. An increase in amylose content was observed with *Dioscorea rotundata* varieties treated with manure and NPK. The observed increase was in the order; manure $>$ NPK $>$ control with manure having 92.66% and NPK 40.2% increase. However, the reverse was in the case with *Dioscorea alata* varieties where decreased the amylose content in the order; manure <NPK < control with manure having 60.17% and NPK 44.73% decrease. It was noticed that most untreated (that is control) *Dioscorea alata* varieties had higher amylose/lower amylopectin content than *Dioscorea rotundata* varieties which was in line with the findings of (Otegbayo 2014)]. The observed reduced amylose content in NPK-treated varieties of *Dioscorea alata* is in line with the findings of (Duan et al. 2019) which reported a decrease in amylose content of sweet potato with 75 kgha^{-1} N fertilizer. Amylose content plays a key role in the digestion of starches, as starches with low amylose content are more digestible than starches with high amylose content (Riley et al. 2015).

For healthy living, starchy foods with slowly digestible starch is desired which is the basis for resistant starch (Miao et al. 2015). High amylose content is associated with high resistant starch in yam (Kouadio et al. 2013). Debranching of cassava starch was done to increase resistant starch, the varieties with the highest resistant starch were those with higher amylose content (Abioye et al. 2017). High resistant starch which is connected to amylose starch physiologically act like dietary fiber (Rosida et al. 2016). In this study, the increased amylose content of *Dioscorea rotundata* varieties with fertilizer treatments implies more resistant starch content making it a healthy food. Amylose content of starch is also a significant factor that influences the characteristics of starch, such as pasting properties and enzymatic susceptibility (Eburneo et al. 2018). The diameter of starch granules ranged from 36.60 to 45.07µm. Fertilizer had no significant effect on the starch granule sizes. All varieties exhibited different granule sizes regardless of fertilizer treatments. Lindeboom et al. (2004) classified starches as large ($> 25\ \mu m$), medium (10-25 μm), small (5-10 μm) and very small ($< 5 \mu m$). The starch granule sizes of all the varieties in this study fall within the category of large granules. Large granules are reported to have higher amylose content which form less molecular bonding hence, enhancing greater swelling power (Singh and Kaur 2004).

Based on microscopic analysis, the extracted starches from yam tubers showed varied granule shapes (oval, triangular, oblong and polygonal) and mixtures of small, medium and large granules (Table 3). The observed shapes and sizes of yam starch granules are consistent with previous results found in literature for different *Dioscorea rotundata* and *Dioscorea alata* varieties (Otegbayo 2014, Fauziah et al. 2016, Ahmadu et al. 2018). Granule size increases the rate at which starch gelatinizes, its gelatinization temperature, swelling power and viscosity (Tsakama et al. 2010). Differences in granule shapes of potato starch with different nitrogen fertilizer rates (Eburneo et al. 2018). According (Ming et al. 2021) granule size has a significant impact on the functional characteristics and suitability of starch for both culinary and non-food applications. The excerpt photomicrographs of the species are presented in Plates 1 and 2.

4. CONCLUSION

The insignificant effect of fertilizer on the colour indices of the tuber flesh of both species should be able to erase farmers' apprehension about colour change of yam tuber flesh most importantly with appropriate fertilizer application. Increased amylose content of *Dioscorea rotundata* tubers through fertilizer application implies increased resistant starch which is healthily advantageous because of its slow digestibility rate. The fertilizer rate (4.5 t/ha and NPK 90:50:75) used in this study had no adverse effects on the colour and starch properties of the studied *Dioscorea rotundata and Dioscorea alata varieties*.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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