Calibration development for nutritional evaluation of Yam (Dioscorea sp.) using Near-Infrared Reflectance Spectrophotometry (NIRS)

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Abstract: The aim of yam breeders is to produce many hybrids, which can form the basis of selecting quality nutritional traits and other characteristics using certain agronomic criteria. Chemical methods are employed to determine the main constituents of yam, which are time-consuming, expensive, and involve sample destruction. However, the constraints of lengthy analysis time and the cost needed to analyze thousands of these genotypes are major constraints to yam breeding in Nigeria. This study was undertaken to develop and validate calibration equations on the Near-Infrared Reflectance Spectrophotometer (NIRS) for determining chemical compositions of selected yam genotypes. Equations developed for moisture, ash, protein, crude fiber, and tannin showed high coefficients of determination (R^2) for the calibration curve (0.87, 0.84, 0.83, 0.80, and 0.89, respectively) and high to medium coefficients of determination in cross-validation (0.80, 0.68, 0.69, 0.68, and 0.50). The standard errors of calibration (SEC) and the standard errors in cross-validation (SECV) were low for most constituents. A total of 360 ascensions of yam flour were predicted for selected traits to test the equations, and the results were comparable with data from conventional methods. Results of this study have shown that NIRS could be a very useful tool to help yam breeders screen large sample sets using limited resources with very short

ABOUT THE AUTHORS

Our research is focused on characterization of food crops and their products for nutritional and functional traits. Specifically, we are working on characterization of improved and released varieties of maize, cowpea, soybean, cassava and plantain and banana. We are into novel products from these crops with aim to use them to improve malnutrition mostly among the vulnerable groups of developing countries. We work closely with crop breeders in IITA to develop and applied improved methods for analysis of the bred crops for various nutritional and antinutritional compositions. Thus, breeders could take prompt and reliable decisions to achieve their various breeding objectives for crop improvement.

PUBLIC INTEREST STATEMENT

Recently, researchers have been working on increasing the nutrient in the crops and improving the quality characteristics of the crops to meet consumer preferences. To achieve this, the researchers need a fast and cost-effective method of analysis. This study was aimed to apply Near-Infrared Reflectance Spectrophotometer (NIRS) for figuring out chemical constituents of different types of yam samples from different locations. NIRS calibration equations were developed, tested and used to analyze the yam flour samples and compared the results with the literature values. The developed equations could be used for moisture, ash, protein and starch contents determinations of yam flour samples. Thus, NIIRS could be considered as a substitute to the time consuming and labor intensive wet chemical methods of analysis which will in turn minimize exposure to toxic chemicals, provide high turnaround time and minimize cost.

time. This will enhance breeders' rapid selection of genotypes at screening stage where many breeding lines are to be evaluated within the shortest time possible.

Subjects: Nutrition; Food Chemistry; Chemistry

Keywords: Yam; NIRS; Calibration development; protein; moisture; Ash

1. Introduction

Yam is a starchy staple food popularly grown in Africa, the Americas, the Caribbean, the South Pacific, and Asia. Yam contributes more than 200 dietary calories per capita daily for more than 150 million people in West Africa and serves as an important source of income to the people (Coursey, 1967; Babaleye, 2003) The main producer of this staple food is Nigeria with 71% of the world's production (Eke-Ejiofor & Owuno, 2012). FAO statistics showed that about 48.7 million tons of yams were produced on 5 million hectares in about 47 countries worldwide in 2005, and 97% of this was in sub-Saharan Africa (FAO, 2013). West and Central Africa account for 94% of world production, with Nigeria producing 34 million tons. Yam is composed mainly of starch, with some proteins, lipids, vitamins, and minerals (FAO, 2010). Most of the yam species contain carbohydrates, mainly starch, i.e. amylopectic branched chain starch, which exists in the cells in the form of starch grains. Yam also has certain economic and social benefits as it is well integrated into the social, cultural, and religious lifestyles of consumers.

Sustainable production and utilization of yam are important steps in enhancing food security and alleviating poverty, particularly in West Africa. There are 10 major edible yam species (*D. alata, D. bulbifera, D. cayenensis, D. esculenta, D. opposita-japonica, D. nummularia, D. pentaphylla, D. rotundata, D. transvers*, and *D. trifida*) and they include thousands of cultivars. Traits such as the physico-chemical characteristics of the tubers are important because they allow the identification of parents with suitable tuber quality, a key factor for breeding acceptable varieties. The chemical composition of the tuber has been shown to depend on the species, the cultivar, or wild form (Eka, 1985; Lasztity, Hidegild, & Bata, 1998).

One of the major constraints breeders face is the long quality evaluation process, which takes much time and resources as they produce many breeding lines. However, NIRS has been used to complement the complex laboratory procedures for quality evaluation, which has helped to reduce the time it takes to analyze the many breeding lines. As a high-precision, low-cost, rapid, and high-throughput technique, near-infrared spectroscopy (NIRS) can predict the content of organic constituents by combining laboratory data and spectral information (Bradbury & Holloway, 1988; Ramirez et al., 2015).

NIR spectrometric analyses of yam flour samples were conducted according to NIR standard procedures, which include selection of calibration and validation samples, and reference data obtained by routine laboratory analysis. NIR spectral data were obtained by scanning samples, selection of optimum equations between spectral data and reference values by calibration, and confirmation of optimum equations by validation. The established prediction equations were used to measure new independent samples. However, other studies have reported the application of near-infrared reflectance spectrophotometry in evaluation of quality traits in germplasm of *Dioscorea alata* of Pacific Island origin (Lebot, Champagne, Malapa, & Shiley, 2009; Lebot & Malapa, 2013a). NIRs has been used for characterization of various biochemical traits in cassava and other tropical root crops (Lebot, Malapa, & Jung, 2013b) and it was reported that NIRS could rapidly predict total N, starch, and sugars contents of these crops.

However, limited studies have reported applications of near-infrared spectroscopy to evaluate chemical constituents in yam genotypes/varieties that are peculiar to the West Africa region. Thus, the need for this study to establish prediction equations for yam varieties commonly grown in West Africa.

2. Materials and methods

2.1. Sample, sampling, and sample preparation

A total of 163 fresh, matured yams bred as improved yam genotypes were obtained from the experimental fields of the International Institute of Tropical Agriculture (IITA) across four locations of different agroecological zones in Nigeria, namely Ibadan (7° 30′N,3° 54′E), Abuja (9° 04′N, 7° 29′E), Ubiaja (6° 38′N, 6° 23′E), and Ikenne (6° 87′N, 3° 7′E). The samples were split into 126 sets for cross-validation and 37 for external validation. At the time of harvest, the yam tubers were about 10–12 months old. Three tubers of varying sizes—big, medium, and small—were selected for each variety by simple randomization from a bulk of freshly harvested tubers. The Harvest Plus sampling protocol for cassava as reported by Alamu, Maziya-Dixon, Okonkwo, and Asiedu (2014) was adapted for the yam tubers. The tubers were washed, air-dried, peeled, and again washed and dried with soft paper. Each peeled root was cut into four portions longitudinally from the proximal to the distal end. Two opposite portions from each tuber were pooled and homogenized. Some of the homogenized samples were put in paper bag and transferred into an oven to dry at 60°C for 48 h. The resulting dry chips were milled to fine flour using a stainless-steel laboratory mill. The dried flour was then divided into two sub-samples; one sub-sample used for wet chemical analysis as a reference and the other for the collection of NIR SPECTRA.

2.2. Collection of spectral data

A part of the yam flour was transferred onto the sample disc and placed in the NIRS machine for collection of NIR spectra (Figure 1). The ISI scan software on a PC was used to control the NIRS machine for the spectra collection and each sample was scanned in duplicate. The reflectance spectrum varied from 400 to 2500 nm and the spectral line is the average spectra acquired from all tested samples. The NIR region has been reported to be associated with combination bands of fundamental vibrations which are very broad and highly overlapped; it is difficult to distinguish them visually (Lebot et al., 2009). This is more difficult with biological material such as yam samples, which are characterized by complex hydrogen bonding interactions between sugars, fatty acids, and proteins. The spectrum was from the absorption features for each chemical compound of a sample (Yang et al., 2017). In addition, the chemical bonds in the sample matrix absorb at different wavelengths; and the interactions among chemical components and particle size differences give the multiple absorption bands in the raw spectral data that gave vital and unique information for each chemical composition (Yang et al., 2017; Cozzolino, 2015).

Figure 1. Work flow in screening of yam genotypes on the Near-Infrared Reflectance Spectrophotometer.
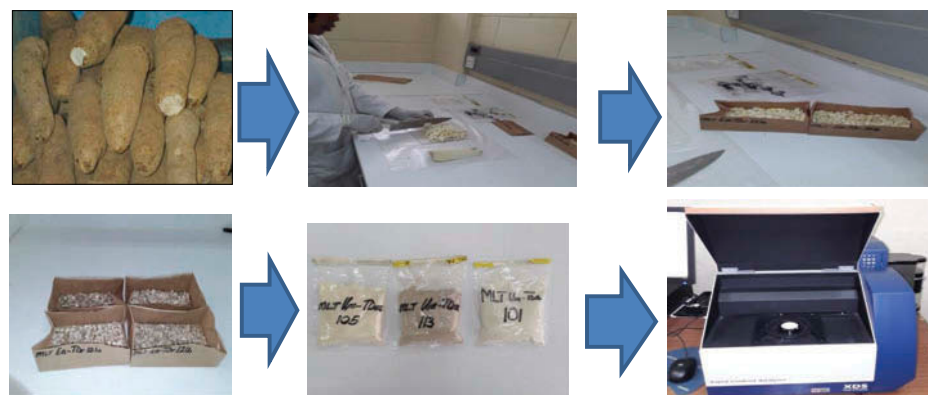
2.3. Biochemical analysis

The moisture content of dried flour was determined using the Association of Official Analytical Chemists' (AOAC) approved method 925.09. Lipid, ash, and crude fiber content of dried yam flour were determined using the Association of Official Analytical Chemists' Approved methods 920.87, 920.39 and 923.03, respectively (AOAC, 1990). Total tannin content of yam flour was determined by the spectrophotometric procedure described by Bainbridge, Tomlins, Wellings, and Wesby (1996).

2.3.1. Determination of crude protein

This was determined by the Kjeldahl method using Kjeltec™ model 2300, as described in FOSS Manual (FOSS, 2003). The method involved digestion of the sample at 420°C for 1 h to liberate the organically bound nitrogen in the form of ammonium sulfate. The ammonia in the digest (ammonium sulfate) was then distilled into a boric acid receiver solution, then titrated with standard hydrochloric acid. A conversion factor of 6.25 was used to convert from total nitrogen to percentage crude protein.

Calculations

$\% \ Nitrogen \ = ((V_a - V_b) * Normality \ of \ HCL \times 1.4007 \times 100)/Sample \ Weight \ (g)$

- Va = Volume, in mL, of standard HCl required for sample
- Vb = Volume, in mL, of standard HCl required for blank

$\% \ Crude \ Protein \ (CP) = \ \% \ Nitrogen \times 6.25$

2.3.2. Determination of phytic acid

Phytic acid content was determined using a method reported by Ndidi et al. (2014). Phytic acid was extracted from 3 g yam flour with 50 ml of 3% TCA by shaking at room temperature followed by high-speed centrifugation of the suspension for 15 min. The phytic acid in the supernatant was precipitated as ferric phytate by adding 4 ml of ferric chloride, heating in a boiling water bath for 45 min, and centrifuging at 2000 rpm for 15 min. The ferric phytate was converted to ferric hydroxide with 2 ml of water and 3 ml of 1.5 N NaOH, then the iron content present in the sample was estimated using a UV/Vis spectrophotometer. The phytate phosphorus was calculated from the iron results assuming a 4: 6 iron: phosphorus molecular ratio. The phytic acid was estimated by multiplying the amount of phytate phosphorus by a factor of 3.55 based on the empirical formula $C_6 \ P_6 \ O_{24} \ H_{18}$.

Calculations

$$Phytate \ mg/g = ((Abs - Intercept) \times Dilution \ Factor \times 2.5 \times 1.5 \times 3.55)$$
$$/(Gradient \times Weight \ of \ sample)$$

2.4. Near-infrared spectra model calibration and validation

The near-infrared spectra models were developed with 163 samples, in "Win ISI 4 Project Manager", by using the modified partial least squares (MPLS) regression and cross-validation techniques (Yang et al., 2017). These techniques were used to calculate the correlation between and laboratory and spectral data. The performance of spectrophotometer was verified, and the wavelength stability checked prior to the collection of spectra. The collected spectra data were transformed with several pretreatments before the calibration process. Each dried flour sample was scanned twice, within the range of 400 to 2498 nm, registering absorbance value logs (I/R) at 0.5 nm intervals using a NIRS monochromator (model FOSS XDS, solid module) and stationary ring cell cup. The derivative and mathematical treatments used for each constituent are 1, 4, 4, and 1. The first number is the derivative, the second is the gap, while the third and fourth numbers show the smooth.

The results of the calibration calculation were checked seeing the t-outliers with t > 2.0 and GH-outliers >4.0. There were two outlier elimination passes and samples with t > 2.0 were dropped from the calibration file. Statistical methods applied in the study included the coefficient of determination calculated in cross-validation (R^2cval) and external validation (R^2V), the standard error of calibration (SEC), the standard error of cross-validation (SECV), and the standard deviation (SD). The prediction ability of the model was estimated using the ratio of prediction to deviation (RPD), which showed the correlations between the SD of the data from standard chemical methods and prediction data by NIRS model (SECV or RMSEC) as reported by Williams and Sobering (1996) and Yang et al. (2017).

### 2.5. Analysis of yam flour samples using the developed calibration profile

The developed calibration equations/models were used for the prediction of proximate and anti-nutritional compositions of yam flour samples. A total of 360 ascensions of yam samples from five different locations in Nigeria, namely Abuja, Ibadan, Ubiaja, Ikenne, and Umudike were analyzed for moisture content, ash, fat, crude fiber, starch, sugar, amylose, phytate, and tannins using NIRS. The prediction equations used had high coefficients of determination for the calibration curves for most of the proximate parameters (moisture, r^2 = 0.87; ash, r^2 = 0.84; protein, r^2 = 0.80; crude fiber, r^2 = 0.83; tannin, r^2 = 0.89); this gives a basis for good prediction of these constituents in the yam flour samples. About 5 g of the dried yam flour was scanned by NIRS; spectral data were collected by measuring the diffuse reflectance from yam flour in the NIR region within 400–2498 nm using a NIRS monochromator (model FOSS XDS, solid module) and a stationary ring cell. The reflectance spectra were collected continuously over a NIR wavelength region with each spectrum represented as absorbance value logs ($1/R$) at 0.5 nm increments (Figure 2). The spectroscopic procedures and data recording were done using Win ISI software (version 4.9.0; FOSS NIR Systems).

3. Results and discussion

3.1. Chemical characteristics of the yam genotypes used as reference samples

The moisture, ash, protein, crude fiber, fat content of the yam flour, and antinutrient factors are presented in Table 1. Mean ± SD of 6.9 ± 1.67% was obtained for moisture content of dried yam

Figure 2. A typical average visible to near-infrared (400–-2500 nm) spectrum illustrating peaks of dried yam flour samples for 163 genotypes.

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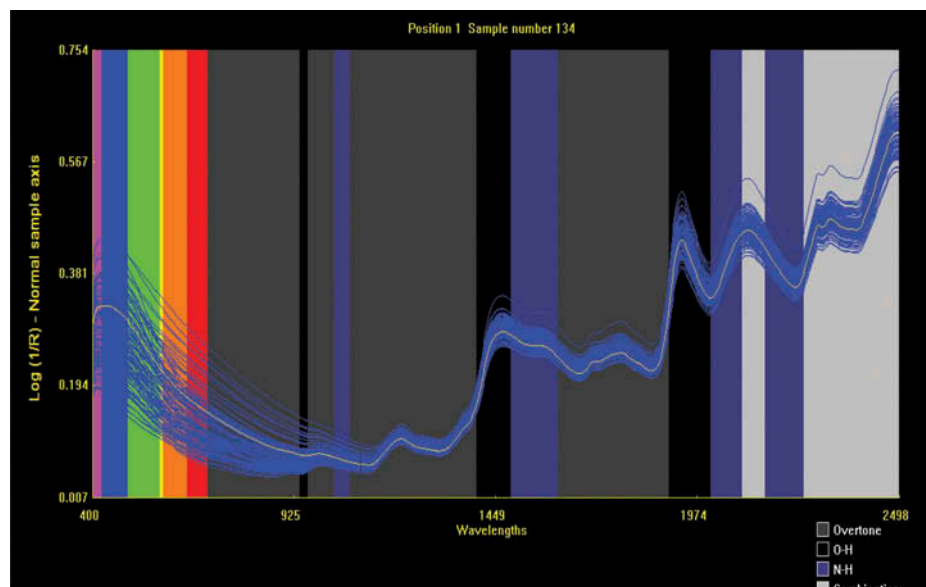
Table 1. NIRS Calibration and validation statistics for proximate and anti-nutritional parameters in yam flour

| Constituents	Reference Values			Calibration				Cross Validation		
	Range	Mean	SD	R^2_{pre}	SEC	RPD_{pre}	R^2_{val}	SEC v	RPD
Moisture	3.79–9.75	6.94	1.67	0.87	0.56	2.29	0.80	0.68	2.24
Ash	1.96–6.26	3.58	0.74	0.84	0.27	2.09	0.68	0.20	3.47
Fat	0.05–1.73	0.31	0.19	0.07	0.14	1.00	0.14	0.20	0.70
Protein	3.33–9.69	6.78	1.57	0.83	0.58	1.75	0.69	0.75	1.87
Crude Fiber	1.22–3.52	2.16	0.44	0.80	0.80	1.84	0.68	0.58	0.62
Amylose	18. 8–44,41	32.48	4.82	0.45	2.90	5.15	0.27	3.45	1.14
Sugar	2.09–9.00	5.02	1.15	0.32	0.78	1.17	0.31	0.81	2.76
Starch	25.05–66.06	50.68	10.32	0.54	7.05	1.30	0.42	8.02	1.29
Phytate	0.33–2.44	1.17	0.42	0.39	0.33	1.12	0.29	0.34	1.15
Tannin	0.05–9.91	2.04	1.93	0.89	0.40	2.17	0.50	0.78	1.58

SD = standard deviation, R^2pre = coefficient of determination in calibration, SEC = standard error of calibration, R^2val = coefficient of determination in cross validation, SECV = standard error of cross validation, RPD = ratio of performance to deviation

Figure 3. A typical scatter plots of predicted moisture and spectra data for the dried yam flour samples for 163 genotypes.
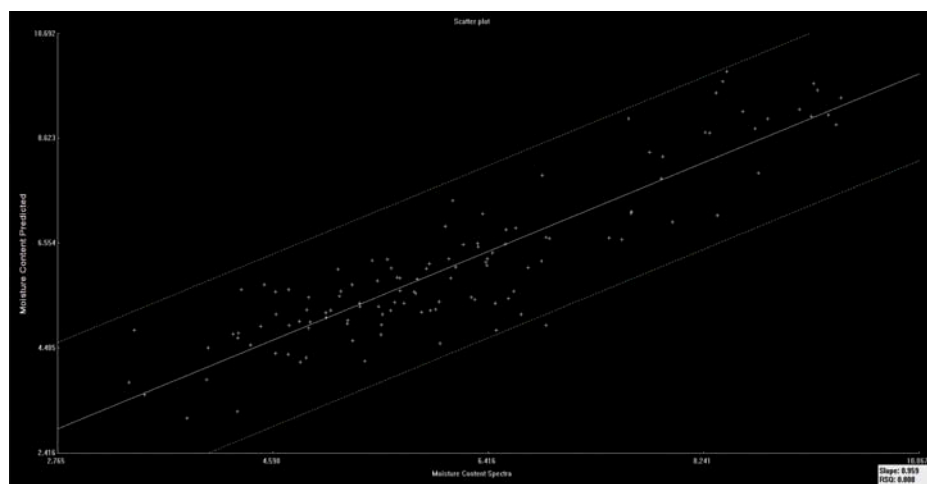
Figure 4. External validation plots for moisture, ash, protein, starch, sugar, and amylose for N = 15 yam samples.
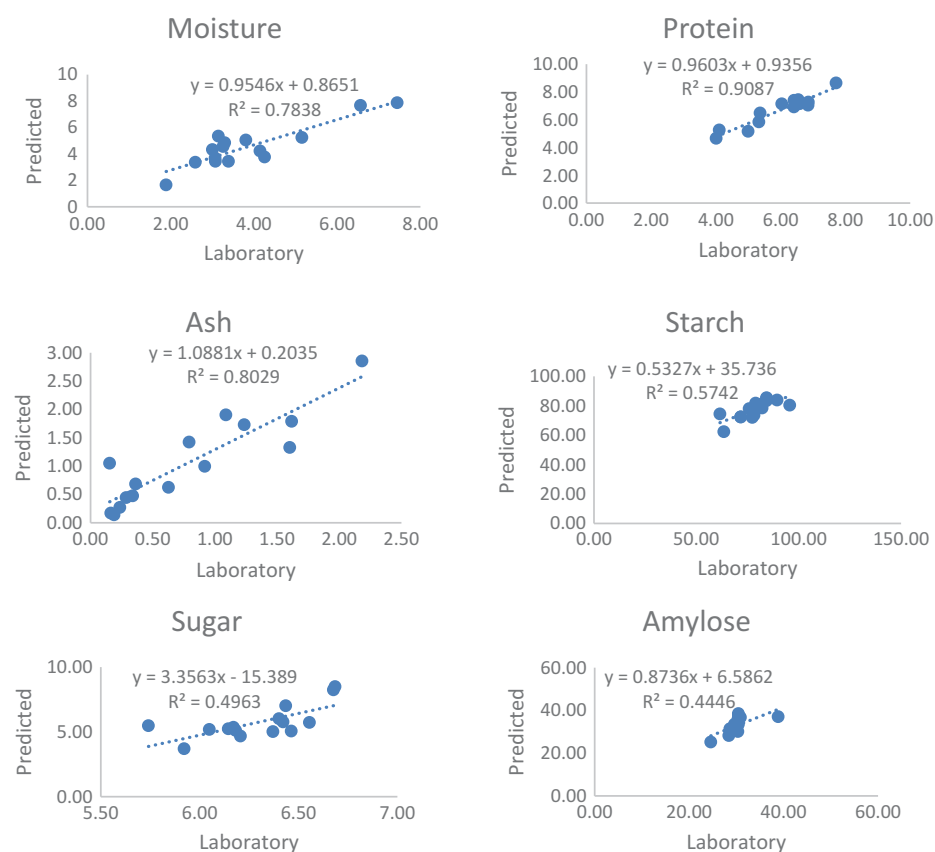
flour, while ash, fat, and protein were 3.58 ± 0.74, 0.31 ± 0.19%, and 6.78 ± 1.57%, respectively. However, these results are consistent with PolyCarp, Afokwa, Budu, and Otoo (2012) who reported <1.0% for fat and 4.0–6.5% for protein. However, amylose content ranged from 18.8% to 44.41% with an average value of 32.84% and in agreement with what was reported in the literature, ranged from 24.3% to 38.1% (PolyCarp et al., 2012; Alamu et al., 2014; Eke-Ejiofor & Owuno, 2012). Mean ± SD for starch (50.68 ± 1.32%) in this study is lower with values of 60.3–74.4% reported by

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Table 2. Mean ± SD of predicted proximate and anti-nutritional content of yam using developed calibration equations

Location	N	aMoisture	aAsh	aFat	aProtein	aCrude Fibre	aAmylose	aStarch	aSugar	bPhytate	bTannin
Ibadan TDr	60	5.29 ± 2.1	3.03 ± 0.68	0.34 ± 0.07	5.74 ± 0.97	1.43 ± 0.29	36.1 ± 2.85	54.27 ± 0.63	5.27 ± 0.63	0.97 ± 0.26	1.4 ± 0.93
Ibadan TDa	36	5.56 ± 2.18	4.55 ± 1.83	0.38 ± 0.06	6.40 ± 1.25	2.01 ± 0.65	34.09 ± 1.92	46.02 ± 20.0	5.10 ± 0.84	0.98 ± 0.37	3.53 ± 1.64
Abuja TDr	62	3.82 ± 1.49	3.10 ± 1.75	0.44 ± 0.06	7.79 ± 1.53	1.04 ± 0.35	33.66 ± 5.26	57.54 ± 0.46	5.49 ± 0.46	0.86 ± 0.21	1.79 ± 0.66
Abuja TDa	34	5.50 ± 1.80	3.01 ± 0.99	0.67 ± 0.05	6.68 ± 0.78	2.23 ± 0.65	34.49 ± 2.84	46.15 ± 13.82	6.04 ± 0.71	1.07 ± 0.29	4.13 ± 2.01
Umudike TDr	60	4.81 ± 1.62	1.41 ± 0.98	0.43 ± 0.06	5.37 ± 1.22	1.26 ± 0.24	37.31 ± 4.26	64.33 ± 12.84	5.64 ± 0.42	0.80 ± 0.15	1.87 ± 0.73
Umudike TDa	36	6.18 ± 2.38	2.78 ± 1.10	0.44 ± 0.05	5.53 ± 1.07	2.07 ± 0.65	34.23 ± 3.01	56.32 ± 10.16	5.30 ± 0.46	0.94 ± 0.18	3.18 ± 1.59
Ubiaja TDr	60	4.94 ± 1.57	2.11 ± 1.09	0.42 ± 0.05	6.78 ± 1.18	1.15 ± 0.35	37.06 ± 2.97	74.13 ± 12.86	5.90 ± 0.47	0.7 ± 0.19	2.10 ± 1.02
Ubiaja TDa	36	5.21 ± 1.71	2.41 ± 0.88	0.39 ± 0.05	6.52 ± 1.10	1.33 ± 0.37	35.25 ± 2.70	64.73 ± 11.99	5.34 ± 0.61	0.95 ± 0.27	1.52 ± 1.17

a Parameters expressed in %; b Parameters expressed in mg/100g; TDr: *Discorea rotundata*; TDa: *Discorea alata*

Maziya-Dixon and Asiedu (2003) and 33.9–75.7% reported by Alamu et al. (2014). The bioactive content of the yam samples shows that phytic acid and tannin had a mean ± SD of 1.17 ± 0.42 mg/ g and 2.04 ± 1.93 mg/g, respectively. The mean and standard deviation of phytic acid (2.16 ± 0.44%) obtained was higher than what was reported (1.82 ± 0.4%) by Alamu et al. (2014) for yam varieties from riverine areas, using chemical methods (Alamu et al., 2014). The difference could be due to genetic and environmental differences.

3.2. NIRS model calibrations and cross validation

Mean values, standard deviations, and ranges of the reference values and the statistics of the NIRS calibration and of the cross-validation are shown in Table 1. NIRS equations were developed in this study using modified partial-least-square (MPLS) regression on the first derivative of reflectance and transmittance spectra (math treatment, D = 1, G = 4, S1 = 4, S2 = 1), and scatter correction of SNVD (standard normal variance and de-trend) for each constituent. D is the derivative order number (that is 0 indicates no derivative operation, 1 means the first derivative and so on); G is gap (the number of data points over which derivation is computed); S1 is the number of data points in the first smoothing and S2 is the number of data points in the second smoothing that is normally set at 1 in the case of no second smoothing.

The NIRS predictive performance for moisture, ash, protein, and tannin were considered good with high R^2pred of 0.87, 0.84, 0.83, 0.80, and 0.89, respectively, and high to medium coefficients of determination in cross-validation R^2_{Val} of 0.80, 0.68, 0.69, 0.68, and 0.50, respectively (Table 1). The standard errors of calibration (SEC) and the standard errors in cross-validation (SECV) were low for all constituents except sugar and amylose. The coefficients of determination in calibration curves for fat, sugar, and phytate were very low at 0.07, 0.32, and 0.39, respectively and consequently had a very low coefficient of determination in cross-validation at 0.14 and 0.31 and 0.29, respectively (Table 1). Therefore, fat, sugar, and amylose might not be predicted precisely; however, the RPD values of 2.14 for sugar and 1.15 for phytate indicate that the prediction for these parameters can be improved. The R^2_{Pred} values of moisture, ash, protein, crude fiber, and sugars are high enough to allow good estimates of their content, confirming the interest of NIRS for predicting rapidly these constituents in yam genotypes. Figure 3 shows typical scatter plots of predicted moisture and spectra data for the dried yam flour samples for 163 genotypes.

3.3. External validation

The robustness of the method was checked by predicting the proximate composition of 15 independent samples which were not included in the calibration group and came from an entirely different location—Abakaliki, Ebonyi State (6°19′N, 8°6′E). The average of two spectra data for each sample was collected as predicted values using the developed equations and compared with those obtained using standard wet chemical laboratory procedures. The external validation plots were obtained as shown in Figure 4. Though the r^2 is affected by distribution of the values, the moisture content, protein, and ash had a higher R^2 value (moisture, 0.78; protein, 0.90; ash, 0.80;) but starch and sugar had low R^2 values of 0.57 and 0.49, respectively.

3.4. Testing the developed calibration equations

The predicted proximate and anti-nutritional composition using the developed calibration equations for yam flour across four different locations is presented in Table 2. The predicted grand mean moisture content for *D. rotundata* flour ranged from 3.82 ± 1.49% (Abuja) to 5.29 ± 0.21% (Ibadan) across the locations. The moisture content of dried flour shows the residual moisture after drying. Moisture content is one of the factors that determines the shelf life of yam flour and low moisture observed for most of the genotypes confers higher shelf life on the flour and is a good indication of microbial stability and may contribute to reducing the tendency of baked food products becoming stale. A range of 1.41 ± 0.98 to 3.10 ± 1.75% was observed for ash; 0.34 ± 0.07 to 0.44 ± 0.05% for fat; 5.37 ± 1.22 to 7.79 ± 1.53% for protein. The results obtained in this study were higher than 1.4%, 2.7%, 0.08% mean values reported by Alinnor and Akalezi (2012) for ash, crude fat, and protein content, respectively. A range of 1.04 ± 0.35 to 2.23 ± 0.65% was obtained for crude fiber, and 33.66 ± 5.26 to 37.31 ± 4.26% for amylose across all

locations. Mean starch values ranged from 54.26 ± 14.07 to 74.13 ± 12.86%; 5.27 ± 0.63 to 5.90 ± 0.47% for sugar; 0.70 ± 0.19 to 0.98 ± 0.37% for phytate, and 1.4 ± 0.93 to 2.10 ± 1.02% for tannin. These values are relatively lower than 4.5% and 2.1% reported by PolyCarp et al. (2012) for phytate and tannin, respectively. Phytates are known to adversely affect mineral bioavailability while tannins are anti-nutrients which form complexes with proteins and reduce their digestibility and palatability (Alinnor & Akalezi, 2012; Bhandari & Kawabata, 2006). Lower phytate and tannin values are therefore desired in yam varieties.

Dioscorea alata (*D. alata*) moisture content ranged from 5.21 ± 1.71 to 6.18 ± 2.38%; ash from 2.41 ± 0.88 to 4.55 ± 1.83; fat from 0.38 ± 0.06 to 0.67 ± 0.05%; protein from 5.53 ± 1.07 to 6.63 ± 0.78%; crude fiber from 1.33 ± 0.37 to 2.23 ± 0.65%, and amylose from 34.09 ± 1.92 to 35.25 ± 2.70%. These observed values agree with what Alamu et al. (2014) who reported in their study using conventional methods of analysis, a range of 1.98 ± 0.49% (ash), 1.2 ± 0.9% (fat), and 2.91 ± 0.77% (protein) were reported, which agreed with the predicted results from this study using NIRS. PolyCarp et al. (2012) also reported moisture content values ranging from 5.71% to 6.60% and protein values ranging from 5.91% to 6.08% for D. alata. Similarly, the predicted range for starch content for *D. alata* across all locations was 46.02 ± 20.0–64.73 ± 11.99%; 5.10 ± 0.84–6.04 ± 0.71% for sugar; 0.94 ± 0.18–0.98 ± 0.37% for phytate, and 1.52 ± 1.17–4.13 ± 2.01% for tannin. These values obtained using the prediction equation from NIRS are in concordance with the range of 60.30–74.4% reported for starch content of *D. alata* by Maziya-Dixon and Asiedu (2003). Umudike had the highest grand mean of moisture content and amylose content for TDa varieties (6.18 ± 2.38) and TDr varieties (37.31 ± 4.26), respectively. The highest mean value for protein content (7.79 ± 1.53%), across the four locations, was from Abuja and it was for TDr varieties. The starch content of 74.13 ± 12.86% was reported for TDr varieties from Ubiaja location and the value agrees with an average of 77.41 ± 6.4% starch content reported by Lebot; et al. (2009) for *Dioscorea* spp. It could be inferred that location and type of yam affected the nutrients of yam varieties and NIRS could be used for their classification in terms of their nutritional and anti-nutritional values.

4. Conclusion

Considering the high prediction performance of the developed equations for most of the yam constituents (moisture, ash, protein, and starch), it could be concluded that NIRS could be used to determine these constituents conveniently and cheaply. In addition, the findings from using the developed prediction equations for the analysis of independent yam samples that compared positively with those reported in the literature making NIRS to be a good substitute for the high cost and time-consuming conventional method. The data generated from this study could be used for the expansion of yam data base in West Africa, especially Nigeria.

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Cover image
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