Research Square

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Phenotypic Behaviour and Association Analysis of Agronomic traits, Proximate, Nutrients and Quality Attributes of West Africa

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Abstract

Background

West African okra (*Abelmoschus caillei*) is a valuable crop for food security and nutrition in sub-Saharan Africa, yet its ability for biofortification remains underutilized. Comprehending the genetic variability and interrelationships among agronomic, proximate, nutrient, and quality traits is important for breeding nutrient-rich, high-yielding varieties to combat malnutrition.

Methods

Twenty-one accessions of West African okra were evaluated using a randomized complete block design with three replications. Phenotypic data were collected on fruit yield components, proximate composition (protein, fiber, ash), nutrient content (zinc), and quality attributes (viscosity) in both fresh fruits and okra meal. Statistical analyses included ANOVA, correlation, clustering, and regression to elucidate trait associations and identify promising genotypes.

Results

Significant genetic variability was observed for yield, protein, fiber, zinc, ash, and viscosity. Genotypes OK18, OK14, and OK17 excelled in fruit yield, while OK3, OK5, and OK6 showed superior protein, ash, and zinc content. Cluster and correlational network analysis showed distinct groupings and positive associations among key nutritional and quality traits, indicating the potential for simultaneous improvement. Regression models identified fruit weight and number at seven days as strong predictors of total yield. The study showcased genotypes with multi-nutrient advantages and identified candidates for biofortification and hybridization. A curvilinear and linear relationships were established among fruit weight, protein, and fruit number, with regression analyses indicating that fruit number and weight at seven days were strong predictors of total fruit yield.

Conclusion

This study shows the genetic potential of West African okra to develop high-yielding, nutrient-dense varieties. Diallel hybridization among selected genotypes and integration of phenotypic and molecular analyses are recommended to accelerate progress toward food and nutrition security. This research provides foundational insights into biofortification strategies, supporting the development of West African okra varieties with enhanced agronomic performance and nutritional value. The study aligns with the United Nations Sustainable Development Goals, delivering practical pathways to produce nutrient-rich crops that address the dietary needs of growing populations in West Africa and beyond. The findings underscore the importance of integrating phenotypic selection with molecular analysis to accelerate breeding for food security and the alleviation of malnutrition.

Introduction

Abelmoschus caillei [A. Chev] Stevels (2n = 184–200), commonly referred to as West African Okra, belongs to the Malvaceae family and is cultivated across the Gulf of Guinea region, including countries such as Nigeria, Ghana, Senegal, Togo, and the Ivory Coast, extending to the southern limits of the Sahel in sub-Saharan Africa. It is widely distributed throughout the humid tropics and peri-humid areas, and predominantly between latitudes 12°N and 12°S, most especially between 15°N and 10°N. West African okra flourishes as a warm-weather crop and is known for its climate toughness and nutritional richness. It plays an important part in promoting a healthy diet and combating malnutrition. Okra is cultivated in backyard farms, along roadsides, or on wasteland, but it is rarely found in undisturbed forests [1]. Optimal growth and flowering are facilitated by temperatures between 25°C and 35°C; conversely, low temperatures (below 15°C) can hinder germination, growth, and flowering [2]. Anthesis is a quantitatively short-day response whereas *A. esculentus*, which is photo-insensitive. West African okra has a longer flowering and fruiting duration, and its fruits are heavier than those of *Abelmoschus esculentus* (Adeniji, 2003). Its leaves are medium-sized, alternate, typically with 5–7 lobes, measuring 7–15 cm in length, and oblong to heart-shaped. Both the green leaves and the petioles are covered with pubescence during the early growth stages, and young fruits are also covered with pubescence. A few accessions develop hard, prickly spines on the stems, leaves, petioles, and fruits at maturity. However, some accessions are glabrous [3]. *Abelmoschus caillei* is grown as a subsistence crop, either as a sole crop or intercropped with cassava, cowpea, and yams. Production of okra hit 2.3 MMT in 2020 [4]. In Nigeria, the annual okra fruit yield is estimated at 1.82 MMT (million metric tonnes), with yields ranging from 4.5 to 11.70 t ha^{-1}.

The fresh fruits of West African okra comprised water of 81.9%, low-fat content of 0.006/100g, 4.9 to 6.3% protein and 7.5 to 8.5% fiber, which contrasts with the 2.3 to 3.7% protein and 9.5 to 10.5% fiber found in *A. esculentus* Ramdhane et al [5]. Okra fruit is high in vitamins C and K, as well as essential minerals like calcium, magnesium, and iron, and polyphenolic compounds (carotene, folates, thiamin, riboflavin, niacin, and vitamin C), raising its nutritional value Ray et al [6]. The dietary fiber in fresh okra is substantial, and it offers a favorable balance of the amino acids, lysine and tryptophan, unlike the proteins found in cereals and pulses Sanjeet et al [7]. This makes okra a super food for managing diabetes. Additionally, okra has been shown to lower cholesterol levels, which is a significant nutritional concern for many. The amino acid composition, proportions, and human assimilation of okra fruit position it as having a high biological value in protein Ewa et al [8]. Okra fruit has a low glycemic index and is good for managing diabetes, and allergies to okra are rare. Fresh okra fruit contains a higher concentration of magnesium and potassium.

Market standards for freshly harvested okra vary by region; in the Mediterranean, the preferred fruit length is between 3–5 cm, while in North America, acceptable sizes range from 7–12 cm or longer, provided that lignification of the fruit walls and seed formation have not yet commenced. In sub-Saharan Africa and Asia, fresh *A. esculentus* fruits are typically culled at seven days. The market standards and preferences for West African okra in sub-Saharan

Africa are rarely documented in the literature. Farmers harvest fresh fruits at a reasonable size with soft tips. Research has shown that a six-day-old okra fruit of *Abelmoschus esculentus* exhibits the best sensory quality. In particular, the Pusa Sawani variety becomes unacceptable for consumption at 8 days, whereas other varieties may remain acceptable for up to 9 days Singh et al [9]. The market demand for fresh okra fruit is growing, driven by its unique flavour and texture Adesuyi et al [10]. Tender fruits can be consumed in various ways, including boiling, steaming, stir-frying, or as an ingredient for thickening soups. The timing of okra fruit culling is crucial for ensuring quality, nutrient bioavailability, and prolonging shelf life. If fruits are picked too early, they may not reach their full size or sweetness. Conversely, older fruits lose their flavor and develop a woody texture. As the fruit matures, its flavour profile changes; it becomes sweeter and less acidic, heightening its appeal. These changes in flavour are attributed to the breakdown of organic acids and the synthesis of sugars.

Climate-induced drought and heat stress during the growing season, coupled with prolonged dry spells and intermittent rainfall, and market glut at the peak of the season, exacerbate productivity and post-harvest losses. This situation requires milling and drying fresh fruit at ambient temperature to produce okra meal, assuring its availability during the prolonged dry season and lessening the impact of drought. The consumption of okra meal is popular in households across Africa, Asia, and Europe [11]. The biochemical composition of okra meal can be influenced by genotype, fruit age, and variations in water loss, temperature, light, and humidity during processing and storage. Okra mucilage is the thick, gelatinous substance present in both young and mature fruits, located in the fruit walls. It is associated with proteins and minerals that improve soups, due to the presence of the chemical compound glycan Gary et al [12]. The mucilage found in fresh okra and okra meal is important in the mastication of heavy food items, such as those made from maize, sorghum, cassava, and yam flour. The viscosity of okra influences mouth feel, ease of swallowing, pourability, and pumping requirements. Additionally, the browning of freshly cooked okra soup and cooked okra meal is linked to the concentration of phenolic compounds in fresh okra.

According to the United Nations, Africa's population is projected to exceed 2.5 billion by the year 2050. The demand for fresh, nutrient-dense vegetables is projected to increase significantly. Over two billion people globally suffer from deficiencies in iron and zinc Anusha et al [13], which have long-term negative consequences for human health Gregory et al 2017 [14]. However, plant-based proteins are often of lower quality due to antinutritional factors that diminish the bioavailability of minerals Kumssa et al 2015 [15]. West African Okra genotypes are an economical source of high-quality protein, fiber and micronutrients, yet research on biofortification in West African okra is still limited. Thus, developing nutrient-rich okra fruit presents a viable strategy to combat malnutrition and obesity. This approach demands an extensive understanding of the macronutrient and micronutrient profiles in fresh West African okra fruits and their preparations. Farmers in West Africa favour local okra varieties for their compatibility with intercropping systems, continuous fruit production, and drought resilience. Additionally, these varieties exhibit numerous traits essential for greater fruit yield and resistance to insect pests and diseases [3]. Our study is premised on identifying a superior, stable and nutrient-dense genotype for Nigeria. This corresponds to the United Nations Sustainable Development Goals (SDGs) to end hunger in all its forms when used in a breeding program. Research on *Abelmoschus caillei* focuses on agro-morphological characteristics. However, there is a lack of information regarding optimal culling times for fruits to maximize nutrient profiles, as well as the viscosity and nutritional content of okra meal. Furthermore, the characters that could act as indicators for improving fresh fruit yield and biochemical properties remain the least understood. Consequently, the primary focus of okra breeding efforts is to develop varieties with consistently high yields, high-quality fruits, and nutrient-dense fruits for a healthier diet. In this study, we aim to quantify the extent of variability and the genotype × year interaction for morpho-physiological and fruit metric traits, proximate and nutrient content, and viscosity in fresh fruits and okra meal over various accessions of West African okra, 2) to select promising genotypes for single and multiple attributes related to fruit yield, nutrient content, and viscosity and 3) explore the association and relationships among, morpho-physiological, proximate, nutrient, and quality attributes to enhance selection and crop improvement in West African Okra.

Materials and Methods

Germplasm and Location

The seeds of nineteen West African okra accessions (OK1 to OK19) from country-wide collection and two varieties of common okra (*Abelmoschus esculentus* [L.]) viz. Check 1 and Check 2 were obtained from the National Centre for Genetic Resources and Biotechnology (NcGRAB) in Nigeria and from agro dealers in Ibadan, Nigeria. The research was conducted at the teaching and research farm of the Department of Crop Science and Horticulture at Federal University Oye Ekiti, Nigeria (longitude 50°29' E, latitude 7°48' N, altitude 535.5 m) from July to November, 2023 and 2024. These periods coincided with short-day length conditions, characterized by temperatures ranging from 25°C to 35°C and moderate humidity.

Nursery Management and Crop Husbandry

The nursery and field planting activities were carried out to coincide with the short-day length required for anthesis. Humus soil and perlite obtained from agro-dealers were blended in a 3:1 ratio. This mixture was then placed into 64 multipot seedling trays, with each genotype assigned two trays. Water was applied to the trays immediately after sowing. Two weeks post-emergence, 2 g of NPK (15:15:15) fertilizer was dissolved in 2 liters of water and applied using a hand-held sprayer with a 2-liter capacity. Four weeks after sowing, 30 mL of VIVA® S.L fungicide (containing Oxamyl 240 as the active ingredient, produced by Almandine Corporations S.A., Switzerland) was diluted in 20 liters of water and sprayed onto the plants. The experimental field was ploughed, harrowed, and structured into double-row flat ridges measuring 3 meters in length, spaced 0.5 meters apart, with a 1.1 m alley separating the rows. A randomized complete block design with four replications was used for allocating treatments into the experimental plots. Vigorous seedlings, approximately four weeks old, were hand-transplanted, retaining the ball of earth, into the ridges at a spacing of 0.5 × 0.5 m within and between rows. Two weeks after transplanting, each plant received 10 g of a compound fertilizer (N20: P10: K10). An additional fertilizer formulation (N20: P10: K20), also at 10 g per plant, was applied during flowering. Weeds were manually controlled through hoeing. Insect infestations and diseases spread were controlled by applying 40 mL of Imidacloprid® (EC) (from Hebei Xintian Biological Technology Co., Ltd.) diluted in 20 L of water.

Measurement of Agronomic and Fruit Quality Traits

The study focused on multiple key horticultural traits, including days to anthesis, the interval between the appearance of the first and last flower (anthesis interval), and the time from the appearance of the fruit to the last fruit (fruiting interval). At anthesis, ten flowers were tagged and subsequently culled seven days later for the measurement of fruit length (cm) and width (cm) using a hand-held electronic Vernier calliper. Fruit length was defined as the distance from the apex to the base of the fruit, while fruit width was measured at the widest point. Following culling, the number of fruits per plant and per plot was counted and weighed using a sensitive weighing balance (Kilogram) (Meetler PE) to determine the total number of fruits per plot and their fresh weight. The fresh fruits culled after seven days were milled, air-dried, and stored in air-tight polyethylene sheets for 90 days at ambient temperature to produce okra meal. The proximate composition (crude fiber, crude protein), nutrient (zinc and ash), and fruit quality attributes (viscosity) were determined using the methods of [16] and [17], respectively, at the Bioscience Laboratory, Afe Babalola University, Nigeria.

Data Summary and Analysis

Average trait values were calculated using Microsoft Excel. The homogeneity of error variance was checked, and the PROC GLM procedure of the Statistical Analysis System (SAS) (ver. 9.4, SAS Institute, Cary, NC) was used to break down total variability into components related to genotypes (G), the environment (E), and genotype-environment interactions (GEI). In this analysis, the environment was treated as a random factor, while the cultivar was classified as a fixed factor. If the interaction was found to be statistically insignificant, multiple comparisons of the main effect were performed using Tukey's Honest Studentized test at 5% and 1% probability levels. The correlation between fruit morphological, proximate and quality data was assessed through correlation matrix and network analyses, created using the 'ggcorplot' and 'agraph' functions in R, respectively [18]. In the correlation network analysis, variables are represented as nodes connected by edges. The strength of the correlation between two variables is indicated by the thickness of the line connecting them in the network plot. This plot permits the identification of variable clusters and their connections. Blue lines denote positive correlations, red lines indicate negative correlations, and faded lines represent coefficients that are close to zero. Thicker lines signify stronger correlation coefficients closer to unity. The morphological traits, yield, and proximate composition of fruit were utilized to establish clusters using Ward's coefficient via agglomerative hierarchical clustering in R. The 'circlize' package within the R environment was used to create a circular visualization of the dendrogram. Linear regression using the fruit weight per plot as the dependent variable (Y) and individual fruit length (X_1) as independent variable:

Fwt= $\int FL$ (1)

Fruit weight/plot (Fwt) - as a function of number of fruit/plot (NoFr):

$$\mathrm{Fwt} = \int NoFr$$

2

The multiple regression of independent variables (individual fruit weight X_1, fruit length X_2, fruit width X_3, days to anthesis X_4, and plant height X_5, and fresh fruit weight X_6, number of fruits/plots X_7) on dependent variable fruit weight/plot (Y) was performed using the second polynomial regression.

Results

Statistically significant mean squares ($P \leq 0.05$) were observed for fruit weight, fruit length and width of seven-day-old fruit, number of days to anthesis (d), flowering duration (d), plant height (cm), fruit length and width at maturity, fruit weight (g)/plot (Table 1), and proximate components (protein and ash contents), nutrients (fiber and zinc), and viscosity of fruits harvested at seven days and from okra meal (Table 2). The year showed significant mean squares ($P \leq 0.05$) for flowering duration, plant height, and fruit length at 7 days, as well as for fruit length at maturity and protein content in fresh fruit. Additionally, the second-order interaction (genotype × year) showed significant effects ($P < 0.05$) on the length of fruit harvested at seven days, protein content in fresh fruit, and okra meal. The mean squares attributed to genotype accounted for a greater proportion of the variation in the total sums of squares compared to those of the year (Y) and genotype × year interaction effects (GYI). The coefficient of variation (%) was lowest (0.65) for protein content in fresh fruit but highest (27.38%) for fresh fruit weight (g) at seven days.

Table 1
Mean squares values for morpho-agronomic and fruit metric traits of 21 Okra genotypes grown in 2023 and 2024 growing seasons

Sources of Variation	Df	Fruit weight of 7-days	Fruit length (cm) at 7d	Fruit width at 7d (cm)	Days to anthesis (d)	Flowering time (d)	Plant height	Fruit length at maturity (cm)	Fruit width at maturity (cm)	Fresh fruit weight (g)	Number of fruit/plots	Days to flower time
Genotypes (G)	20	138.59**	27.18**	1.12**	202.63**	100.54*	4437.48*	318.19*	15.19*	4393569.17*	5501.61*	1516.74
Replication	2	39.00**	4.71**	0.06	29.83**	48.72**	11452.27*	121.81*	1842.05*	1178482.43*	7021.04*	87.8**
Year (Y)	1	16.76	0.45	0.02	53.48	44.33*	1303.56	119.65*	0.62	153070.8	209.47	3.29
G × Y	20	8.95	1.40**	0.06	1.41	6.33	62.99	4.64	0.77	25671.13	46.65	5.91
Error	82	7.79	0.55	0.07	3.89	8.45	451.96	7.26	5.92	153255.6	229.35	15.06
CV (%)		14.74	8.93	11.27	3.9	7.95	14.8	5.71	15.45	27.38	23.17	4.69
Grand mean		18.93	8.27	2.26	50	37	143.59	46.82	15.6	391.47	68.29	82.65

Table 2
Mean squares for fruit proximate, nutrient and quality attributes of 21 Okra genotypes culled at 7 days after flowering and Okra meal during 2023 and 2024 seasons

Sources of variation	Df	Ash (%)	Protein (%)	Fiber (%)	Zinc (%)	Viscosity (cP)	Protein (%)	Fiber (%)	Viscosity (cP)	Protein (%)	Fiber (%)
		In fresh fruit culled at 7 days					In Okra meal			Difference over fresh and okra meal	
Genotypes (G)	20	8.80**	20.95	40.62**	7.41**	3.900**	16.72**	9.77**	0.04**	9.39**	63.85**
Replication	2	0.02	0.02	0.09	0.003	0.11	0.1	0.08	0.003**	0.08	6.73
Year (Y)	1	0.047	0.91**	0.09	0.003	0.0006	0.08	0.04	0.000009	0.002	0.22
G x Y	20	0.01	0.51	0.09	0.002	0.0009	0.19**	0.004	0.00004	0.003	0.22
Error	82	0.01	0.0086	0.09	0.002	0.04	0.07	0.008	0.0004	0.07	1.85
CV (%)		1.14	0.65	2.05	1.14	12.19	2.59	3.09	4.34	12.80	21.42
Grand mean		9.19	11.95	15.21	4.18	1.73	10.13	9.27	0.48	2.10	6.36

As illustrated in Table 3, the top five genotypes (OK11, OK18, OK14, OK17, and OK15) for individual fruit weight at seven days had mean values ranging from 22.07 to 31.31 g, whereas Check 1 and Check 2 recorded 20.8 g and 16.09 g, respectively. Both Checks 1 and 2 excelled in fruit length at seven days, with measurements of 15.21 mm and 11.23 mm, respectively. OK11, OK1, and OK17 performed best for fruit width, while OK09 had a long fruit length of 9.80 mm. The time (d) from sowing to the appearance of the first flower occurred at 38 days in Checks 1 and 2, while the genotype OK16 flowered late at 103 days. The number of fruits culled per plot was the least at 23 fruits in OK13, whereas OK8 had the highest at 135. Regarding fruit numbers, OK8 (134), OK9 (123), OK17 (118), and OK18 (102) had high mean values. OK16 is tall at 187 cm at maturity. The fruit weight per plot was highest in OK8 at 3194.25 g, followed closely by OK17 (3148.85 g), OK18 (2710 g), and OK9 (2341.4 g). The ash content in fruits culled at 7 days post-flowering was highest (11.28%) in OK6, followed by OK19 (11.13%), OK7 (10.77%) and OK10 (10.28%) (Table 4). In terms of protein content in fruit culled at 7 days, OK3 (14.92%), OK2 (14.33%), OK5 (14.57%), and OK6 (15.23%) demonstrated the highest levels. Conversely, OK13 (13.06%), OK2 (12.75%), OK1 (12.43%), and OK5 (12.41%) performed best in protein content in okra meal (Table 4). The top three entries for fiber content in fruits harvested at 7 days were OK6 (20.30%), OK3 (18.66%), and OK2 (18.08%), while OK15 (11.77%), OK16 (10.59%), and OK11 (10.36%) performed poorly. Moreover, OK6 consistently had high protein and fiber content in the fruits at 7 days, although in the okra meal, OK3 and OK15 outperformed the other genotypes for protein and fiber, respectively (Table 4). The viscosity of the fresh fruit was lowest in Check 2 (0.86 cP) but highest in OK05 (3.25 cP). The genotypes OK05 (3.25 cP), OK08 (2.72 cP), and OK02 (2.67 cP) performed best for viscosity in fresh fruit; however, their performance in okra meal varied, with OK08 retaining consistent results. OK15 (0.64 cP), OK8 (0.55 cP), and OK14 (0.58 cP) showed high mean viscosities in okra meal. The largest difference in protein content between fresh fruit and okra meal was observed in OK6 (5.19), OK17 (3.68), and OK11 (2.91), while the smallest differences were noted in OK15 (0.11) and OK2 (5.26), Check 2, and Check 1 (0.39). Additionally, OK05 (6.14) and OK11 (5.63), OK09 (5.39) and OK16 displayed superior zinc (5.08 mg) content in fresh fruit, whereas OK05 (6.34 mg), OK09 (4.75 mg), and OK16 (4.75 mg) recorded high zinc (mg) content in okra meal. Taking multiple traits (protein, fiber, zinc and viscosity in fresh fruit and okra meal) into account, OK6, OK5, OK13, and OK3 show promise for protein, fiber, and zinc content in fresh fruits. Among the fresh fruit samples, check 01 had the lowest viscosity at 0.66 cP. In contrast, OK5 (3.25 cP), OK8 (2.72 cP), OK2 (2.67 cP), and OK17 (3.46 cP) exhibited higher mean viscosity values.

Table 3
Mean values for agronomic and fruit metric traits in 21 Okra genotypes during 2023 and 2024 cropping seasons

CHECK 01	Days to anthesis	Plant height (cm)	Individual fresh fruit weight	Fruit length (cm)	fresh fruit width (cm)	Fresh fruit weight/plot (g)	Flowering cycle
	39	**135.4**	**20.8**	**15.21**	**1.83**	**1928.46**	**38**
CHECK 02	32	122.86	16.09	11.23	1.13	1857.27	38
OK01	35	84.2	18.08	4.76	2.75	1288.44	81
OK02	30	136.76	17.77	7.59	2.51	825.61	82
OK03	31	122.63	13.88	6.51	2.18	495.69	84
OK04	32	172.76	18.94	7.87	2.37	1258.78	85
OK05	40	172.13	13.01	7.92	2.22	817.57	93
OK06	46	158.26	15.31	6.06	1.56	795.4	97
OK07	43	142.5	12.436	7.17	1.59	353.78	95
OK08	31	119.66	21.67	8.32	2.32	3194.25	80
OK09	33	107.6	19.66	9.8	2.23	2341.41	78
OK10	33	118.13	10.65	6.94	2.41	621.77	84
OK11	37	166.13	31.31	8.5	2.95	1862.42	89
OK12	40	132.03	21.06	6.68	2.39	860.18	91
OK13	39	145.75	15.3	8.02	2.09	410.11	87
OK14	39	129.7	22.94	9.51	2.43	1262.41	87
OK15	39	167.66	22.07	7.23	2.55	1549.77	85
OK16	35	186.6	19.37	7.71	2.1	1084.28	103
OK17	35	175.56	22.22	8.73	2.67	3148.85	79
OK18	34	178.2	25.76	9.57	2.57	2710.61	85
OK19	35	122.46	20.45	8.1	2.53	1096.02	86

Table 4
Mean values for fruit proximate, nutrient and quality attributes of 21 Okra genotypes culled at 7 days after flowering and Okra meal during 2023 and 2024 seasons

Genotype code	Ash (%)	Protein (%)	Fiber (%)	Zinc (%)	Viscosity (cP)	Protein (%)	Fiber (%)	Viscosity (cP)	Weight of 50 Fruits (g)	Difference in protein over fresh fruit and okra meal	Difference in fiber over fresh fruit and okra meal	Difference in viscosity over fresh fruit and okra meal	Dry weight of 50 fruits
	In okra fruit culled at 7d					In okra meal							
CHECK 01	9.07	10.31	11.94	4.12	4.01	10.05		0.89	928.84	0.34	6.07	0.50	137.42
CHECK 02	9.63	10.62	12.99	4.29	0.86	10.63	10.25	0.86	995.15	0.40	4.22	0.53	132.32
OK01	7.53	13.19	16.14	4.76	1.30	12.43	8.23	1.30	942.29	0.67	7.99	0.41	132.73
OK02	9.16	14.33	18.07	5.26	2.66	12.75	8.50	2.66	907.69	1.14	9.64	0.45	223.36
OK03	8.56	14.92	18.66	4.94	2.37	13.06	7.59	2.37	661.92	1.48	14.02	0.33	137.77
OK04	6.27	10.82	15.71	2.80	1.72	9.56	9.12	1.72	905.30	2.28	6.61	0.45	125.37
OK05	9.23	14.57	17.30	6.14	3.25	12.41	7.47	3.25	630.5	2.15	9.83	0.40	94.50
OK06	11.28	15.23	20.30	3.90	2.42	10.11	7.38	2.42	782.19	5.19	13.13	0.37	118.98
OK07	10.77	13.98	18.09	4.62	2.19	10.22	9.41	2.19	633.32	3.72	8.93	0.40	92.71
OK08	8.92	11.47	15.51	2.75	2.72	10.66	9.60	2.72	1223.30	1.47	6.26	0.57	240.65
OK09	9.14	11.61	17.22	5.39	1.55	5.19	7.60	1.55	953.71	2.43	9.64	0.39	117.72
OK10	10.28	12.32	12.53	3.06	0.96	5.45	9.23	0.96	526.89	2.89	3.17	0.43	88.69
OK11	8.75	12.98	17.37	5.63	1.73	5.99	10.36	1.73	1554.90	2.90	6.89	0.48	781.05
OK12	8.46	11.57	14.36	4.91	1.24	8.66	10.62	1.24	979.53	2.85	3.66	0.55	134.76
OK13	9.55	9.73	13.16	2.57	0.33	7.18	7.96	0.33	772.3	2.57	4.21	0.48	133.09
OK14	9.23	9.36	11.00	2.09	0.87	6.92	10.23	0.87	1178.07	2.40	0.66	0.58	158.77
OK15	7.95	10.17	13.47	4.16	1.54	10.08	11.77	1.54	1176.20	0.11	1.76	0.64	199.72
OK16	8.65	10.31	13.65	5.08	1.62	8.80	10.59	1.62	1032.95	1.48	6.54	0.56	117.26
OK17	10.53	12.65	16.57	4.92	2.46	9.04	9.81	2.46	1347.40	3.68	6.70	0.54	178.89
OK18	9.35	11.32	12.92	3.16	1.74	9.58	8.43	1.74	1366.93	1.65	4.28	0.46	298.89
OK19	11.13	9.62	13.18	3.63	1.21	11.82	10.91	1.21	1029.19	2.15	2.21	0.53	192.28

In terms of nutritional attributes, OK04 was found to be high in protein, while OK08 excelled in viscosity in both fresh fruit and okra meal, as well as fruit weight and number. Genotypes OK13 and OK14 showed promise for greater fruit viscosity in fresh fruit. OK10 and OK18 were identified as the top performers in fruit weight, achieving a moderate yield of fresh fruit harvested per plot. OK3 and OK5 were recognized for their superior protein content in fresh fruit, with OK5 also leading in fiber content. Both OK2 and OK5 showed potential for viscosity, while OK17, OK7, and OK16 performed best in terms of ash content and fruit weight. OK17 outperformed other genotypes for fruit weight and OK16 for fiber in okra meal. OK19 was notable for its ash content in fresh fruit and fiber in okra meal. Moreover, OK11 ranked highest for fiber and zinc in fresh fruit, with OK04 leading in protein content, and OK06 surpassing other entries in terms of high fruit viscosity.

The clustering of fruit metrics (fruit yield, fruit number, fruit length, and width at 7 days) appears on the right side of the correlation network, while other traits are positioned on the left. As shown in Fig. 1, morphological traits, fruit proximate, nutrient and quality attributes of fresh fruits and okra meal formed a distinct cluster. Fruit yield, number of fruits, fruit length, and width formed a cluster of positive associations with directly and indirectly associated traits. The ash content in fresh fruit, days to anthesis, and fruit length displayed direct and indirect associations. The zinc in okra meal, zinc in fresh fruit, protein content in okra meal, viscosity in fresh fruit and fiber in fresh fruit formed a group of fruit attributes that are positively associated. On the other hand, protein and fiber in fresh fruit, viscosity and fiber in okra meal formed a cluster of negatively associated fruit attributes. Further, viscosity and fiber in fresh fruit, and fruit length, constitute a group of positively associated traits. The protein and zinc contents in fresh okra fruit were positively associated with protein and zinc in okra meal. In contrast, the viscosity and fiber in okra meal are negatively correlated with viscosity and fiber in okra meal.

Hierarchical clustering of twenty-one genotypes of West African okra, based on morpho-physiological, proximate, and fruit quality attributes, grouped the twenty-one West African okra genotypes into four clusters (Fig. 2), represented by red (cluster 1), black (cluster 2), green (cluster 3), and blue (cluster 4). Cluster one included six genotypes (OK06, OK01, OK03, OK09, OK02, and OK05). Within this cluster, OK01, OK03 and OK02, OK05 are closely related, linking them at the lower end to OK06 and OK09. Members of this cluster exhibited better performance for protein (OK03 and OK06), zinc (OK05), and viscosity

(OK02 and OK05) in fruits culled at seven days. OK02, OK03, and OK05 also demonstrated optimal protein levels in okra meal, with a lower fiber content in fresh fruits. Cluster 2 consisted of OK17, OK07, and OK16. The members of this cluster showed promise for high ash content and fruit weight (OK17) in fresh fruit, as well as high fiber content in okra meal (OK16). Both Check 1 and Check 2 were placed in cluster 3, which showed the lowest reduction in protein content in fresh fruit compared to okra meal, while OK19 excelled in ash content. The analysis of fresh fruit and fiber content in okra meal revealed the clustering of nine genotypes into four distinct groups. The third cluster comprised nine genotypes into four distinct groups. Genotypes OK15, OK11, and OK12 were categorized into sub-cluster ' a ', while OK04 and OK08 formed sub-cluster 'b'. Additionally, OK13 and OK14 were grouped in sub-cluster 'c', and OK10 and OK18 in sub-cluster 'd'. Members of sub-cluster 'a' demonstrated promise in terms of fiber and zinc content in fresh fruit. OK15 exhibited the least numerical reduction in protein levels in fresh fruit compared to okra meal.

The fiber content in fresh fruit showed a positive correlation coefficient with zinc levels in okra meal (r = 0.58*), protein in okra meal (r = 0.54*), viscosity in fresh fruit (r = 0.54**), and protein in okra fruit (r = 0.59**), while displaying a negative correlation coefficient with fruit length at maturity (r= -0.46**) and fruit width (r = 0.50*) (Table 5). Protein content in fresh fruit was positively correlated with zinc content in okra meal (r = 0.78**), protein content in okra meal (r = 0.77**), fiber in fresh fruit (r = 0.59**) and a negative correlation coefficient with plant height (r= -0.46). Conversely, protein content in okra meal was positively correlated with zinc in okra meal (r = 0.90**), viscosity in fresh fruit (r = 0.57**), protein content in fresh fruit (r = 0.77**), fiber in fresh fruits (r 0.54*), but was negatively correlated with plant height (r= -0.60**) and fruit length (r-0.60**). Zinc contents in okra meal correlated positively with protein contents in okra meal (0.90), viscosity in fresh fruit (r = 0.49**), protein in fresh fruit (r = 0.78**), fiber (r = 0.58**) and negatively with plant height (r= -0.64**), and fruit length at maturity (r = – 0.68**). The fiber in okra meal had a positive and significant correlation coefficient with viscosity in okra meal (r = 0.92**), fresh fruit weight/plot (r = 0.75*), and fruit length (r = 0.60*). The viscosity in okra meal had a positive correlation coefficient with fruit length (r = 0.48*), and fiber in okra meal (r = 0.92).

Regression Analysis

The linear relationship between mass of fruits culled at 7 days (X) and the fresh fruit weight per plot (Y) indicated a positive 'b' value (100), a negative intercept value (a = -620), and a significantly moderate positive linear regression coefficient (R^2 = 0.57) at a 0.001 level of probability (Fig. 3a). The prediction equation for this linear regression is as follows:

Y = -620 + 100X (3)

The linear relationship between fruit weight per plot (Y) and fruit number per plot (X) demonstrates a positive correlation coefficient, characterized by a negative intercept of -530, a positive coefficient (b) of 29.0, and an R^2 value of 0.84 (Fig. 3a, b). The prediction equation for this linear relationship can be expressed as follows:

Y = -520 + 29X (4)

The contour and perspective plots depicting fruit weight per plot as a function of both fruit number and fruit length (Figs. 4a, 4b) indicate that fruit weight was strongly influenced by fruit number compared to fruit length. Specifically, at a fruit number of 25 and a fruit length of 7.5 cm, the fruit weight per plot remained below 500 g. In contrast, a fruit number of 100 combined with a fruit length greater than 7.5 cm resulted in a maximum fruit weight per plot reaching up to 3000 g.

Furthermore, the multiple regression analysis of the dependent variable, fruit yield (Y), as a function of fruit width (X_1), fruit length at 7 days (X_2), fruit width at 7 days (X_3), days to anthesis (X_4), plant height at maturity (X_5), fresh fruit weight per plant (X_6), number of fruit per plot (X_7), and days from anthesis to the appearance of last flower (X_8) yielded a statistically significant model (Table 6). This model displayed an R^2 value of 0.98 and an adjusted R^2 of 0.98, along with a negative intercept of -171.20. The prediction equation representing the contributions of these variables to fruit weight is as follows:

Table 6
Multiple regression analysis of individual fruit weight (X1), fruit length (X2), days to anthesis (X3), plant height (X4), fresh fruit weight (X5) fruit weight/plant (X6) and flowering time (X7) on fruit weight per plot (Y).

Intercept	Estimate	Standard Error	t -value	Pr(> ltl)
	-171.20	**181.79**	**-0.94**	**0.35**
Individual fresh fruit weight	70.51	5.58	12.63	0.00012
Fruit length at 7d	-56.17	13.47	-4.17	0.00019
Days to anthesis	-1.17	5.65	-0.21	0.84
Plant height	0.62	0.79	0.79	0.44
Fresh fruit weight per plant	-69.60	53.50	-1.30	0.20
Number of fruits per plot	21.57	0.85	25.27	0.00011
Flowering time	-8.07	3.34	-2.41	0.02

VCO = Viscosity in okra meal, FBO = Fiber in okra meal, PROF = Protein in fresh fruit, FIB= Fiber IFL= Individual fruit length, DFF= Days to flowering, VCF = Viscosity in fresh fruit, PROK = Protein in okra meal, ZNF = Zinc in fresh fruit, PHT = Plant height, FLT = Flowering time, ZNO= Zinc in okra meal, IFD = Individual fruit diameter, IFW= Individual fruit width, ASH = Ash content in fresh fruit, TFR = Total fruit harvested, FRY = Fruit yield, FRN= fruit number/plant.

$Y = -171.2 + 70.51(X_1) - 56.18(X_2) - 1.18(X_3) + 0.62(X_4) - 69.6(X_5) + 21.58(X_6) - 8.07(X_7)$.

Discussion

Breeding efforts in biofortification have revealed that the utilization of West African okra fruits remains limited. As a result, high fruit-yielding and nutrient-dense varieties are not widely available for commercialization. There was a significant genotypic response for the length and width of fruits culled at 7 days, fruit weight per plot, proximate (protein and fiber) and nutrient (zinc and ash) contents, as well as viscosity in fruits culled at 7 days and okra meal. Those variations are attributed to genetic factors. Differences in flowering time, plant height, fruit length, and protein content in fresh fruits correlated with variations in temperature, sunshine hours, humidity, and precipitation data during the years. Therefore, further investigations are essential to identify stable and high-performing genotypes. In another study, [19] illustrated the distinctions among okra germplasm regarding agronomic and nutritional traits. The sensitivity of fruit length and protein content in fruits culled at 7 days, as well as okra meal, to the Genotype-Year Interaction (GYI) suggests a curvilinear relationship between fruit length, protein content in fresh fruit, and okra meal, and the environment, along with non-additive cross-over performance. Therefore, predicting fruit length and protein content in fresh fruit and in okra meal solely from genotypic responses is challenging, particularly for selecting superior West African okra genotypes for crop improvement. Relying exclusively on phenotypic measurements for selection and recommendations would also be insufficient. This illustrates the need for further assessments across multiple locations and years before making selections. The insensitivity of fiber, zinc, and ash contents in both fresh fruit and okra meal indicates a clear lack of crossover performance and linear response of the genotype to the environment for these traits, which exhibit high broad-sense heritability and a favourable selection response.

Growers' choices of West African okra varieties are largely influenced by market standards and end-user preferences. Genotypes such as OK11, OK18, OK14, OK17, and OK15 show promise for fruit yield and fruit yield component traits at seven days. Check 1 and Check 2 performed better than other genotypes concerning fruit length, while OK17 stands out for its fruit width. OK2 is best for an early-maturing genotype suitable for two production cycles during the short-day lengths of July and February, assuming adequate water availability. The genotypes (OK3, OK5, OK6 and OK15) demonstrated higher protein, ash, zinc and fiber contents, making them superior sources for biofortification. Zinc is an essential micronutrient that plays a vital role in cellular metabolism, immune support and carbohydrate breakdown. An adult male requires 11 mg/day, while an adult female requires 8 mg/day. This may increase to 11 mg during pregnancy and 12 mg for lactating mothers [20]. In this investigation, results showed that the protein, ash, and zinc contents in fresh okra fruit are significantly higher than those found in pulses, which contain 2.93 mg/100 mg of zinc, and in maize, which has protein content ranging from 3.5% to 4.5%, 1.5% to 2.0% ash, and 1.5% to 2.1% crude fiber Ranum et al 2014 [21] and Singh et al 2014 [22]. OK6, OK7, OK10, OK17 and OK19 are potential donor parents for ash content in fresh fruits, and possess favourable alleles associated with high protein content in fruits harvested at 7 days. In contrast, OK3, OK2, OK1, and OK5 show promise for high protein content in okra meal and are promising as donor parents in the Okra breeding program. Furthermore, the okra meals from OK15, OK19, OK12, and OK11 are optimal for high fiber content. Similarly, OK6, OK3, OK7, and OK2 exhibit potential for fiber content in fresh fruit. Dietary fiber is vital for supporting the digestive system, regulating blood sugar and cholesterol levels, and assisting within weight management. The recommended daily intake is about 25–38 grams for men and 21–25 grams for women. OK6 averaged 20 mg/kg of fiber, aligning closely with World Health Organization (WHO) standards. The desirability of a genotype is more reliably assessed when multiple traits are considered rather than focusing on a single characteristic [23]. OK6 performs well in both protein and fiber content in fresh fruits, while OK3 and OK15 are notable for protein and fiber content in okra meal. This highlights a varied array of West African okra genotypes suitable for both fresh fruit consumption and okra meal production. For viscosity in fresh fruit, OK5, OK9, OK16, and OK7 are particularly desirable, whereas OK5, OK8, OK2, and OK17 show promise for viscosity in okra meal. Okra viscosity is important for granule swelling and the strength of the associative forces between molecules. The range of okra mucilage viscosity in this study was higher than that reported by Adetuyi et al 2011 [24] and Ofori et al 2020 [25]. OK5 had the highest fruit viscosity, showing its ability to form a gel during cooking Ameena et al 2010 [26] and its suitability for consumption. Even though low-viscosity okra is desirable as a composite for baby foods Ofori et al 2020 [25].

West African Okra breeding program aimed at recombining genes for fruit yield and nutritional content, a diallel crossing pattern among OK11, OK18, OK2, OK7, and OK6 will develop a segregating population ideal for the selection of pure lines, multiline, and hybrids that mature early or at a medium time, guaranteeing high fruit yield and nutrient richness. Recognizing nutrient-dense genotypes can greatly improve breeders' crossing blocks. The clustering of

twenty-one genotypes into four groups based on agronomic, proximate, nutrient, and fruit quality attributes suggests that inter-cluster differences could be leveraged to develop superior hybrids and composites, therewith broadening the genetic diversity of West African okra genotypes. In cluster 1, genotypes OK03 and OK06 excelled in protein and fiber content in fruits culled at 7 days, while OK05 proved ideal for zinc and viscosity in both fresh fruits and okra meal. Additionally, OK02 showed promise for viscosity in fresh fruit. This illustrates the substantial variation within groups that can be harnessed, either through the selection of donor parents for single or multiple traits, or through the development of composites with transgressive segregants to enhance biofortification. Furthermore, OK06, OK02, and OK05 possess positive alleles for protein, ash, fiber, and zinc in fresh fruit. In cluster 2, genotypes OK17, OK07, and OK16 exhibited high performance in terms of ash content, fruit weight in fresh fruit, and fiber in okra meal. Inter-cluster crossing between members of clusters 1 and 2 will lead to new recombinants that is able to enhance fruit yield, proximate nutrients, and overall quality, resulting in the development of new varieties and hybrids. Cluster four displayed the greatest variability among the West African okra genotypes with respect to nutrients in both fresh fruit and okra meal.

Correlation is important for developing efficient selection methods to enhance fruit yield components. The fruit width, fruits per plot at 7 days, and the mass of fruits culled at 7 days per plot are directly linked to overall fruit yield. Improving the phenotypic traits related to fruit number per plant and fruit width will complement improvements in fruit weight. Also, the fruit length increases with age; likewise, the fiber in the fruit. A significant negative correlation exists between fruit length at 7 days and fiber content in fresh fruit, indicating that as fiber content increases, fruit length also tends to increase. The zinc and ash contents in fresh okra fruit at seven days showed a hub of interconnectivity with other traits, with both positive and negative associations. Nutritionally, older okra fruits become fibrous and less palatable. There is a positive association between protein content in fresh fruit and both fiber and zinc, as well as viscosity and protein levels in okra meal. This suggests that simultaneous improvements in these attributes are significant and offer opportunities for reciprocal nutrient improvements. Furthermore, the nutrients and quality characteristics of the fruit are positively associated with one another, indicating the potential for combined multi-nutrient biofortification. A significant negative association between fiber and viscosity in okra meal derived from 7-day-old fruits suggests that an intentional increase in fiber content beyond this period, which correlates with fruit maturity, may lead to lower viscosity in okra meal. The drying and milling processes of okra fruits reduce moisture content, impacting the viscosity of the resulting okra meal. The positive correlation between protein, fiber, and zinc in fresh fruit, along with protein levels in okra meal, indicates that improving protein content is supported by selecting for these nutrients.

This investigation also supports combined multi-nutrient biofortification in okra. However, the enhancement of protein content in fresh fruit, fiber, and viscosity in okra meal may not significantly increase the high protein levels due to their independent associations. The fiber in fresh fruit shows a positive correlation with zinc, viscosity, and protein in okra meal. This finding is key for promoting food security and confronting global zinc deficiency. Furthermore, the relationship between days to 50% flowering and nutrient content (protein) is found to be insignificant and negatively correlated, which is a challenge with developing early lines that possess high protein content. The selection of protein in okra meal, along with zinc and other factors, can effectively support protein improvement. The positive correlation between zinc and other nutrients (fiber, viscosity, and protein) suggests a reciprocal enhancement of nutrients. Although the association between zinc and fruit yield is insignificant, it remains positively correlated, highlighting its importance in advancing food security and mitigating zinc deficiency globally. Nutrient-dense genotypes with favorable agronomic characteristics can improve food and nutritional security. Insights from this study can serve as a foundation for single-nucleotide polymorphism (SNP)-based genome-wide association studies (GWAS) aimed at identifying genetic variants linked to nutrients that could boost genetic gains in okra biofortification. A bi-dimensional network representation of a p-dimensional correlation matrix can aid in detecting important structures and complex patterns. The interaction among fruit nutrients, fruit morphometric traits, and yield attributes constitutes a distinct focus of this research. The results suggest that the genotypes in this correlated group have strong potential for both nutrient enhancement and agronomic breeding. A correlation structure that includes nutrients such as protein, fiber, zinc and viscosity appears to be reasonable. The clustering of traits related to nutrients in fresh fruit harvested at 7 days, as well as okra meal, from the central and bottom sections to the top right of the correlation network, indicates the effectiveness of genotype selection. This identification of both correlated and clustered traits backs the concept that direct selection of traits can facilitate nutrient improvement. Furthermore, the correlation between fruit-metric traits and a cluster of fruit-yield traits demonstrates the importance of indirect selection within a West African breeding program.

The negative intercept value in the linear regression analysis between individual fruit weight harvested at 7 days (X) and fruit weight per plot (Y) suggests that the line of best fit crosses the Y-axis below zero. This indicates that when the independent variables are at zero, the closer the data points are to this line, the stronger the relationship between individual fruit weight at 7 days and fruit weight per plot. Consequently, for every one-unit increase of the weight of fruit culled at 7 days, the fruit weight per plot increases by 100. The strength of this association is moderate, at 57% (Fig. 3a). Additionally, the linear relationship between fruit weight per plot (Y) and the number of fruit (X) shows that a considerable portion of the variation in fruit weight is explained by this linear function of the independent variable (number of fruits per plot) (Fig. 3b). This relationship is exceptionally strong; a 1-unit increase in fruit number corresponds to a 29-fold increase in fruit weight. The fruit weight is thus 29 times as much as the fruit per plot. This model can be utilized to estimate actual fruit weight and commercial production results. The multiple regression analysis of fruit weight (Y) based on factors such as fruit length, days of anthesis, and plant height further explains on this relationship. The dependent variable, fruit yield (Y), is modeled as a function of a number of factors: fruit width (X_1), fruit length culled at 7 days (X_2), fruit length at 7 days (X_3), days to anthesis (X_4), plant height (X_5), fresh fruit weight per plant (X_6), number of fruits per plot (X_7), and flowering time (X_8). This model shows a statistically significant relationship, with an R^2 value indicating that 98% of the total variation is explained. Furthermore, the high heritability observed for proximate nutrients (such as protein and ash) and viscosity in fruits culled at 7 days, as well as in okra meal, suggests a strong potential for these traits to respond favorably to breeding and selection efforts, particularly through backcrossing geared toward enhancing biofortification.

Conclusion

This study demonstrates significant genetic variability for agronomic traits, protein, fiber, zinc, and viscosity in fruits harvested at 7 days and in okra meal. The observed variation among West African Okra genotypes presents an opportunity to develop varieties with enhanced agronomic performance and nutrient profiles, including protein, fiber, zinc, and viscosity in fresh fruits culled at 7 days and in okra meal. Diallel hybridization could generate new recombinants that yield improved fruit output and nutrient-dense varieties, thereby contributing to food security and addressing malnutrition. Furthermore, conducting molecular analyses of macro and micronutrient variability in conjunction with sequencing West African Okra genotypes could facilitate the development and selection of promising varieties based on their agronomic and biochemical traits.

Abbreviations

MMT= million metric tonnes

SDG = Sustainable Development Goals

PROC GLM = Procedure of the Generalized Linear Model

SNP = Single-Nucleotide Polymorphism

TETfund = Tertiary Education Fund

Declarations

● Ethics approval and consent to participate

The study has no conflict with the norms and beliefs of the people in West Africa. we have a consent of the University and the community to carry out this research.

● Consent for publication

This research was approved by TETfund (Tertiary Education fund in Nigeria) the Principal Investigator has the consent of the research group to publish the findings emanating from the study.

● Availability of data and materials (Please ensure to provide exactly the same statement of Data availability on the submission system and in the main manuscript)

The data used in this investigation were analyzed and publish in the manuscript. In addition, the data is available for public use.

● Competing Interests

The research group and authors have to competing interests

● Funding

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● Authors' contributions
Prof Adeniji, O.T (Principal Investigator, conceived the research, experimental layout, data analysis, laboratory analyses, report writing and finalization of the report)

Prof. Adekoya Modinat (Researcher, was involved in the experimental layout, laboratory analysis, data collection and report writing)

Dr Badmus, Adesile (Researcher, field establishment, data collection, report writing)

Dr Baiyeri Samuel (Researcher, was experimental layout, field investigation, data analysis, report writing).

Dr Iseghohi Innocent (Researcher, was involved in field investigation and data collection)

Ajewole Grace (Research student, field establishment, data collection and data analysis)

Olutayo Goodness (Postgraduate research student, field establishment, data collection and data analysis)

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Table 5

Table 5 is available in the Supplementary Files section.

Figures

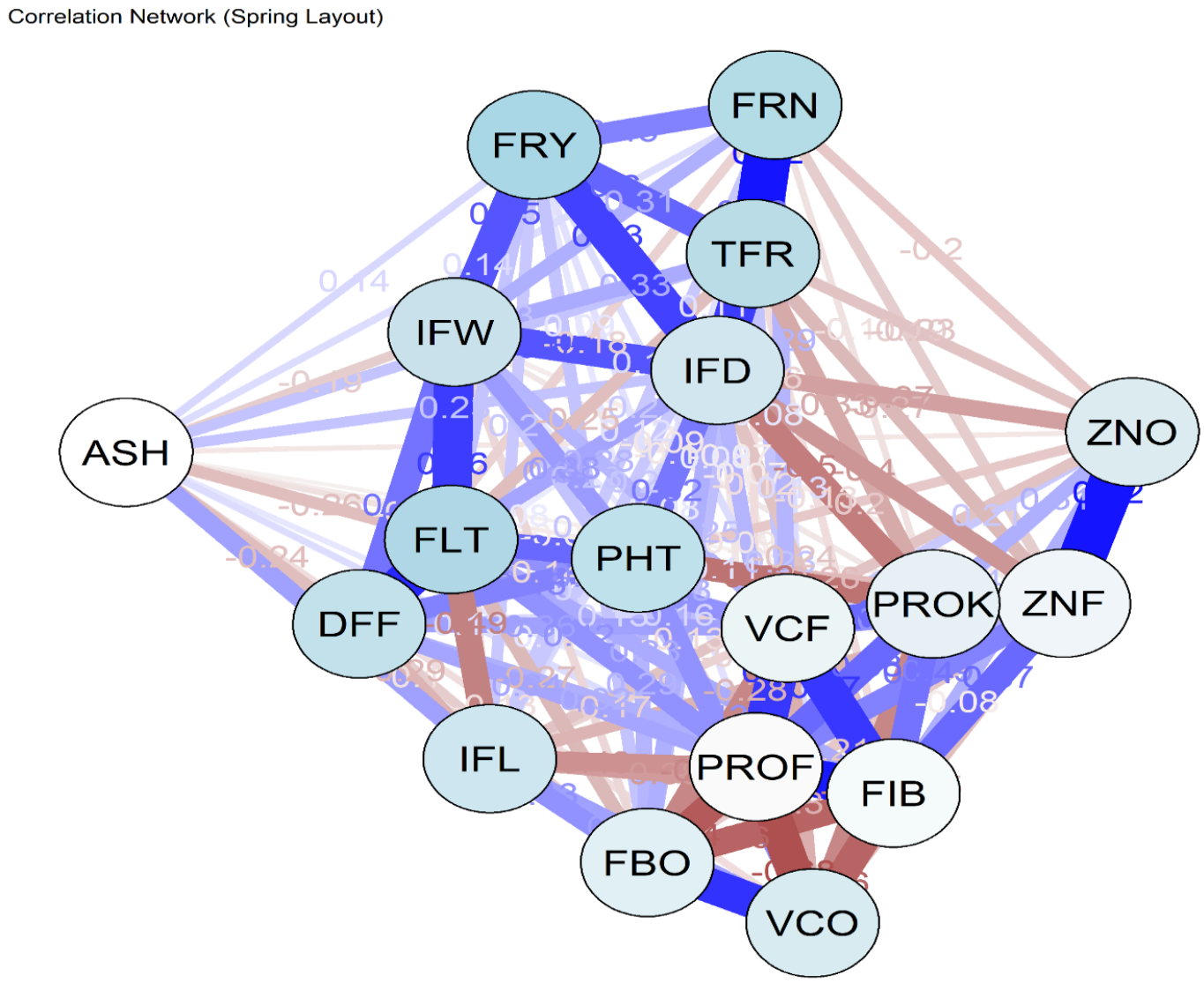

Figure 1

Correlation network among morpho-physiological and fruit proximate, nutrient and fruit quality attributes of fresh and okra meal.

VCO = Viscosity in okra meal, FBO = Fiber in okra meal, PROF = Protein in fresh fruit, FIB= Fiber IFL= Individual fruit length, DFF= Days to flowering, VCF = Viscosity in fresh fruit, PROK = Protein in okra meal, ZNF = Zinc in fresh fruit, PHT = Plant height, FLT = Flowering time, ZNO= Zinc in okra meal, IFD = Individual fruit diameter, IFW= Individual fruit width, ASH = Ash content in fresh fruit, TFR = Total fruit harvested, FRY = Fruit yield, FRN= fruit number/plant.

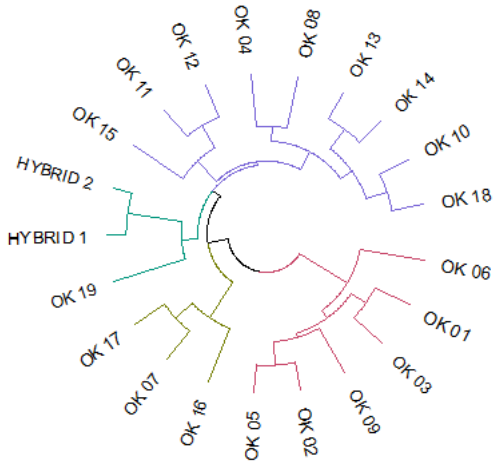

Figure 2

Hierarchical clustering of twenty-one genotypes of West African okra, based on morpho-physiological, proximate, and fruit quality attributes.

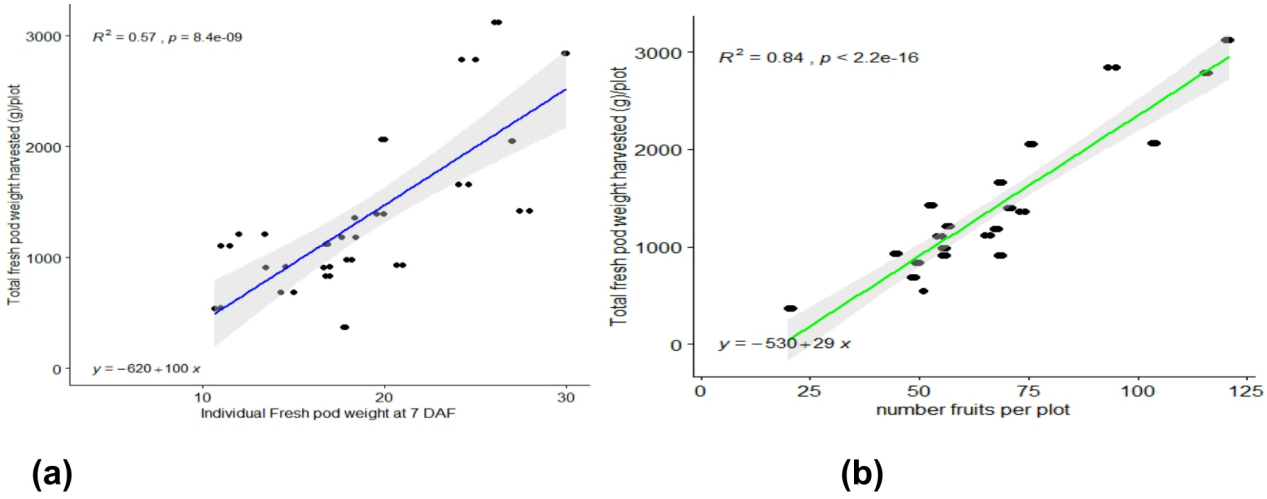

Figure 3

a, b. Scatterplots, regression lines and prediction equation between (a) fresh fruit weight (Y) and individual fresh fruit weight/plot (X) and (b) fruit weight/plot (Y) and number of fruits/plot (X).

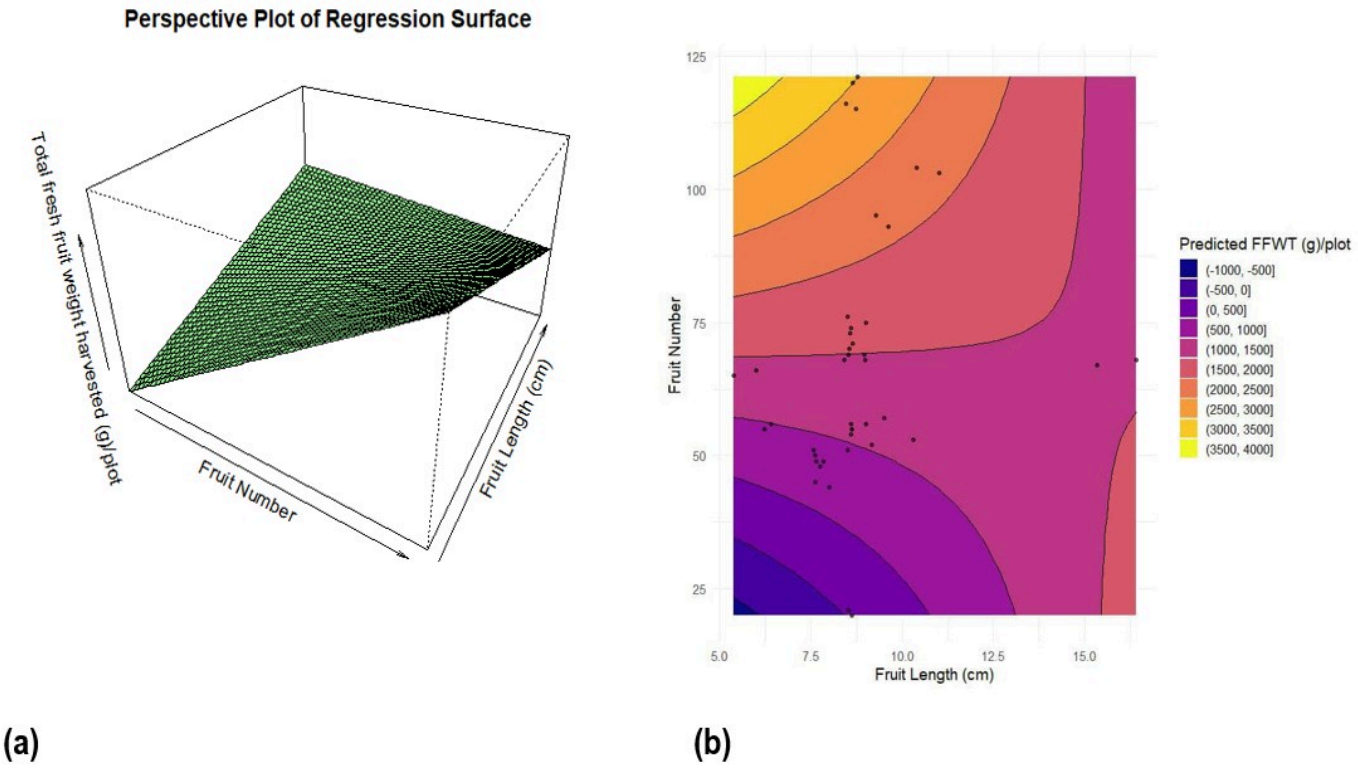

Figure 4

a, b. Perspective plot of multiple linear regression of fruit number (X_1), fruit length (X_2), and total fresh fruit weight/plot (Y).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table5.docx