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Original Paper

Morphometry of Mango Varieties and Sociodemographic Factors Influencing Mango Production in Uganda

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***Abstract*— Mangoes are Uganda's most extensively distributed fruit crop. This study documented the morphological characteristics of mango fruit varieties and farming practices aimed at developing value-added food products. A total of 390 mango growers participated in the survey. A digital weighing scale and Vernier caliper were used to measure the morphological characteristics of mango fruits at physiological maturity. Twenty-two mango varieties were identified. Kagoogwa, Apple mango, and Doodo were the common varieties grown by over 30% of the growers. Kent, Tommy Atkins, and Bire were also widely grown, as reported by over 20% of growers. Of the six commonly grown varieties, four were indigenous, namely, Kagoogwa, Apple mango, Doodo, and Bire. Kent recorded the highest fruit weight (830.00 g) and Koona had the lowest (107.50 g). Principal component (PC) analysis showed that PC1 and PC2 explained 85.93% of the overall variation in data. PC1 explained 76.06% of the variation and PC2 accounted for 9.87%. Both PC1 and PC2 were positively linked to fruit and pulp weights. However, PC1 had a substantial influence with an eigenvalue of 5.32 while PC2 had an eigenvalue of 1.69. Non-indigenous varieties were larger ($p<0.05$) and had more pulp than indigenous varieties. The study provides insights into mango diversity in Uganda and highlights the potential for commercial exploitation of these fruits in the development of nutrient-rich food products.**

Keywords*— Mango, Morphology, Sociodemographic factors

I. Introduction

Mango (Mangifera indica) thrives in tropical and subtropical regions [1]. Globally, the annual production of mangoes exceeds 57 million tonnes with Asia accounting for 73% of the total output, followed by Africa at 15% and America at 12% [2]. Mango production in Uganda is estimated at 875,000 metric tonnes per annum [3]. Uganda exports 10,112 tonnes of mangoes accounting for 3.4% of the country's gross domestic production [4, 5, 6]. However, data on the annual per capita consumption of mangoes in Uganda is lacking and yet essential for assessing the significance of mangoes in the daily diet of the population. Mangoes are consumed in largely fresh and juice forms [7]. Peels, seeds, and kernels are commonly discarded despite their inherent possibility for use in producing value-added food products [8, 9].

Mango growing in Uganda is distinguished by a diversity of varieties including indigenous and non-indigenous varieties [10]. Indigenous varieties have high fiber content and require less attention during growth [11]. The non-indigenous varieties have superior qualities especially higher juice yields and appeal to both local and international markets [12, 13]. Studies have focused mainly on the impact of climate change on mango cultivation and pests and diseases that affect mango yield [10, 14]. Limited research has been directed toward the exploration of mango varieties adopted by growers, their associated morphological characteristics, and agricultural practices. Morphological changes in fruits have a direct influence on nutrient content [15]. Larger fruits contain higher amounts of vitamins, minerals, and dietary fiber [15]. Reference [16] showed that as fruit size increased, the glucose and fructose content of cucumber increased from 0.80 to 1.16% and 0.95 to 1.25%, respectively. Information on mango diversity and morphology as well as their link with nutrient composition serves as a benchmark for screening varieties with higher prospects for use in the food industry

II. Materials And Methods

A. Survey Design

The survey was conducted across 10 agroecological zones in Uganda from March to April 2023. Luwero, Budaka, Nakaseke, Gulu, Nwoya, Abim, Rukungiri, Lira, Kagadi, and Kasese were surveyed since they are key mango growing areas within the zones. The study involved 390 mango growers. Individual interviews and field observations were conducted to obtain data.

B. Sample Collection

Mature green mango fruits were collected based on flat shoulder at the stem end, fullness of cheeks, presence of bloom, and change in peel color from dark to light green [17]. Five mango trees for each variety were selected from Luweero, Budaka, and Nakaseke. These sites had most of the mango varieties and prominent growers. Ten fruits per tree were randomly collected [18].

C. Determination of the Morphological Characteristics

The morphological characteristics of mangoes were measured in 10 replicates [19]. Fruit, pulp, peel, and stone weights were measured using a digital weighing scale (S-model HV-15KC, Japan). A digital Vernier caliper (Mitutoyo 500-196-20, Japan) was used to measure fruit length, width, and thickness.

D. Statistical Analysis

Data analysis was carried out using SPSS software version 22.0 (IBM, Chicago, USA) and JMP software version 15 (SAS Institute Inc. Cary, North Carolina). Welch's ANOVA was used to assess differences in fruit length, thickness, and peel weight between indigenous and non-indigenous varieties. Kruskal-Wallis test was employed to measure differences in fruit weight, width, pulp weight, and stone weight between indigenous and non-indigenous varieties. Pairwise comparisons further elucidated the specific varieties with different morphological characteristics. The principal component analysis technique was employed to investigate which morphological characteristics played a significant role in distinguishing indigenous and non-indigenous varieties. All values were significantly different at $p<0.05$.

III. Results And Discussion

A. Sociodemographic Characteristics Of Mango Growers

The majority (50.3%) of growers were in the age category of 36 and 45 years, with those over 45 years accounting for 41%. The age group of 25 to 35 years made up the least proportion (8.7%). Most (72.8%) growers were male while 27.2% were female. On average, 44.1% of mango growers had completed secondary school, 27.7% had finished primary school, 9.5% had attended tertiary school, and only 5.4% had a university degree. The percentage of growers without formal education was 13.3%. Most (61.3%) growers were self-employed. The growers also engaged in activities such as livestock and poultry rearing, vegetable and cereal cultivation, and operating grocery stores to diversify their revenue streams.

The findings agree with [20] who reported mango growing by middle-aged growers in Ghana but contrasted with [21] who recorded aged growers. Also, [20] reported that 89% of mango growers were men. In Africa, women are heavily involved in agricultural activities. However, the limited engagement of women in mango growing could be attributed to limited access to land and financial constraints [22]. The observed high number of educated mango growers provides core literacy that supports an understanding of agricultural techniques and the ability to embrace modern technologies [23]. This is evident in the competitiveness of the mango sector in Uganda [6]. The low involvement of university-educated growers could be attributed to limited access to tertiary education. Most growers were self-employed indicating that mango production is a profitable venture

B. Mango Growing Systems in Uganda

The majority (80.5%) of growers had mango trees within backyards while a few (19.5%) had farm fields. Most (76.5%) growers planted the mango trees whereas 23.5% had them in the wild. Backyard cultivation was preferred because of convenience and easy accessibility during regular field maintenance and harvesting. Reference [24] reported a similar situation where few (18.2%) growers planted mangoes on a commercial scale. The growers who planted mango trees used locally sourced seedlings and seeds from their own fruit harvest. Mango trees in the wild grew naturally either from discarded seeds or as remnants of old orchards. Farming systems in other developing countries employ monoculture with intercropping at early stages of mango tree growth [25, 20].

C. Features Used for Mango Variety Differentiation

Fruit shape was the primary feature for differentiating mango varieties reported by 53.0% of the growers. Only 34.9% of growers used fruit size. Peel color was reported by 10.2% of growers while apex shape was the least used feature at 1.9%. The findings align with [26] who adopted the use of fruit shape in the classification of fruits including mangoes. Growers prioritize the physical dimensions of fruit, influenced by consumer preferences and market demands. Few growers use the apex shape as a distinguishing feature because it is perceived to be of less importance compared to fruit size and peel color.

D. Mango varieties grown in Uganda

Twenty-two mango varieties were identified in the 10 agroecological zones (Fig. 1). Indigenous mango varieties were mostly (68.3%) grown whereas 31.7% of the growers had non-indigenous varieties. Apple mango, Kagoogwa, and Doodo were the most grown varieties by over 30% of growers followed by Kent, Tommy Atkins, and Bire accounting for more than 20%. Boribo, Fairchild, Kakule, Palmer, Seena, Batawi, Mabbere, Sayuni, and Julie were the least grown (Fig. 2). The popularity of Kagoogwa, Apple mango, and Doodo could be attributed to climate adaptability, disease resistance, and desirable taste [12, 27]. The findings are supported by [28] who mentioned Apple mango as the most (80%) widespread variety in Kenya. India has about 1000 mango varieties, Kenya has 50, and the United States has 208 [29, 30]. Uganda has, therefore, not fully exploited the wide diversity of mangoes. This necessitates increased investment and strategic initiatives to unlock the potential of its mango processing industry to foster economic growth.

Fig. 1. Twenty-two Mango Varieties Grown in Uganda.

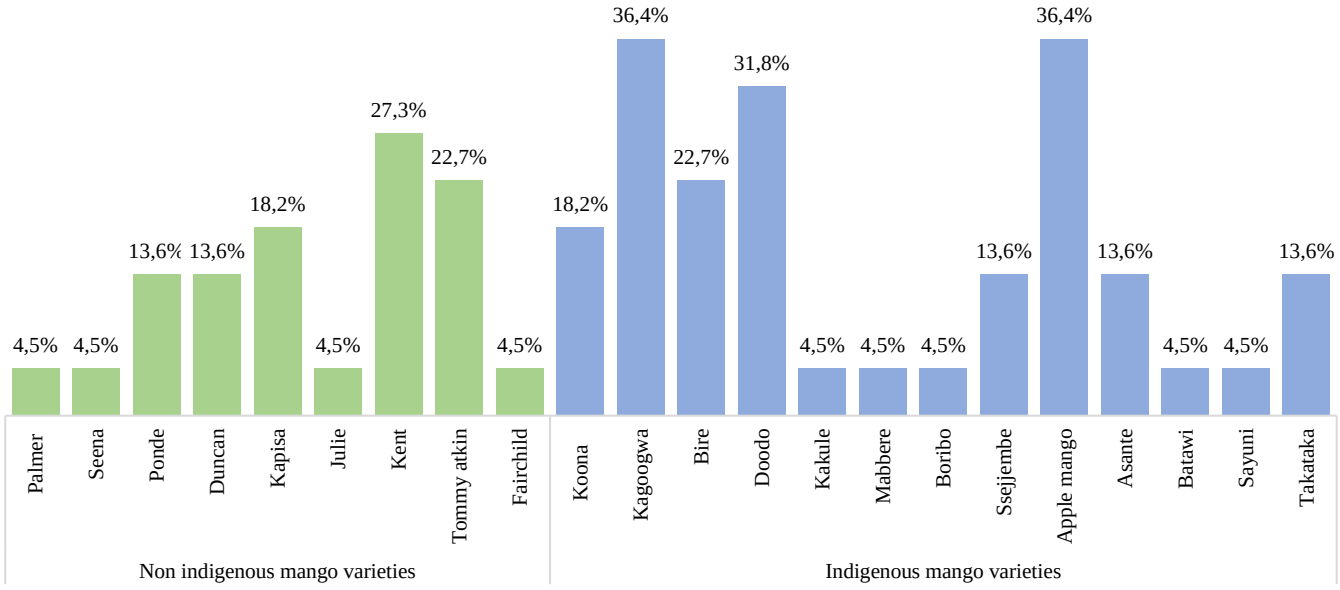

Fig. 2. Proportion of growers with various mango varieties.

E. Mango Growing Site Management Practices

Pruning was carried out by nearly half (47.7%) of the growers. Weeding was adopted by 26.1% of growers, followed by pest control at 21.4%, and application of manure and fertilizers at 3.8%. Conversely, irrigation ranked lowest at 0.9%. This was consistent with the findings of [31] who reported that 90% of growers in Ethiopia did not use fertilizers. The growers' limited use of inorganic fertilizer could be due to lack of expertise and exorbitant costs associated with the purchase and handling of fertilizers. The low yield and quality of mangoes in Uganda could be attributed to the insufficient use of fertilizers which hinders fruit-bearing mango trees from absorbing sufficient nutrients such as nitrogen, phosphorus, and potassium [21, 32]. Fertilization awareness program is therefore required to minimize the drop in yield and fruit quality [33]. Mango growers in Uganda did not have particular irrigation patterns which contradicts the findings of [31]. The depth and frequency of irrigation vary with the cultivar, age of the tree, cultural practice, and environmental conditions. Reference [34] reported that irrigated trees retained 33% of the fruits compared with 14% of non-irrigated trees. This disparity shows that inadequate irrigation practices among mango growers in Uganda directly affect the health and productivity of mango fruit trees in the region.

F. Pre-and Post-Harvest Handling of Mangoes

Most (48.4%) growers harvested mangoes while partially ripe. The ripe mangoes were harvested by 42.7% of the growers whereas 8.8% collected mature green fruits. Harvest maturity was determined by mostly (86.4%) changes in peel color. Only 5.1% of growers used the elevation of shoulders. Visual cues are an easier and more convenient way to judge ripeness. Hand picking of mangoes was the most (53.6%) common method for harvesting followed by the use of sticks at 45.7%. Reference [21] also reported similar mango harvesting practices.

A large proportion (92.1%) of growers reported that mangoes are consumed in mostly fresh form while 7.9% opted for juice production. Only 29.2% of growers utilized the peels and seeds as animal feed while 2.8% engaged in composting. Most (67.9%) growers discarded the peels and seeds generated from mango consumption. The byproducts were discarded probably because growers lacked a technological approach to develop nutrient-rich beverages and bakery products [9, 35].

G. Morphological Characteristics of The Mango Varieties

Fruit weight ranged from 107.50 to 830.00 g (Table I). The weights of peel, pulp, and stone for mango varieties varied from 21.25 to 101.50 g, 59.50 to 642.5 g, and 22.00 to 86.00 g, respectively (Table 1). Fruit width ranged from 49.75 to 109.66 mm, length from 76.25 to 161.41 mm, and thickness from 45.75 to 93.20 mm (Table 1). Kent exhibited the highest fruit weight (830.00 g), peel weight (101.50 g), pulp weight (642.50 g), stone weight (86.00 g), fruit length (161.41 mm), width (109.66 mm), and thickness (93.20 mm). Koona had the lowest fruit weight (107.50 g), fruit length (56.95 mm), and pulp weight (59.50 g). Seena had the lowest (22.00 g) stone weight. The lowest fruit width (49.75 mm), fruit thickness (45.75 mm), and peel weight (20.50 g) were observed in Fairchild. Differences ($p<0.05$) were recorded in the morphological characteristics of mango varieties.

TABLE I. . FRUIT WEIGHT, LENGTH, WIDTH, THICKNESS, PEEL WEIGHT, PULP WEIGHT, AND STONE WEIGHT OF INDIGENOUS AND NON-INDIGENOUS MANGO VARIETIES

Mango type	Mango variety	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Fruit thickness (mm)	Peel weight (g)	Pulp weight(g)	Stone weight(g)
Indigenous	Apple mango	360.62±84.49^{bc}	98.60±9.65^{bc}	93.99±7.84^{b}	83.18±7.26^{ab}	62.63±20.50^{bcd}	256.13±65.26^{bc}	41.88±3.68^{b}
	Asante	405.00±25.17^{bc}	95.33±3.32^{bc}	96.00±2.14^{b}	79.73±1.44^{b}	62.50±5.00^{bcd}	271.25±19.31^{bc}	71.25±7.50^{a}
	Batawi	518.75±59.77^{b}	131.68±6.06^{b}	92.43±0.88^{b}	81.33±5.78^{ab}	63.75±7.50^{bcd}	397.50±52.04^{b}	57.50±5.00^{a}
	Bire	336.11±51.76^{bc}	114.84±5.97^{b}	81.54±5.74^{b}	71.10±3.98^{c}	56.44±8.47^{de}	226.67±41.12^{bc}	53.00±6.54^{ab}
	Boribo	358.33±14.43^{bc}	97.40±5.24^{bc}	81.97±1.17^{b}	78.10±3.36^{bc}	83.33±2.89^{b}	220.00±10.00^{bc}	55.00±10.00^{ab}
	Doodo	410.71±30.30^{bc}	102.63±11.72^{bc}	88.23±6.97^{b}	78.13±9.60^{bc}	69.86±22.79^{bc}	288.14±14.06^{b}	52.71±11.54^{ab}
	Kagoogwa	163.67±36.97^{cd}	79.96±9.76^{de}	61.78±6.45^{b}	60.77±3.57^{d}	33.25±6.97^{f}	97.51±29.18^{e}	32.91±6.50^{b}
	Koona	107.50±10.61^{e}	56.95±0.92^{f}	57.45±5.16^{bc}	52.70±1.70^{e}	21.50±2.12^{g}	59.50±6.36^{e}	26.50±2.12^{bc}
	Mabbere	345.00±0.00^{bc}	117.67±5.13^{b}	72.33±2.52^{b}	67.00±2.65^{cd}	68.00±0.00^{bcd}	214.00±0.00^{bc}	63.00±0.00^{a}
	Sayuni	233.33±7.64^{c}	109.17±5.36^{bc}	69.83±3.15^{b}	61.00±1.14^{d}	48.33±2.89^{e}	155.00±5.00^{e}	30.00±8.66^{bc}
	Ssejjembe	232.50±6.45^{c}	99.75±6.50^{bc}	86.25±4.35^{b}	83.25±4.35^{ab}	74.75±2.50^{bc}	111.75±11.09^{e}	46.00±1.00^{b}
	Takataka	287.00±71.38^{c}	92.64±7.82^{bcd}	82.65±9.61^{b}	74.60±8.49^{bc}	48.88±0.72^{de}	195.37±13.27^{cd}	42.75±8.70^{b}
	Kakule	467.50±23.98^{b}	124.58±8.09^{b}	90.73±3.65^{b}	79.40±1.70^{bc}	85.25±6.55^{ab}	328.50±28.90^{b}	53.75±8.54^{ab}
Non- indigenous	Duncan	287.25±62.71^{bc}	117.50±5.97^{b}	81.50±3.70^{b}	68.00±3.56^{cd}	58.50±1.00^{d}	171.75±60.69^{cde}	57.00±2.00^{a}
	Fairchild	147.25±4.50^{bc}	76.25±3.86^{e}	49.75±2.75^{c}	45.75±2.06^{e}	20.50±1.00^{g}	101.25±5.50^{b}	25.50±1.00^{bc}
	Julie	413.75±17.02^{bc}	117.65±5.19^{b}	92.90±2.38^{b}	72.45±2.06^{c}	71.25±2.50^{bc}	306.25±13.14^{b}	36.25±2.50^{b}
	Kapisa	310.00±0.00^{bc}	103.40±2.79^{bc}	66.88±10.24^{b}	61.05±8.14^{d}	58.75±6.29^{cd}	196.25±9.64^{bcd}	55.00±5.77^{ab}
	Kent	830.00±20.76^{a}	161.41±11.39^{a}	109.66±4.40^{a}	93.20±6.57^{a}	101.50±5.88^{a}	642.50±11.04^{a}	86.00±20.31^{a}
	Palmer	545.00±0.00^{bc}	142.00±14.40^{ab}	101.25±12.85^{ab}	84.75±6.29^{ab}	108.25±6.50^{a}	400.00±6.00^{d}	46.75±0.50^{b}
	Ponde	324.00±0.00^{c}	136.33±4.73^{b}	96.67±2.52^{b}	84.67±3.51^{ab}	74.33±4.62^{bc}	171.34±10.97^{c}	78.33±6.35^{a}
	Seena	123.00±0.00^{de}	87.75±6.70^{cde}	69.70±5.04^{b}	62.08±1.31^{cd}	21.25±2.50^{g}	79.75±2.06^{e}	22.00±2.16^{c}
	Tommy Atkin	496.38±87.57^{b}	109.70±8.63^{bc}	95.55±7.33^{b}	86.60±5.45^{ab}	72.13±19.49^{bc}	361.87±72.53^{b}	62.38±8.13^{a}

Different superscript letters in the same column indicate significant differences ($p < 0.05$).

The findings were in agreement with [36] who reported variation in fruit weight among mango varieties ranging between 113.4 and 1906.30 g. The Kent variety in Uganda showed a similar pattern to the findings of [25] where it was

ranked among the heaviest varieties. Palmer exhibited lower fruit weight compared to the 566.7 g reported by [37]. Reference [38] also recorded a higher fruit weight of 600.0 g for Palmer which further highlights the variability of mango varieties. These discrepancies may be attributed to environmental factors, regional variations, and genetic differences [39]. The Mallika variety in India had the highest fruit length while the Ratna variety exhibited the highest peel weight [36, 40]. Reference [41] reported fruit length ranging from 80 to 148 mm for 20 indigenous mango landraces which is comparable to the findings. The absence of standardized nomenclature across studies necessitates taxonomists and horticulturists to form a unified mango classification system that transcends reliance on local names.

1) ANOVA and Kruskal -Wallis Test.

The Welch's ANOVA revealed significant differences in fruit length ($F = 22.316$, $p = 0.001$) and peel weight ($F = 7.288$, $p = 0.008$) between indigenous and non-indigenous mango varieties (Table 2). No variation ($F = 1.970$, $p = 0.163$) was observed in fruit thickness. From the Kruskal-Wallis test, observed p-values of 0.024, 0.008, 0.040, and 0.045 of the respective variables (fruit weight, fruit width, pulp weight, and stone weight) differed across the two mango groups. Differences in fruit traits between indigenous and non-indigenous mango varieties stem from genotypic factors [42].

TABLE II. WELCH'S ANOVA AND KRUSKAL-WALLIS TEST FOR MORPHOLOGICAL CHARACTERISTICS ACROSS INDIGENOUS AND NON-INDIGENOUS MANGO VARIETIES

Variable	Welch's ANOVA					
		Sum of squares	***Df***	***Mean square***	***F***	***Sig.***
Fruit length (mm)	Between groups	11110.745	1	11110.745	22.316	0.000
	Within groups	60742.764	122	497.892		
	Total	71853.509	123			
Fruit thickness (mm)	Between groups	304.892	1	304.892	1.970	0.163
	Within groups	18882.580	122	154.775		
	Total	19187.472	123			
Peel weight (g)	Between groups	4076.910	1	4076.910	7.288	0.008
	Within groups	68251.436	122	559.438		
	Total	72328.347	123			
	Kruskal-Wallis test					
Fruit weight (g)	-	-	-	-	-	0.024
Fruit width (mm)	-	-	-	-	-	0.008
Pulp weight (g)	-	-	-	-	-	0.040
Stone weight (g)	-	-	-	-	-	0.045

2) Principal Component Analysis

The total variation explained by the first two principal components; PC1 and PC2 was 85.93% with PC1 contributing 76.06% and PC2 explaining 9.87% (Table 3). The selection of PC1 and PC2 for the description of mango varieties was justified by respective eigenvalues of 5.32 and 1.69 (Table 3). Eigenvalues greater than 1 are considered significant [43]. PC1 and PC2 showed strong positive associations with fruit weight and pulp weight with positive loadings of 0.91 and 0.55, respectively (Table 3). PC1 predominantly reflected differences in mango size with high positive loadings for fruit weight, width, length, thickness, and peel weight (Table 3). Kent exhibited the highest positive scores on PC1 signifying larger and heavier fruits while Koona had the lowest negative scores indicating potentially smaller fruits (Fig. 3b). PC2 dominated by Fairchild captured additional unique traits beyond size (Fig. 3b). Non-indigenous varieties displayed positive loadings on both PC1 and PC2 indicating larger size and more pulp compared to indigenous varieties (Fig. 3a). This positive and negative loading observed in comparing morphological characteristics of indigenous and non-indigenous mangoes agrees with findings of [43] and [44].

TABLE III. LOADINGS AND SCORES OF THE PRINCIPAL COMPONENTS BASED ON MANGO TYPES AND MORPHOLOGICAL CHARACTERISTICS H'S ANOVA AND KRUSKAL-WALLIS TEST FOR MORPHOLOGICAL CHARACTERISTICS ACROSS INDIGENOUS AND NON-INDIGENOUS MANGO VARIETIES

Variables	Principle component					
	1	***2***	***3***	***4***	***5***	***6***
Fruit weight (g)	0.91	0.42	-0.04	0.04	-0.05	-0.00
Fruit width (mm)	0.90	-0.26	-0.26	-0.00	0.14	-0.20
Peel weight (g)	0.89	-0.25	0.05	-0.06	-0.38	-0.02
Fruit thickness (mm)	0.89	-0.28	-0.28	0.13	0.07	0.19
Fruit length (mm)	0.86	-0.06	0.23	-0.43	0.13	0.05
Pulp weight (g)	0.83	0.55	-0.11	0.02	-0.00	0.00
Stone weight (g)	0.83	-0.10	0.44	0.31	0.09	-0.02
Indigenous	-0.62	-0.07	-0.10	0.08	0.01	0.02
Non-indigenous	1.31	0.15	0.22	-0.16	-0.03	-0.05
Apple mango	0.29	-0.33	-1.03	0.19	0.07	0.01
Asante	0.88	-0.27	0.06	1.15	0.34	-0.40
Batawi	1.72	0.62	-0.07	-0.34	0.47	0.15
Bire	-0.10	-0.02	0.25	-0.13	0.22	-0.05
Boribo	0.41	-0.45	0.03	0.47	-0.74	0.13
Doodo	0.94	0.14	-0.35	0.30	-0.18	-0.10
Duncan	-0.33	-0.36	0.77	-0.26	0.23	-0.17
Fairchild	-3.20	2.39	0.30	-0.07	-0.26	-0.07
Julie	0.49	0.23	-0.61	-0.79	-0.25	-0.41
Kagoogwa	-2.94	0.11	0.12	0.13	-0.03	0.20
Kakule	1.50	0.03	-0.04	-0.39	-0.44	0.01
Kapisa	-1.05	0.33	1.07	0.02	-0.37	-0.00
Kent	5.40	1.19	0.31	-0.19	0.13	0.02
Koona	-4.04	0.26	-0.11	0.56	-0.07	-0.30
Mabbere	0.01	-0.01	1.19	-0.18	-0.14	0.17
Palmer	1.81	-1.56	-0.24	-1.25	-0.76	-0.07
Ponde	1.12	-2.12	1.09	0.02	0.68	0.02
Sayuni	-1.79	0.15	0.11	-0.97	-0.12	-0.01
Seena	-3.12	-0.07	-0.42	-0.41	0.56	0.05
Ssejjembe	-0.24	-1.36	-0.42	0.15	-0.36	0.32
Takataka	-0.86	-0.17	-0.45	0.27	0.21	0.04
Tommy Atkin	1.71	0.12	-0.40	0.57	0.10	0.10
Eigenvalues	5.32	1.69	0.41	0.30	0.19	0.07
% of variance	76.06	9.87	5.84	4.33	2.78	1.12
Cumulative (%)	76.06	85.93	91.77	96.10	98.88	100

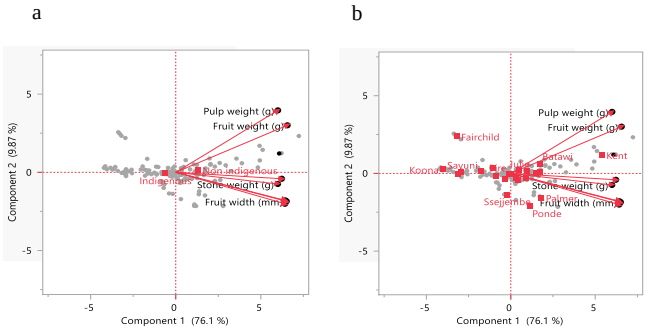

Fig. 3. Biplots of Qualitative Variables Represented On The Principal Components 1 And 2.

CONCLUSION

Middle-aged males play a pivotal role in the mango agricultural landscape of Uganda. Growers strongly preferred indigenous varieties especially Kagoogwa, Apple mango, Bire and Doodo. Non-indigenous varieties were superior to indigenous varieties in terms of fruit size and pulp quantity. Fruit and pulp weights emerge as crucial morphological characteristics for differentiating indigenous and non-indigenous mango varieties given their positive loadings on PC1 and PC2.

The research highlights the underutilization of mango peels, seeds, and kernels, creating a path for other studies to evaluate the nutrient composition of mango pulp and byproducts to boost the economic viability of the mango industry in Uganda.

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