frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 01 November 2023
DOI 10.3389/fsufs.2023.1252036

OPEN ACCESS

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RECEIVED 03 July 2023
ACCEPTED 04 October 2023
PUBLISHED 01 November 2023

CITATION
Tchokponhoué DA, Legba EC, N'Danikou S, Nyadanu D, Oselebe HO and Achigan-Dako EG (2023) Developing improvement strategies for management of the Sisrè berry plant [*Synsepalum dulcificum* (Schumach & Thonn.) Daniell] based on end-users' preferences in Southern Nigeria. *Front. Sustain. Food Syst.* 7:1252036. doi: 10.3389/fsufs.2023.1252036

Developing improvement strategies for management of the Sisrè berry plant [*Synsepalum dulcificum* (Schumach & Thonn.) Daniell] based on end-users' preferences in Southern Nigeria

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Synsepalum dulcificum is a valuable horticultural and lesser-known crop, famous for the uniqueness of its taste modifying properties, which is candidate for genetic improvement in West Africa. Semi-structured interviews were conducted with 100 respondents purposively selected to analyze the current production systems and constraints as well as to document the farmers' and consumers' preferences for breeding traits in Southern Nigeria. The results showed that none of the investigated farmers applied all required crop management practices to produce the species (land cleaning before establishment, pegging and lining, holing, base manure application, crop irrigation, weeding, pruning, fertilizers application, and pests and diseases control). Farmers were grouped into three clusters based on crop management practices. There was a strong and highly significant agreement among farmers (Kendall's $W = 0.8$, $p < 0.001$) that bush fire, poor plant growth, drought, pests, and parasitic weed were the five most important constraints in Southwest Nigeria. In Southeast Nigeria, damage by insects and birds, poor seed germinability and poor knowledge of cultivation technics were the most important constraints challenging production. Farmers' agreement around these constraints was moderate but highly significant (Kendall's $W = 0.6$, $p < 0.001$). Overall, the top three desired breeding traits by farmers included: high growth rate, extended fruit shelf-life, and high fruits yield while the top three consumer's preferences included: high miraculin potency (long lasting action of the miraculin), fruit glossiness, and high metabolites content. However, cultural specificities were detected in these preferences with a higher agreement in Yoruba farmers' preferences compared with their counterparts Igbo. The Igbo consumers showed a higher concordance in their traits' preferences than the Yoruba consumers. These findings pave the way for an informed cultivar development for the Sisrè berry plant in Nigeria and expand knowledge on end-users' preferences for the species in West Africa.

10.3389/fsufs.2023.1252036

KEYWORDS

sweet berry, Southern Nigeria, management system, end-users' preferences, *Richardella dulcifica*

1. Introduction

The Sisrè berry (Syn: miracle fruit) plant [*Synsepalum dulcificum* (Schumach & Thonn.) Daniell] is a West African native shrub/tree species belonging to the Sapotaceae family with its centers of diversity shared between the Dahomey Gap and the Upper Guinea parts of the West African rainforest (Tchokponhoué et al., 2020; Huang et al., 2022). The species can reach 7.5 m height (Tchokponhoué et al., 2020) and produces green fruits called Sisrè berry (Syn: magic berry, sweet berry, and miracle fruit) that turn to red when they are ripe (Figure 1). *Synsepalum dulcificum* is famous for being a unique natural source of "miraculin" a sweetening glycoprotein contained in the miracle fruit pulp, which has the ability to change any sour taste in a sweet one (Kurihara and Beidler, 1968). Besides this sweetening property that has been valued in diabetes treatment throughout insulin resistance improvement (Chen et al., 2006) and cancer treatment throughout taste perception restoration during chemotherapy (Wilkie et al., 2012), the species has many other modern applications in cosmetics as well as in the food and the beverage industries. For instance, the seeds have been recently reported as a potential drug against Alzheimer's disease (Huang et al., 2022) whereas the derived oil is used to treat women hair breakage (Del Campo et al., 2017). The Sisrè berry red exocarp served as an excellent beverage colorant in addition to be an excellent source of flavonols and anthocyanins (Buckmire and Francis, 1976). Recent developments also revealed the potential of the miracle fruit to reliably replace synthetic sugar in lemonade (Rodrigues et al., 2016). In Florida (United States) for instance, the Sisrè berry was reported to help some patients suffering from COVID-19 to beat taste loss.[1] In addition to be a rich source of Vitamins A, C, and E (Njoku et al., 2015), the species also exhibits a number of healing properties and constitutes a rich reservoir of a number of phytochemicals (Achigan-Dako et al., 2015). The species is also an excellent source of income since a kg of the dry powder of the Sisrè berry fetches an astounding price of USD 2,500.[2]

Given all its above-mentioned importance, the species constitutes a strong asset for an improved livelihood and lifestyle, with the potential to contribute to West Africa economic growth. Consequently, a sub-region-wide breeding initiative bringing together the countries where the species naturally occurs including Benin, Togo, Ghana, and Nigeria is ongoing with the objective to develop elite cultivars for an increased production and utilization of the species. One of the very first steps in any plant improvement endeavor is the development of product profiles. Such an exercise is important in that it helps focus on traits that guarantee a high adoption rate for the released varieties. This can be highly successful when it is conducted using a participatory approach (e.g., participatory rural appraisal) as this latter emphasizes local knowledge and assists local people to make their own appraisal, analysis, and plans (Almekinders et al., 2007). In Nigeria, the nutritional importance, the phytochemical contents, and the health-promoting benefits of the species had been extensively documented (Nkwocha et al., 2014; Jeremiah et al., 2015; Njoku et al., 2015; Obafemi et al., 2019). However, no evidence suggested the existence of an active breeding initiative for the species while the development of pre-breeding tools in the species is still at its infancy (Iloh et al., 2017).

FIGURE 1
Branches of Sisrè berry plant bearing ripe (red) fruits.

Many studies on traits preference highlighted instances of preference variation following sociolinguistic groups, gender, and region. In Nigeria for instance, traits preference in Cassava (*Manihot esculenta* Crantz) differed between farmers in Southeast and Southwest, with those in the Southeast prioritizing traits such as "high yielding" and "early maturity," whereas farmers in the Southeast placed more value on traits like "Fast cooking" (Teeken et al., 2018). In Uganda, while women mainly indicated traits such as "taste," "color," and "biotic and abiotic stress resistance/tolerance" as the most preferred breeding traits in Banana (*Musa sp*), men rather prioritized yield-related traits such "high yielding" and "big bunch size" (Marimo et al., 2019). Similarly, in Burkina-Faso, while kersting's groundnut [*Macrotyloma geocarpum* (Harms) Maréchal & Baudet] farmers in Bobo indicated tolerance to high soil moisture as preferred breeding trait, their counterpart in Bwamu rather were looking for grains with a "short cooking time" (Coulibaly et al., 2020).

In this study, we investigated the current Sisrè berry plant farming systems, documented the production constraints, and analyzed farmers and consumers' preferences for breeding traits and preference variation across sociolinguistic groups, gender, and regions (Southwest and Southeast).

2. Materials and methods

2.1. Study area

The study was carried out from November 2019 to March 2020 in four States of Southern Nigeria including Anambra, Enugu,

1 https://www.youtube.com/watch?v=AfkOp2o47Wg

2 https://www.miraclefruitfarm.com/supplements

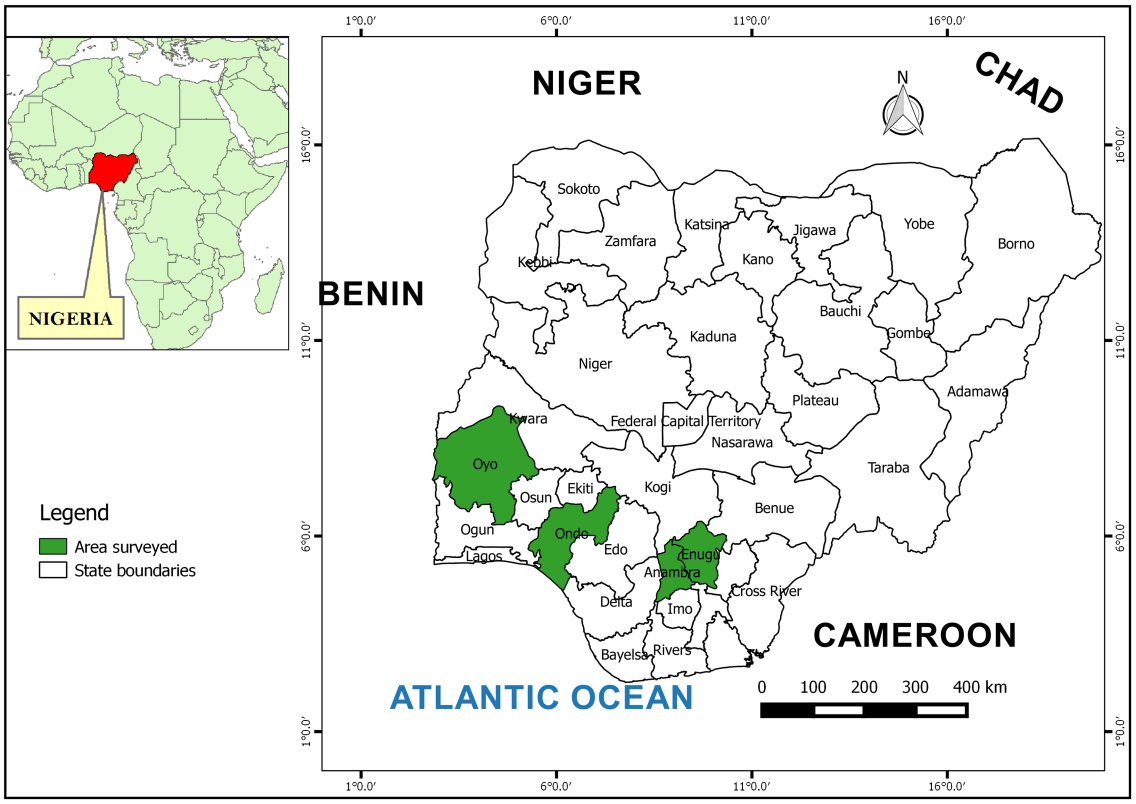

FIGURE 2
Map showing the study area.

Ondo, and Oyo (Figure 2), situated between longitudes 2°0′ and 10°5′ E and latitudes 2°5′and 11°0′ N (Iloeje et al., 1981). These sites were selected based on information retrieved from literature which indicated them as home of the species in Southern Nigeria (Ogunsola and Ilori, 2008; Nkwocha et al., 2014; Njoku et al., 2015). Anambra and Enugu, forming the Southeast region, are inhabited by Igbo, while Ondo and Oyo, forming the Southwest, are Yoruba populated. The climate of south Nigeria is dominated by the presence of three major wind currents, namely the maritime tropical (mT) air mass, the continental tropical (cT) air mass, and the equatorial easterlies (Ojo, 1977; Iloeje et al., 1981). The regions enjoy a tropical climate with two distinct seasons including the rainy season (April–October) and the dry season (November–March). The mean annual rainfall falls between 1,250 and 1,500 mm, whereas the mean monthly temperature ranges between 25.7°C (in July) and 30.2°C (in February). The soils are of sandy, loamy sandy or clay loamy, sandy clay, sandy loam, silty clay, and silty loam. Generally, the soil is deep and well drained (Adejuwon and Ekanade, 1988; Nkwunonwo et al., 2020).

2.2. Respondents sampling approach

The respondents were selected by combining convenience and referral-chain sampling approaches, two commonly used non-probabilistic sampling methods (Pechansky et al., 2004; Bolfarine and de Oliveira Bussab, 2005; Mendenhall et al., 2006). Convenience sampling is a sampling method in which units are selected based on easiness of access or availability. This method of sampling is generally less time-consuming and of lower cost. Referral-chain sampling is a technique that is often used for intentional selection of expert informants. In this study, we were only interested in respondents who have produced the species for at least 5 years, and/or who consumed/exploit its fruits. In this method, the first contact with the community may be through a well-known expert who then indicates another expert, and so on, until the sample size is reached (Albuquerque et al., 2010). The entry points in our case were the community chiefs or leaders. Combining these two sampling strategies was relevant to our study since we did not have any prior information on the species owners, and interestingly the sampling threshold imposed by the saturation point (defined as the point at which there are no new names of key informants being mentioned by the last interviewee; N'Danikou et al., 2015) was observed to represent enough the population studied.

2.3. Data collection

Data were collected through formal semi-structured interviews with respondents using a questionnaire. During the exercise, information describing the respondents' socio-demographic and cultural characteristics (sex, age, and sociolinguistic group affiliation), farm characteristics, cultivation practices of Sisrè berry plant, awareness of existence of varieties or morphotypes of the species, farmers and consumers' preferences for breeding traits as well as their production constraints.

2.4. Statistical analyses

Analysis of data involved the use of descriptive statistics such as frequency, percentages, standard deviation, and mean, to describe the socio-economic characteristics of respondents. The mean values and the standard deviation were calculated on farmers and consumers preferences scores. The χ^2 Fisher exact test was performed to assess the dependence relationships between (i) the awareness of a specific morphotype and the sociolinguistic group affiliation and (ii) the respondent's involvement in Sisrè berry cultivation and their gender / education level /main activities. The ANOVA with least significant different (LSD) *post hoc* test was performed using "agricolae" package (de Mendiburu and de Mendiburu, 2019) to assess the statistical grouping in informants' age, household size, total farm size (acre), and farmers experience in Sisrè berry plant management (years). The factorial analysis of mixed data was performed to describe Sisrè berry plant farming systems and establish the typology of the farmers while the Factorial Analysis of Correspondence (FAC) was performed using "FactoMineR" package (Lê et al., 2008) to test the relationship between the listed preferences and sociolinguistic groups, regions, and gender. The mean value and the standard deviation were calculated for scored constraints across regions and sociolinguistic groups. The Kendall's Coefficient of Concordance (KCC) was computed using "irr" package (Gamer et al., 2012) to test the level of agreement among the listed constraints. The value of KCC is positive and ranges from 0 to 1. All the analyses were carried in the R environment (version 4.1.2; R Core Team, 2021).

3. Results

3.1. Socio-demographic characteristics of respondents

A total of 100 respondents from four States including Ondo, Oyo, Anambra, and Enugu were interviewed in this study. Across these four States, a greater proportion of male farmers was involved in the Sisrè berry plant cultivation compared with women (Table 1). The greatest proportion of women involvement (36% of respondents) was observed in Enugu state. Respondents from Anambra and Enugu belong to the "Igbo" sociolinguistic group, while those from Ondo and Oyo are "Yoruba." Informants from Oyo and Enugu were the most literate (68 and 16% for tertiary and secondary levels, respectively, in Oyo region; and 36 and 32% for tertiary and secondary levels, respectively in Enugu). The highest proportion of respondents with no formal education was observed in Ondo. Agriculture ($p < 0.0001$, $\chi^2 = 28.04$, df = 3) and trade ($p < 0.0001$, $\chi^2 = 42.41$, df = 3) were the main activities of the respondents with high significant difference across the states.

TABLE 1 Characteristics of the informants.

Variables	Igbo ($n1 = 50$)		Yoruba ($n2 = 50$)	
	Anambra ($n1.1 = 25$)	Enugu ($n1.2 = 25$)	Ondo ($n2.1 = 25$)	Oyo ($n2.2 = 25$)
Gender of respondents (%)				
Male	84	64	76	80
Female	16	36	24	20
Significance	$p < 0.0001$, $\chi^2 = 46.2$, df = 1	$p < 0.005$, $\chi^2 = 7.8$, df = 1	$p < 0.0001$, $\chi^2 = 27.0$, df = 1	$p < 0.0001$, $\chi^2 = 36$, df = 1
Level of formal education (%)				
Tertiary	28	36	12	68
Secondary	32	32	16	16
Primary	24	28	36	4
No formal education	16	4	36	12
Significance	$p < 0.05$, $\chi^2 = 7.5$, df = 3	$p < 0.0001$, $\chi^2 = 33.1$, df = 3	$p < 0.0001$, $\chi^2 = 26.2$, df = 3	$p < 0.0001$, $\chi^2 = 135.5$, df = 3
Main occupation (%)				
Farmers	36	24	52	20
Business	12	36	12	44
Drivers	28	16	12	24
Teachers	16	16	20	8
Others (nurse, tailor, etc.)	8	8	4	4
Significance	$p < 0.0001$, $\chi^2 = 34$, df = 4	$p < 0.0001$, $\chi^2 = 35.9$, df = 4	$p < 0.0001$, $\chi^2 = 88$, df = 4	$p < 0.0001$, $\chi^2 = 62$, df = 4
Means ± standard deviation (statistical group)				
Informant age (years; $p = 0.08091$, df = 3)	47.4 ± 7.5 (a)	50.2 ± 9.9 (a)	49.3 ± 7.4 (a)	44.5 ± 8.1 (a)
Household size ($p = 0.01123$, df = 3)	9.3 ± 3.2 (a)	7.8 ± 2.7 (ab)	8.8 ± 3.1 (ab)	6.8 ± 2.5 (b)
Total farm size (acre; $p = 0.129$, df = 3)	14.6 ± 8.5(a)	7.7 ± 6.7 (a)	13.5 ± 9.0(a)	9.8 ± 18.20 (a)
Experience in Sisrè berry plant management (years; $p = 0.00518$, df = 3)	26.1 ± 6. (a)	12.9 ± 7.1 (ab)	18.6 ± 4.9 (ab)	18.1 ± 7.9 (b)

Means with different letters in the same row are statistically different at $p = 0.05$ (LSD test).

The respondents were on average 47.8 ± 8.5 years old, with respondents in Oyo being the youngest (44.5 ± 8.1 years old), while those from Enugu were the oldest (50.2 ± 9.9 years old). Informants from Anambra and Enugu states had a greater experience (26.1 ± 6.5) in the Sisrè berry plant management (Table 1).

3.2. Management practices-based farmers typology

The Sisrè berry plant was mainly found in home gardens although also existing in cultivated farms, fallows or naturally growing in forests. Most of Sisrè berry plant owners also possessed plantations of other perennial species including for instance cashew (*Anacardium occidentale* L.), cocoa (*Theobroma cacao* L.), coconut (*Cocos nuciferae* L.), palm trees (*Elaeis guineensis* L.), among others. None of the farmers applied all required management practices in the production of the species (land clearing before crop establishment, pegging and lining, holing, base manure application, crop irrigation, weeding, pruning, fertilizers application, and pest and diseases control).

The factorial analysis of mixed data grouped the farmers into three (03) categories based on the various farming practices they applied (Figure 3). The distribution of variables characterizing these various categories is presented in Figure 4. The cluster 1 contained 93.6% of the interviewed farmers. Famers in this cluster owned on average two stands of Sisrè berry plant and had 18.50 ± 8.8 years of experience in the species management. None of them attended a training in biodiversity conservation and 97.7% of them possessed individual trees of Sisrè. Trees were mainly inherited (59.1%) and dispersed in home gardens or cultivated farms. Seeds were obtained from the ripe fruits and the regeneration mode they applied included: seeds sowing (97.9%), seedlings transplanting (82.9%), and cuttings (23.4%). A small proportion of these farmers (21.3%) applied base manure before transplanting the seedlings and irrigated the transplanted seedlings (44.7%). Farmers mostly applied the weeding (65.9%) while the chemical pesticides spray was only applied by 2.1% of them. This cluster included 22.7% of farmers from Ondo, 31.8% of farmers from Oyo (54.5% of Yoruba), 18.2% of farmers from Anambra, and 38% of farmers from Enugu (45.5% of Igbo).

The cluster 2 contained 2.1% of farmers (one respondent) belonging to the Yoruba sociolinguistic group (Oyo). This farmer was the only one to possess a plantation of Sisrè berry plant with up to 2,700 stands. This farmer established the Sisrè berry plant orchard by transplanting the seedlings produced by sowing matured fruits. Required management practices such as basal dose of manure, irrigation, weeding, and phytosanitary spraying were done.

The cluster 3 encompassed 4.2% of farmers from Oyo (Yoruba) with a moderate number of Sisrè berry trees (up to 115 stands). They have attended some training in biodiversity conservation and established the plantations themselves. The land clearing, pegging, lining, holing, and base manure application were systematically carried out before transplanting the seedlings. Crop management included weeding and irrigation. There were no phytosanitary products spraying by farmers in this cluster (Figure 4).

3.3. Knowledge of varieties and morphotypes in the Sisrè berry plant

None of the surveyed farmers in Southern Nigeria differentiated any variety of *S. dulcificum*. However, they recognized two morphotypes based on the color of the fruit exocarp: a red-skinned

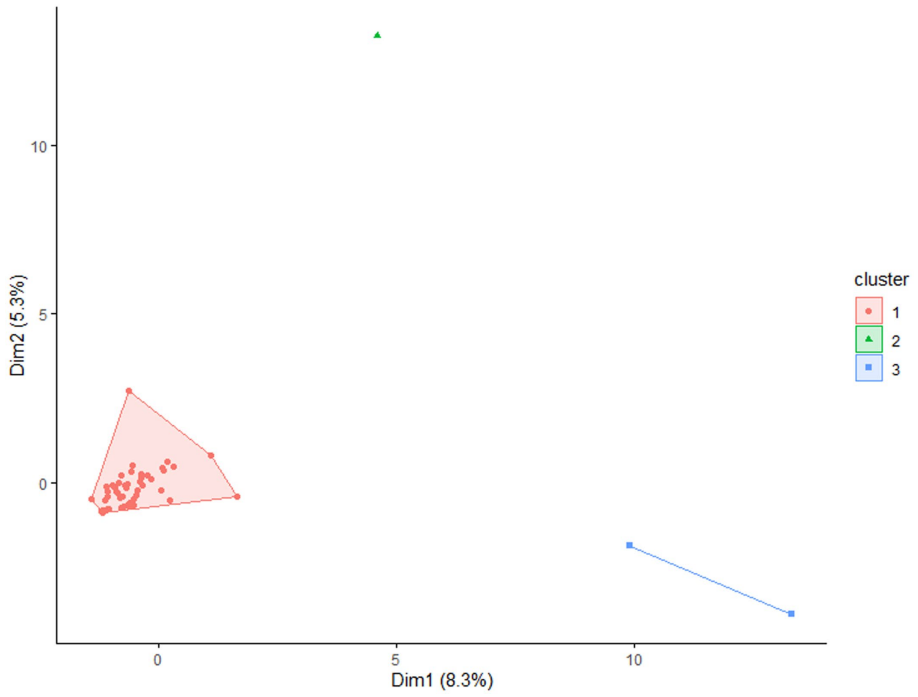

FIGURE 3
Typology of Sisrè berry plant farmers in Southern Nigeria.

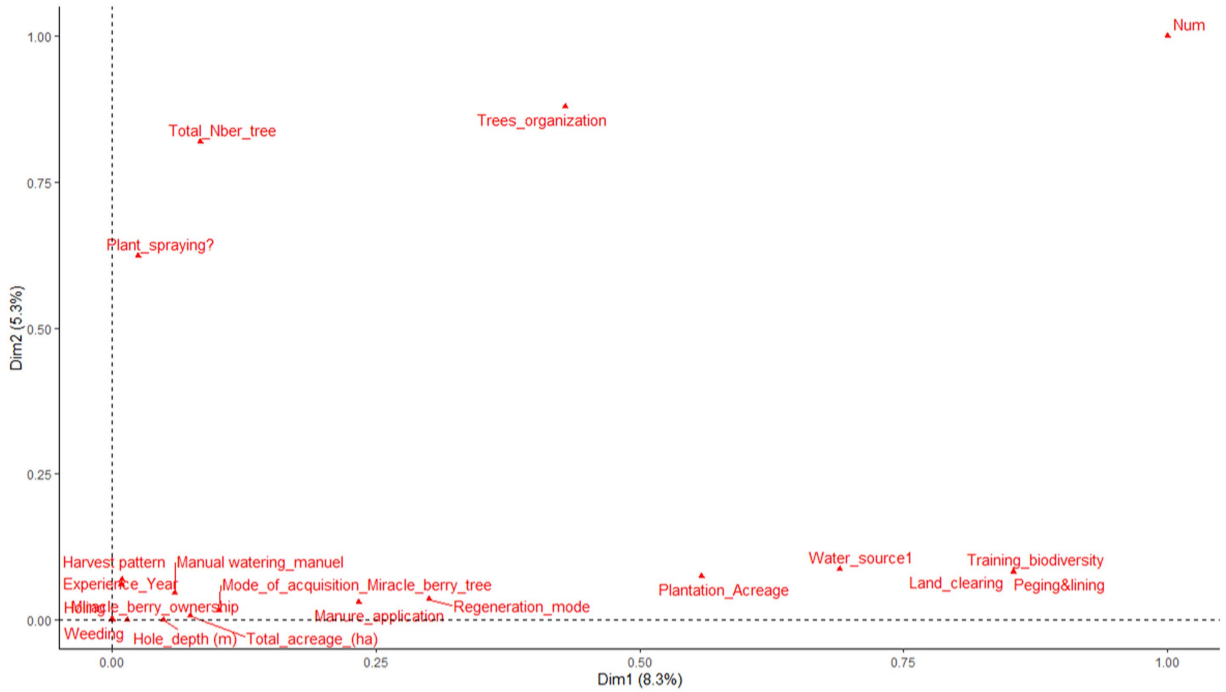

FIGURE 4
Factor map displaying the variables associated with farmers' clusters detected.

morphotype (Figure 5A) and a yellow-skinned morphotype (Figure 5B). There was a strong association between awareness of different morphotypes and sociolinguistic group affiliation ($p < 0.0001$, $\chi^2 = 96.0$, df = 1) and the agroecological region ($p < 0.0001$, $\chi^2 = 96.0$, df = 3) with the yellow morphotype exclusively reported by the Igbo in the Southeast region and the red-skinned morphotype only known by the Yoruba, in the Southwest. In both regions, the species is becoming less and less available despite having two fruiting seasons yearly. Seventy-four percent (74%) of the respondents confirmed the scarcity of the species in Southeast as compared to 62% in Southwest ($p = 0.30$, $\chi^2 = 1.0$, df = 1). Several reasons justified this state of availability including bush fire during the dry season, destruction of the habitat of the species for settlement, road construction or agriculture expansion, the poor rate of the plant growth, and the fact that the species is not yet entirely domesticated and that cultivation in agricultural production systems remained low (Figure 6).

FIGURE 5
Morphotypes of Sisrè berry plant recorded in the study: red-skinned morphotype **(A)** and yellow-skinned morphotype **(B)**.

3.4. Production constraints

In Southeast Nigeria, inhabited by Igbo, the top five constraints identified by the Sisrè berry plant growers included insect and birds' damages, poor knowledge of cultivation technics, drought, and low seed germination (Table 2). While farmers in Anambra and Enugu had three (03) out five of these constraints in common, there was only a moderate agreement in their ranking of the constraints (Kendall's $W = 0.6$, $p < 0.001$). In the Southwest region inhabited by the Yoruba, the five most important constraints included insect and birds' damages, drought, bushfire, and low seed germination. There was a higher concordance in the ranking of the constraints between farmers in Ondo and Oyo (Kendall's $W = 0.8$, $p < 0.001$) compared with their peers in Anambra and Enugu (Kendall's $W = 0.6$, $p < 0.001$). Overall, there was a good agreement for the constraints list and ranking between the surveyed Igbo and the Yoruba farmers (Kendall's $W = 0.6$, $p < 0.001$; Table 3).

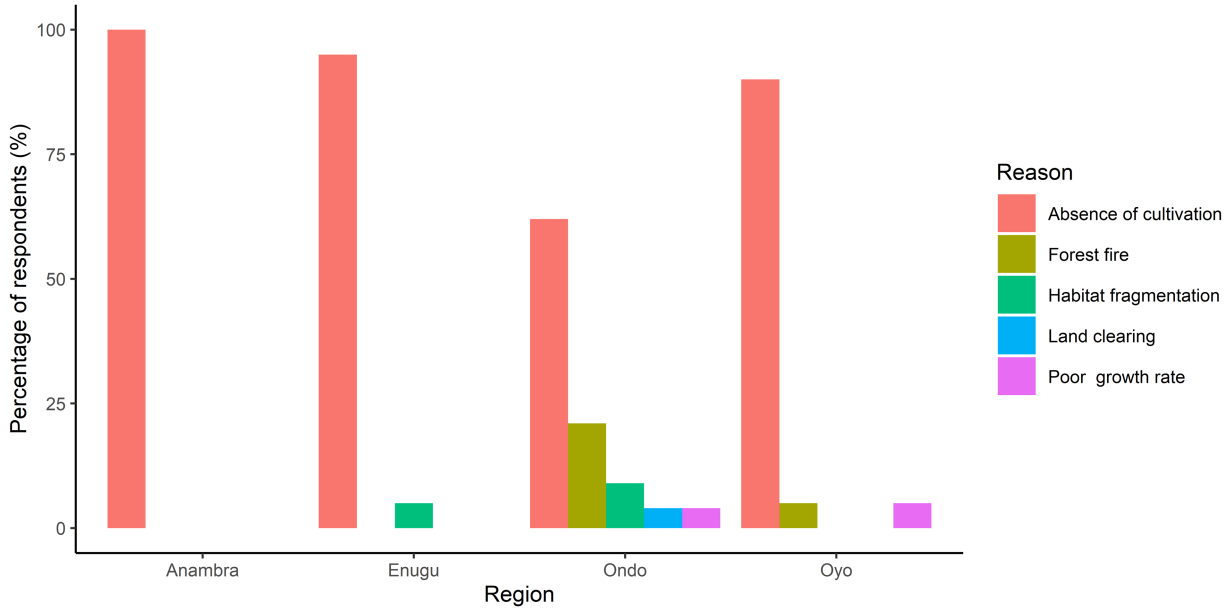

FIGURE 6
Reasons of the scarcity of Sisrè berry plant across the studied regions in Southern Nigeria.

3.5. Market chain analysis

The harvested products were mainly for household use (63.2%), followed by sales (21.3%) and gifts (15.5%). The fruits sales mainly occurred on local market (94.3% of respondent selling the fruits), while only a low proportion of harvested fruits was processed into powder or juice and sold in capital city Lagos or exported to the United States (Table 4). There was not specific selling unit for sales in the local market while the kilogram is used for the international market.

3.6. Farmers' and consumers' preferences for breeding traits

Producers and consumers desired a range of traits for an improved variety of *S. dulcificum*. A total of 11 and six traits were mentioned by farmers and consumers, respectively. For farmers, the top five most preferred breeding traits for *S. dulcificum* included by descending importance, a high plant growth rate, an expanded fruit shelf -life, a high fruit yield, a high pest and drought resistance or tolerance, and a high fruiting frequency. The most important traits for consumers in descending importance included a longer sweetening action of the fruit, a higher fruit glossiness, higher metabolites content, a thicker pulp size, and a larger fruit size (Table 5). All these desired attribute were in comparison with their local landraces' performance.

The factorial analysis of correspondence revealed a variation of farmers' preferred traits across sociolinguistic groups and gender. For Igbo, the priority breeding traits included fruits size, early fruiting, seed viability, and germinability, while Yoruba rather mainly targeted fruits yield, fruits shelf life, fruits glossiness, plant growth rate, tree life span, and the fruiting frequency. The gender exerted a lesser influence on farmers' preferences compared with sociolinguistic groups, with men prioritizing fruits glossiness, fruits shelf life, early fruiting, and seed viability while women did not show any specific preference (Figure 7). There was also a larger variation of trait preferences within Igbo compared with Yoruba farmers (Figure 8). Noticeably, the Anambra respondents had a higher interest for traits such as early fruiting, fruit glossiness, and seed viability, while their counterpart from the Enugu were more interested in fruits shelf life and seed germination (Figure 8). Consequently, a higher congruity was found in farmers' preferences in Southwest also known as Yoruba land (Kendall's $W = 0.9$) compared with a moderate congruity in the identified preferences in the Southeast known as Igbo land (Kendall's $W = 0.5$; Table 6).

Consumer's preferences varied across ecological zones (Figure 9A) on one hand, and across sociolinguistic groups and gender (Figure 9B) on the other hand. Consumers from Southeast region, the Igbo, valued the glossiness of fruits (fruits aspect) and its metabolites content while those in the Southwest, the Yoruba, preferred a long sweetening action of the fruit, the taste, the fruits size, and the fruits shelf life. There was no variation in consumer's preferences within the Southeast region (Anambra and Enugu states). Conversely, in the Southwest region, while the informants from Ondo state preferred the fruit shelf life and the fruits size, their peers in Oyo state preferred the fruit taste and its potency (long lasting of the sweetening activity). There was also a significant concordance in consumers preferences in Southeastern Nigeria (Kendall's $W = 0.7$), while a weak congruity was found in the identified preferences in Southwestern Nigeria (Kendall's $W = 0.4$; Table 6). Consumers' preferences were also gendered with women prioritizing fruit taste, fruit shelf life, and metabolites content whereas men were rather interested in traits including the fruit glossiness, potency, and the fruit size (Figure 9B).

TABLE 2 Farmers-faced constraints in *Synsepalum dulcificum* production in Southern Nigeria.

Constraints	Southeast Nigeria				Igbo	
	Anambra		Enugu			
	Mean score ± SD	*Rank*	*Mean score ± SD*	*Rank*	*Mean score ± SD*	*Rank*
Insect damages	5.3 ± 0.6	1	3 ± 1.1	4	4.4 ± 1.5	1
Bird damages	3.8 ± 1.0	3	3.7 ± 1.7	3	3.7 ± 1.4	3
Low germinability	3.8 ± 2.2	4	2.3 ± 1.2	7	3 ± 1.9	5
Poor knowledge of cultivation technics	4.1 ± 1.2	2	4.4 ± 1.9	1	4.3 ± 1.7	2
Quick seed viability loss	2.2 ± 0.4	6	2.3 ± 0.5	5	2.3 ± 0.5	7
Drought	–	–	4.3 ± 1.5	2	3 ± 1.4	4
Lack of selling market	3.3 ± 2.0	5	2.3 ± 0.7	6	2.8 ± 1.	6
Constraints	Southwest Nigeria				Yoruba	
	Ondo		Oyo			
	Mean score ± SD	*Rank*	*Mean score ± SD*	*Rank*	*Mean score ± SD*	*Rank*
Poor plant growth rate	3.7 ± 0.6	7	2.7 ± 1.2	8	3.2 ± 1.0	9
Drought	6.5 ± 0.7	1	4 ± 1.4	3	4.8 ± 1.7	2
Insects' damages	5.3 ± 01.5	2	6.3 ± 1.5	1	5.8 ± 1.5	1
Parasitic weed	2.7 ± 1.2	10	4.7 ± 2.1	2	3.7 ± 1.9	6
Birds' damages	3.7 ± 0.9	6	3.8 ± 2.2	4	3.8 ± 1.8	5
Quick loss of seed viability	3.2 ± 2.4	9	2.6 ± 0.7	9	2.9 ± 1.7	10
Poor knowledge of cultivation technics	4.1 ± 1.9	4	3.3 ± 2.3	6	3.7 ± 2.2	7
Low germinability	4.3 ± 3.3	3	3.5 ± 2.4	5	3.9 ± 2.7	4
Bush fires	4 ± 1.4	5	–	-	4 ± 1.4	3
Lack of labor	3.5 ± 2.1	8	–	-	3.5 ± 2.1	8
Lack of selling market	2.2 ± 0.4	11	2.8 ± 1.5	7	2.4 ± 1.0	11

TABLE 3 Kendall's concordance coefficient for the listed constraints in Southwestern Nigeria (Ondo and Oyo), in Southeastern Nigeria (Anambra and Enugu), and between Igbo and Yoruba sociolinguistic groups.

Regions	Kendall's coefficient of concordance (W)	Chi square (χ^2)	*p* value (*p*)
Southwest Nigeria	0.8	182	< 0.0001
Southeast Nigeria	0.6	46.1	< 0.0001
Southern Nigeria	0.6	172	< 0.0001

TABLE 4 Management of harvested products.

	Proportion of fruits (%)			
	Anambra	Enugu	Ondo	Oyo
Fruits sales	11.3	12.5	30.0	31.3
Household use of fruits	60.0	63	66.9	63.1
Fruits gift	28.7	24.5	3.1	5.6

4. Discussion

4.1. Management practices-based farmers typology

This study, conducted in Nigeria, expanded our knowledge of the current habitats of the Sisrè berry plant in West Africa. Previous studies reported the species to be predominantly present in-home gardens, cultivated farms, fallows, and gallery forests (Fandohan et al., 2017; Tchokponhoué et al., 2021). In this study, the species was also found in rainforests, which reflected that the suspected habitat fragmentation in the species may not be evolving at a similar rate across the distribution range in West Africa. Home gardens are overall becoming a back-up habitat for the species and serve as a reservoir for biodiversity conservation (Catalán et al., 2007; Galluzzi et al., 2010; Fandohan et al., 2017). The farmers typology pointed out to three groups with most of farmers (cluster 1 members) applying only limited practices, a result that corroborated observations in the republic of Benin where management intensity index was low (Management intensity Index < 15 vs. >30 in the evergreen region of Ghana; Tchokponhoué et al., 2021). The overall poor management of the species (from cluster 1 members) could be explained by the low economic value ascribed to the species by respondents in this cluster. Such a perception is not likely to trigger any active production initiative, and this was illustrated by the high tendency to inherit the species, a result that is also congruent with several previous studies on the dominant mode of acquisition of the Sisrè berry plant (Fandohan et al., 2017; Tchokponhoué et al., 2021). Only, a low proportion of

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TABLE 5 Overall farmers' and consumers' preferences for breeding traits.

Preferences	Variable definition	Mean score ± *SD*	*Rank*
Farmers-desired traits for ideal variety development			
Plants growth rate	Developed variety is required to grow faster than the existing landraces.	1.8 ± 0.9	1
Fruit shelf life	Fruits from developed variety is required to have a longer shelf life than the landraces.	1.7 ± 6	2
Fruit yield	New variety is expected to produce stable and consistent yield across production environments.	1.6 ± 1.1	3
Pest and drought tolerance	New variety is expected to tolerate the drought, pests, and diseases, and produce even in the bad season.	1.4 ± 0.5	4
Fruiting frequency	The improved Sisrè berry plant is expected to fruit at least twice times per year.	1.3 ± 0.7	5
Seed longevity	New variety is required to have a high seed longevity and a good capacity to germinate.	1.2 ± 1.1	6
Early fruiting	Developed variety must be capable to bear fruit earlier than their current landraces.	1.2 ± 0.8	7
Tree span	New variety of Sisrè berry plant is expected to have an upright growth habit with several branches.	1.1 ± 1.1	8
Fruit glossiness	Fruits from the new variety must be glabrous, uniform, attractive, and good looking.	1.1 ± 0.9	9
Seed germination	New variety is required to have a high seed viability and a good capacity to germinate.	0.5 ± 0.7	10
Fruit size	The new variety is expected to have bigger fruits than the existing landraces.	0.3 ± 0.5	11
End-consumers expectation for an improved sweet berry's variety			
High miraculin potency	The sweetening effect of the improved miracle fruits is expected to last longer.	2 ± 1.6	1
Fruit glossiness	Fruits from the new variety must be glabrous, uniform, attractive, and good looking.	1.6 ± 0.8	2
Metabolites content	Improved Sisrè berry plant is expected to have high miraculin content and other nutrients.	1.5 ± 0.7	3
Pulp size	Improved variety is expected to provide much more pulp to facilitate the processing.	0.9 ± 0.7	4
Fruits size	The new variety is expected to have bigger fruits than the existing landraces.	0.4 ± 0.6	5
Taste	Improved variety is expected to have a good taste.	-	6

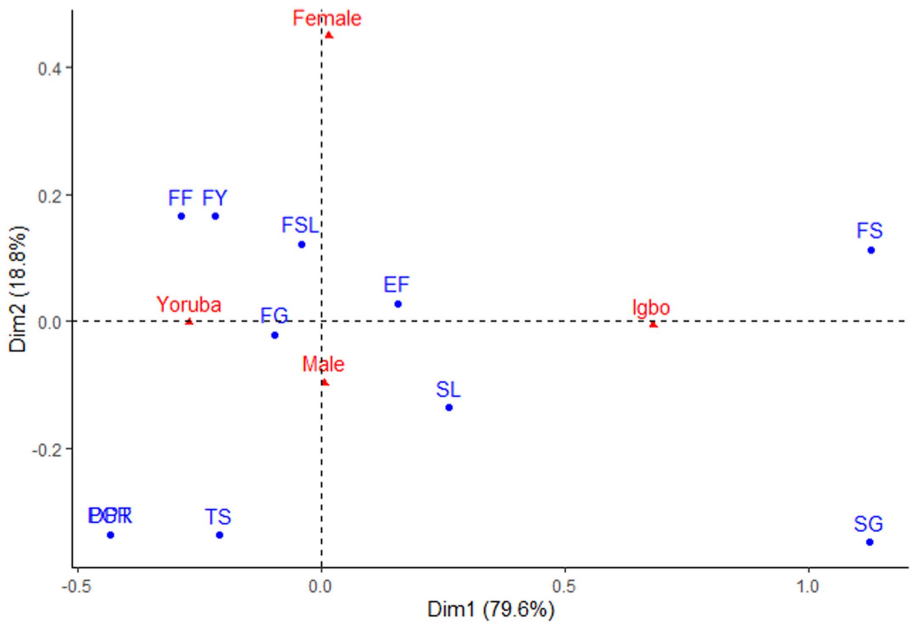

FIGURE 7
Association between farmers' preferences for breeding trait and sociolinguistic group and gender. DPT, Drought and pest tolerance/resistance; EF, Early fruiting; FF, Fruiting frequency; FY, Fruits yield; FS, Fruits size; PGR, Plant grow rate; TS, Tree span; FSL, Fruits shelf life; SL, Seeds longevity; SG: Seeds germination; and FG, Fruit glossiness.

respondents (cluster 2 and cluster 3) considered the species as economically important. Noticeably, those respondents mostly had a high level of education, which explained their motivation for large-scale cultivation of the species (up to 2,700 stands). These farmers have a better access to the information about the crop, in particular the trading opportunities in the crop. Indeed, these farmers

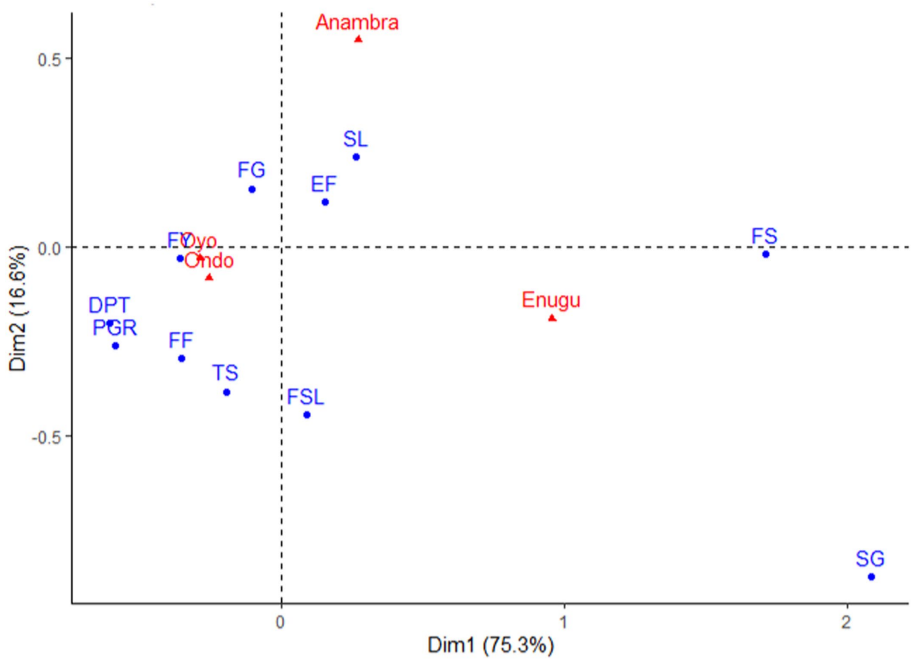

FIGURE 8
Association between farmers' preferences for breeding traits and ecological zone. DPT, Drought and pest tolerance/resistance; EF, Early fruiting; FF, Fruiting frequency; FY, Fruits yield; FS, Fruits size; PGR, Plant grow rate; TS, Tree span; FSL, Fruits shelf life; SL, Seeds longevity; SG, Seeds germination; and FG, Fruit glossiness.

TABLE 6 Kendall's concordance coefficient for the identified preferences in Southwest Nigeria (Ondo and Oyo), in Southeast Nigeria (Anambra and Enugu), and between Igbo and Yoruba sociolinguistic groups.

Regions	Kendall's coefficient of concordance (W)	Chi square (χ^2)	*p* value (*p*)
Consumers' preferences			
Southwest Nigeria (Yoruba)	0.4	4.1	0.5
Southeast Nigeria (Igbo)	0.7	7	0.2
Farmers' preferences			
Southwest Nigeria (Yoruba)	0.9	18.4	0.0
Southeast Nigeria (Igbo)	0.5	10.5	0.4

are anticipating on the potential value of the species and are targeting either the international niche market (cluster 3) or have local market to satisfy (Cluster 1). In Ghana already, it was noticed that any single farmer holding a plantation of the Sisrè berry plants has a contract with a processing company that not only guarantees the market, but also provides funding for the plantation maintenance (Tchokponhoué et al., 2020). This calls for the necessity for implementing a subsidy system for the production of the Sisrè berry plantations, should West African governments promote this tremendous resource.

4.2. Awareness of varieties or morphotypes in Sisrè berry plant

The two cultivars of Sisrè berry reported in this study were previously signaled by various authors (Njoku et al., 2015; Tchokponhoué et al., 2020). While the red-skinned morphotype is widely distributed across Africa (Inglett and May, 1968; Bartoshuk et al., 1974; Huang et al., 2012; Njoku et al., 2015; Iloh et al., 2017) and well known worldwide (Inglett and May, 1968; Bartoshuk et al., 1974; Huang et al., 2012; Njoku et al., 2015; Iloh et al., 2017), the yellow-skinned morphotype seemed to be confined to Southeast Nigeria in West Africa (Inglett and May, 1968; Bartoshuk et al., 1974; Huang et al., 2012; Njoku et al., 2015; Iloh et al., 2017). Indeed only the red morphotype was reported by famers investigated in Benin, Ghana, and Togo in the framework of the ongoing breeding initiative on the species (Tchokponhoué et al., 2020). The fact that the two morphotypes reported by farmers are each specific to a region could be explained either by a low or absence of exchange of planting material of the species between Igbo and Yoruba or the hypothesis of habitat preference by each morphotype. Angeles et al. (2017) already reported an emergence of the yellow-fruited morphotype in a lot of 23,000 Sisrè berry plants cultivated in Calauan, Laguna, Philippines though where these plants batches were obtained from was unclear. Nevertheless, since the Sisrè berry plant is known to originate from West Africa, we can speculate that Southeast Nigeria would the center of origin of the yellow morphotype. In the context of the breeding strategies in the species, this yellow morphotype represents a potential source of favorable alleles that can be tapped to improve some key traits of interest for the farmers. Indeed, the fruit of the yellow morphotype is nearly two times bigger (data not shown) than the red morphotype and can for instance be relevant in the development of big fruit-sized cultivars. In addition, the yellow morphotype exhibited some primitive characters such as prominence of pubescence in several plant parts (fruits, leaves), seed coat thickness (data not shown). Consequently, further in-depth comparative phenotypic analysis and molecular phylogenetic analysis

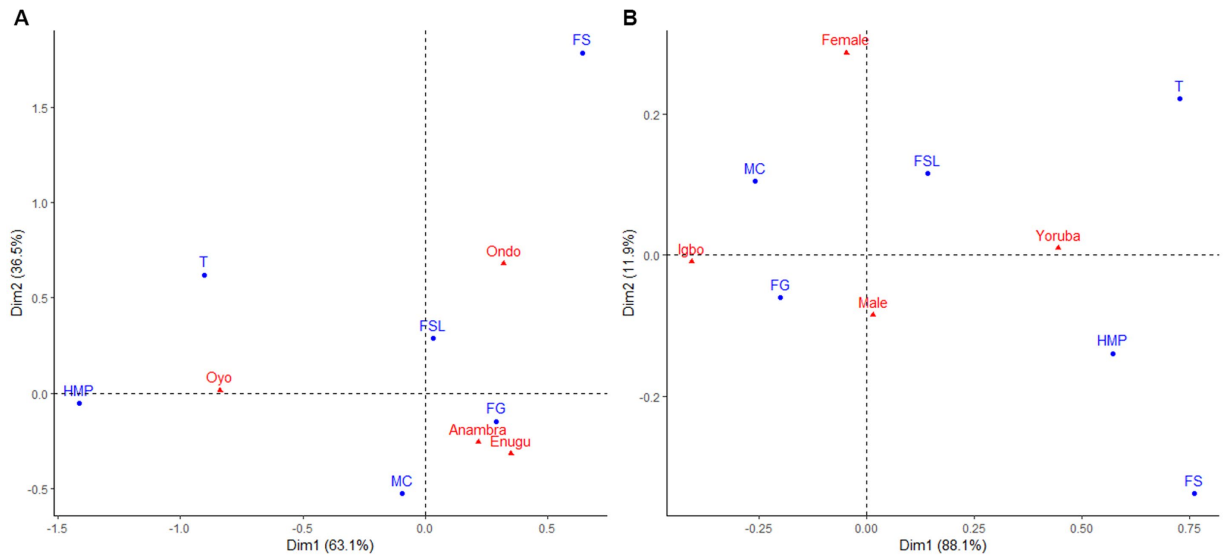

FIGURE 9
Association between consumers' preferences for breeding traits and ecological zone **(A)**, and sociolinguistic group and gender **(B)**. HMP, High miraculin potency; MC, Metabolites content; FG, Fruits glossiness; FS, Fruits size; T, Taste; FSL, and Fruits shelf life.

are then needed to clarify the relationship between these supposed morphotypes.

4.3. Production constraints and other challenges

Insect and bird damages and difficulties in the crop management were the major constraints faced by the surveyed farmers in Southern Nigeria. In fact, the ripe miracle fruit is a small berry finely pubescent with bright red/yellow skin. The brightness combined with the fruit's sweetness attracts herbivorous insects and birds which feed on the fruits (Stevens and De Bont, 1980). These insects and birds-induced damages were previously reported in cherries (Lindell et al., 2012), peach, apple, pear, grape, and loquat cultivation (Hao et al., 2011; Lindell et al., 2012) and are likely to induce important economic impact on producers (Anderson et al., 2013; Angeles et al., 2017). As a physical protection technique, pre-harvest bagging of fruits was developed and have been chiefly used in several species including *Vitis vinifera* L. (grapevines; Karajeh, 2018), *Psidium guajava* L. (guava; Srivastava et al., 2023), and *Mangifera indica* L. (mango; Nadeem et al., 2022). The pre-harvest bagging optimizes fruit quality by reducing physical damages and damages by pathogens, and increases market value of the fruits (Sharma et al., 2013).

Quick loss of seed viability and poor germination seemed to be more common in Southeast, while slow plant growth, drought, and bushfires were prominent in the Southwest region. It has been established that *S. dulcificum* produces recalcitrant seeds with seeds losing viability in few days after harvesting (Tchokponhoué et al., 2019). This explains farmers' observation of quick loss of viability and poor germination. A slow growth of plants was reported by over 70 % of respondents. This observation was experimentally established by Tchokponhoué et al. (2018). These observations suggested farmers' good knowledge of the species' biology. Other studies also reported Sisrè berry plant as a slow-growing species with two growth phases. The first growth phase corresponding to the first 4 years where the plant grows very slowly reaching about 50 cm tall, and a second phase, starting from 4-year-old onwards where the plant grows faster. *Synsepalum dulcificum*'s growth is slow compared to other economically important species. For instance, at the same age, *Vitellaria paradoxa* (a sister species to *S. dulcificum* in the Sapotaceae family) can be four times taller (Allaye Kelly et al., 2004). The higher frequency of seed-biology related challenges reported in the Southeast indirectly suggested that the yellow-skinned morphotype could have a more sensitive seed physiology compared with the red-skinned, since producers of the later morphotype did not face too much such a challenge. This poor seed physiology marked by a short seed lifespan of the yellow-skinned morphotype might explain its low popularity. Drought and bushfires are important constraints in the Southwest of Nigeria. Indeed, in this region, the species is mainly found in farms, fallows, or forests, which are open-habitats, hence low protection and management by farmers as compared with plants found in home gardens in the Southeast. Bushfires were commonly reported to threat for several economically important trees such as *Vitellaria paradoxa* C. F. Gaertn., *Tamarindus indica* L., and *Sclerocarya birrea* (A. Rich.) Hochst (Gaisberger et al., 2017). The dry season in southern Nigeria lasts for 6 months (November to March) yearly (Ojo, 1977), a period over which local communities used to burn the bush and some parts of forests which are also habitats of Sisrè berry plant.

4.4. Market chain analysis

The harvested products were mainly for household use or sold on local markets by about 94% of respondents. However, the other 6% of the farmers have access to the international market, with an important export of fresh fruits to United States. This more advanced farmers also explore the potential for processing fruits into powder or juice locally. This

indicates that there is a potential to up-scale production as market opportunities exist. An illustration is the European Union market that has recently admitted the dry powder of the Sisrè [EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) et al., 2021]. Besides fruit uses, the dry seeds have high commercial value as the dry seeds attract approximately two times higher price compared with the fresh fruits. The dry seeds are used in the production of a cosmetic oil used in women hair breakage treatment (Del Campo et al., 2017).

4.5. Farmers' and consumers' preferences for breeding traits

An analysis of end-users' preferences helps breeders detect hidden traits of interest, and both famers and consumers formulated their trait preferences (Bolfarine and de Oliveira Bussab, 2005). For instance, the slow growth was on the highlighted challenges, indicating the desire of farmers to have a fast-growing cultivar that can bear fruits earlier. Although farmers in Nigeria listed a lower number of preferred-traits (11) compared with their counterparts in Benin and Ghana (who highlighted 19 traits), it is worth pointing out that seven out of the 11 traits were already reported by farmers in Benin and Ghana (Tchokponhoué et al., 2021). This suggest that Sisrè berry plant farmers in West Africa share preferences for an improved variety of Sisrè berry plant. More importantly, four out of the top five desired traits in this study were previously highlighted by the species producers from Ghana and Republic of Benin (Tchokponhoué et al., 2021), thus strengthening the necessity to promote region-wide cultivars development initiatives.

Most of the farmer's preferences converged to high fruit yielding while consumers preferred visual and nutritional traits. Farmers in miracle fruits production are seeking to maximize the profit through increased fruits yield while consumers would like to enjoy quality fruits with high glycoproteins and metabolites contents. End-users' preferences are most important to increase adoption of new varieties. To illustrate, most farmers in Africa and Latin America keep growing some specific Andean type of rice varieties with lower yield to satisfy particular traits required by consumers, even though some high-yield improved varieties (Mesoamerican types) exist (Beebe, 2012). Our findings revealed a variation of farmer's preferences across regions, sociolinguistic groups, and gender. However, from a West Africa regional perspective, combining previous findings (Tchokponhoué et al., 2020) with the current ones will lead to the definition of key breeding traits for both farmers and consumers, and the establishment of product profiles by breeders.

5. Conclusion

The study investigated the management practices, farmers and consumers' preferences for Sisrè berry plant. Several constraints limited Sisrè berry plant cultivation with the insect and bird attacks and seed germinability related constraints being dominant. Additionally, parasitic weeds infestation was exclusively mentioned in Southwest Nigeria. A total of nine preferred traits were mentioned by farmers while six traits were reported by consumers. For farmers, the desired variety should be a fast growing and high yielding one that withstands pests and birds' attacks while producing fruit with an extended shelf life. As for the consumers, the desired variety should be big size fruits with a high edible mass, metabolite content and a high potency of miraculin. These findings pave the way for a west Africa-wide elite cultivar development to meet the increasing demand in the Sisrè berry plant and its by-products.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

DT and EA-D: conceptualization, visualization, and project administration. DT and EL: methodology, formal analysis, and writing—original draft preparation. EA-D and HO: validation and supervision. EL: investigation, data curation, and funding acquisition. SN'D, DN, HO, and EA-D: writing—review and editing. All authors contributed to the article and approved the submitted version.

Funding

This study was partially funded by the GENES INTRA-AFRICA mobility program through a grant awarded to the EL (No. EACEA/2017/2552) for his Master research in Ebonyi State University, Nigeria.

Acknowledgments

We acknowledge Aniekwe, Samuel Aniekwe, and Isaac Giwa for their help during the survey.

In memoriam

We graciously thank the late Emmanuel Ogah O. for his invaluable help during the field work.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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