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Determinants of farmers' willingness to pay for improved cultivars of *Macrotyloma geocarpum* (harms) Maréchal and Baudet in Benin and Togo

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Introduction: Quality seed is essential to satisfy food demand. This is also true for neglected crops especially those that are economically valuable such as Kersting's groundnut (*Macrotyloma geocarpum*), which holds the potential to improve farmers' livelihoods. In this study, we assessed the attributes that drove Kersting groundnut farmers' willingness to pay for improved seeds.

Methods: A total of 567 respondents were selected in the Northern Guinea and Southern Sudanian production zones in Benin and Togo using chain referral sampling, and they were then interviewed with a semi-structured questionnaire. Classification and regression trees, Ordinary Least Squared, and Tobit regression were combined to assess the relationship between the socio-demographic variables and farmers' Willingness to Pay (WTP) and Amount they are Willing to Pay (AWTP).

Results and discussion: Results suggested that more than 90% of respondents involved in the production of *Macrotyloma geocarpum* were willing to access its improved seeds, including those who had already abandoned the cultivation of this crop due to constraints such as the very low seed yield of current cultivars, the difficulty to access seeds, and the cultivation practices. The factors which affected the amount farmers are willing to pay included the following: the low yield of current cultivars used by farmers, the expected yield of the improved variety, which should be higher than 1 ton per ha (1 t.ha^{-1}), the socio-linguistic group affiliation, and the adoption level of improved agricultural technologies. The average amount fixed by seed companies that farmers were willing to pay for 1 kg of the improved seed was USD 5.35 but they have freely proposed to pay the average amount of USD 4.63 to access 1 kg of improved seed. The white-seeded cultivar was the most appreciated by farmers and was the most cultivated in the Northern Guinean Zone whereas the cultivation of the colored-seeded (e.g., black-seeded) cultivars was mainly noted in the Southern Sudanian Zone. Furthermore, the respondents indicated seed yield improvement and disease management as their main research needs to help increase the production of the crop. The findings of this research will help refine *Macrotyloma geocarpum* improvement programs to release farmer-needed varieties.

KEYWORDS

orphan legumes, technology adoption, breeding traits, improved cultivars, *Macrotyloma geocarpum*

1. Introduction

The extent of food insecurity in Africa (and in Sub-Saharan Africa in particular), the growing population in the region, and a changing climate suggest that many efforts are required to end hunger. In this context, policies that aim to strengthen food security need to implement actions based on evidence related to factors that are likely to affect the availability and accessibility of quality food. Increasing food diversification through sustainable intensification of crop production programs can help fight hunger and reduce poverty. In Africa, climate change is one of the main threats to agricultural productivity due to erratic rainfall patterns, unpredicted floods and droughts, and unexpected temperature fluctuations, and these have severe consequences on food and nutrition security (Zougmoré et al., 2018). Through rising temperatures crop productivity in Africa will continue to decrease. Agriculture is facing the challenges of climate change, and as the backbone of food production, a more diverse crop production system is required to meet food demand in terms of both quantity and acceptable quality (Waha et al., 2018) for the increasing population. Agricultural diversification systems appear as a sound solution to climate change with the development of improved and resilient varieties and the cultivation or domestication of new crops (Sognigbé and Tchokponhoué, 2020).

Since agricultural production in Sub-Saharan Africa is mainly rainfed, the impact of unfavorable weather on yields is more pronounced, with severe consequence on the subsistence and incomes of smallholder farmers (Callo-Concha et al., 2013). Historically, only a few crops (e.g., wheat, maize, and rice) constitute the basis of food security worldwide and are well integrated into most agricultural policies. Unfortunately these major crops only represent 2.14% of the existing crop diversity (Padulosi et al., 2013). In West Africa, local communities refer predominantly to some orphan crops (neglected crops) for their food needs (Ebert, 2014) while most of these orphan plants have no established crop improvement programs to support the development of improved varieties.

One of the most used crop groups by local population are leguminous crops. They are an important commodity group owing to the multi-purpose nature of their member species. They can help regenerate soil through nitrogen fixation, and they constitute a good source of vegetal protein (Graham and Vance, 2003; Considine et al., 2017). They also exhibit a great ecological adaptability with resilient attributes for adaptation to climate change (Considine et al., 2017; Cullis and Kunert, 2017). Some of the leguminous crops are well cultivated and supported by crop improvement programs (e.g., cowpea and soybean), while a number of them are still in the orphan stage without much attention from research. *Macrotyloma geocarpum* (Harms) Maréchal & Baudet, known as Kersting's groundnut (also referred to as *doyi*, the local name used in Benin), is an economically valuable legume crop in Benin and West Africa that can be used in diversifying food and income generation (Achigan-Dako and Vodouhè, 2006). However, the potential of the species is being hindered by its continuously decreasing production. This could be attributed to the poor access to quality seeds (Coulibaly et al., 2020); this alone could determine up to 40% of crop productivity (Ilieva et al., 2013; Achigan-Dako et al., 2014). Because of its orphan nature, farmers face challenges accessing *M. geocarpum* quality seeds. Providing high-yielding and quality seeds of *Macrotyloma geocarpum* to farmers will help contribute to the improvement of the household incomes through higher crop productivity. Farmers usually rely on low-performing seeds, obtained from previous harvests (Almekinders and Elings, 2001), and consequently end up with very low yields. In an attempt to understand how willing *Macrotyloma geocarpum* farmers are to adopt high-yielding improved seeds, this study modelled smallholder farmers' willingness to pay for improved *Macrotyloma geocarpum* seeds in the Republic of Benin and Togo by assessing trait preferences by farmers, the determinants of their willingness to pay (WTP), and the amount of money they are willing to pay for improved *doyi* seeds. Our results will enable breeding programs or seed companies to better understand adoption of improved *doyi* varieties by farmers. Understanding farmers' WTP before initiating a breeding program has the potential to help gauge the likely profitability of implementing a breeding program, an aspect often overlooked in orphan crops pre-breeding. We hypothesized that farmers' socio-demographic characteristics, current farm characteristics including farm size, and revenues are likely to affect their willingness to pay for improved *doyi* seeds.

Previous studies of Kersting's groundnut evaluated farmers' knowledge of the production and utilization of the species (Akohoué et al., 2019; Coulibaly et al., 2020; Kafoutchoni et al., 2022; Toure et al., 2022) and highlighted the importance of developing a research program focused on cultivar improvement. However, the success of a plant breeding program depends on the extent to which a released variety is adopted. Hence, unravelling factors shaping adoption of genetic innovation by end-users is key to improving crop productivity. In this study, statistical models were combined to model farmers' willingness and the extent of their willingness to pay for improved *M. geocarpum* seeds.

2. Agricultural extensions services and factors affecting seed adoption and willingness to pay

In Africa, farmers have different levels of access to agricultural extension services as a result of the various efforts of the Government, non-governmental organizations, and private companies. Extension services in agriculture are supposed to contribute to and have a great impact on the incomes of farmers (Cunguara and Darnhofer, 2011), which basically are characterized by low income attributed to the subsistence nature of their farming system. Access to quality agricultural extension services can play a tremendous role in increasing food production and ensuring food security in Africa as witnessed in the case of maize improved varieties which contributed to increase household food security in South Africa (Sinyolo, 2020).

The willingness of farmers to pay for extension services can depend on several factors including the severity of the problem which the extension services will solve as well as the economic return of the services (Singh and Narain, 2016). Many methods are used to analyze the WTP for technology adoption in agriculture including the stated preference, fixed methods (Waldman et al., 2014; Channa et al., 2019), Becker De-Groot-Marschack (BDM), and auction (Cole et al., 2020).

Studies conducted on agricultural technology adoption revealed that adoption of improved varieties in Africa exhibited a positive impact on food and nutritional security (Ochieng et al., 2019; Sinyolo, 2020). In the Democratic Republic of Congo, many factors were reported to determine decision making for improved potato variety adoption. Among them are the age and the distance between house and field, which are negatively correlated with the decision to adopt improved potato varieties, whereas factors like small farm size, the education level of farmers, income, cooperative membership, and access to extension services positively correlated with the decision to pay (Mugumaarhahama et al., 2021). In Ghana, rice technology adoption intensity was shaped by gender, age, and number of adults in the household, the latter emphasizing the availability of labor (Addison et al., 2022). Other factors like access to finance to support activities, farm size characteristics, and household income also affect climate smart agriculture technology adoption including improved seeds (Andati et al., 2022). Likewise, Ullah et al. (2018) reported that socio-demographic factors such as farmers' age, farm size, household size, education levels, experience, extension service, and credit access as well as climatic factors affect farmers' willingness to adopt improved peach cultivars. Under climate variation, smart adaptation strategies are needed for agricultural development. In Pakistan, climate change adaptation strategies are supported by many factors including farmers education, the family and farm size, and climate characteristics (Ali et al., 2020).

3. Materials and methods

3.1. Study area and respondents' sampling

The study was carried out from June to October 2019 in the Northern Guinea Zone of Benin and Southern Sudanian Zone of Benin and Togo (Figure 1), two suitable production areas of Kersting's groundnut in West Africa according to Coulibaly et al. (2022).

Villages that produce *doyi* were selected based on production areas previously identify by Akohoué et al. (2019) while respondents were selected using a snowball technique in each zone. Also known as the chain referral sampling method, the snowball technique is a widely used approach for intentional selection of expert informants, which in our case are the farmers who are cropping or who have cropped at least once in their lifetime Kersting's groundnut. Briefly, as part of this method, we went to the study sites and sought in each community an informant that is culturally competent (Kersting's groundnut farmers) regarding the production of Kersting's groundnut; they would then bestow upon others a similar competence, repeating the process from new participants progressively until the desired respondents sample size of local experts in the community is completely covered. This respondent selection approach led to a result of 3 villages (with 30 *doyi* producers) in Togo and 77 villages in Benin (with 537 *doyi* producers). The three villages in Togo included Pimimi, Nadoba, and Matema. Example of villages of higher number of producers in Benin included Gounoukouin, Kingni, Agouna, Sovlegni, Kemondji, Sowiandji, and Thio.

The Northern Guinean Zone, located in south of the Sudanian Zone, is covered by a semi deciduous forest with tall trees. Its average rainfall varies from 1,200 to 2,200 mm per year, and it experiences a long drying season that can last up to 7 or 8 months. The Southern Sudanian Zone is characterized by one rainy season with an annual rainfall ranging from 600 to 1,200 mm per year and a temperature ranging from 21 to 35°C daily. The Southern Sudanian Zone's vegetation is mainly made up of woodlands, savannas, and gallery forests. This zone is characterized by a unimodal rainfall pattern with one rain season and one dry season. The Southern Sudanian Zone is considered as a transition zone between the Sudanian and Guinean zones with wooded savannas.[1]

3.2. Data collection

After the enumerator got respondents' consent, the interview was then carried on using a semi structured questionnaire. The data collected included information on the respondents' socio-demographic characteristics, knowledge of the crop (cropping zones the last 3 years, production data, utilization, and constraints in the production), the number of cultivars they know and their perception of the crop cultivation (depletion and factors that favor that depletion in the area), and the different use categories of the crop (food, sales, medicinal, and cultural uses) in each community. The economic value of the crop, which was measured using its market value at sowing, was also recorded. As for the willingness to pay, the method of willingness to pay used during the study was the stated preference question type with dichotomous choice contingent valuation methods (Breidert et al., 2006; Huffman and McCluskey, 2017). Data on the amount farmers were willing to pay were also collected in two ways. The first method was direct by asking farmers to fix the maximum and minimum amount that they would freely pay for improved *M. geocarpum* seeds. Secondly the willingness of farmers to pay was evaluated by using indirect survey techniques. At this stage, respondents were provided a range of some bid amounts fixed by a seed enterprise to sell 1 kg of improved *doyi* variety. Those amounts fixed by the seed enterprise varied from USD 13.23 (XOF 8000) to USD 1.15 (XOF 700), see detail in Supplementary Table 1. The willingness to pay or not for the improved variety started with the highest amount; the responses of farmers were recorded as yes or no. The value of the amount that farmers were willing to pay was identified by checking the maximum bid the farmers accept to have access to the seeds. Farmers who did not intend to buy improved seeds were attributed a value of USD 0.

Quantitative data (agricultural income, farm size, total income, revenue from *doyi* production, expected yield of improved varieties,

1 https://eros.usgs.gov/westafrica/node/147

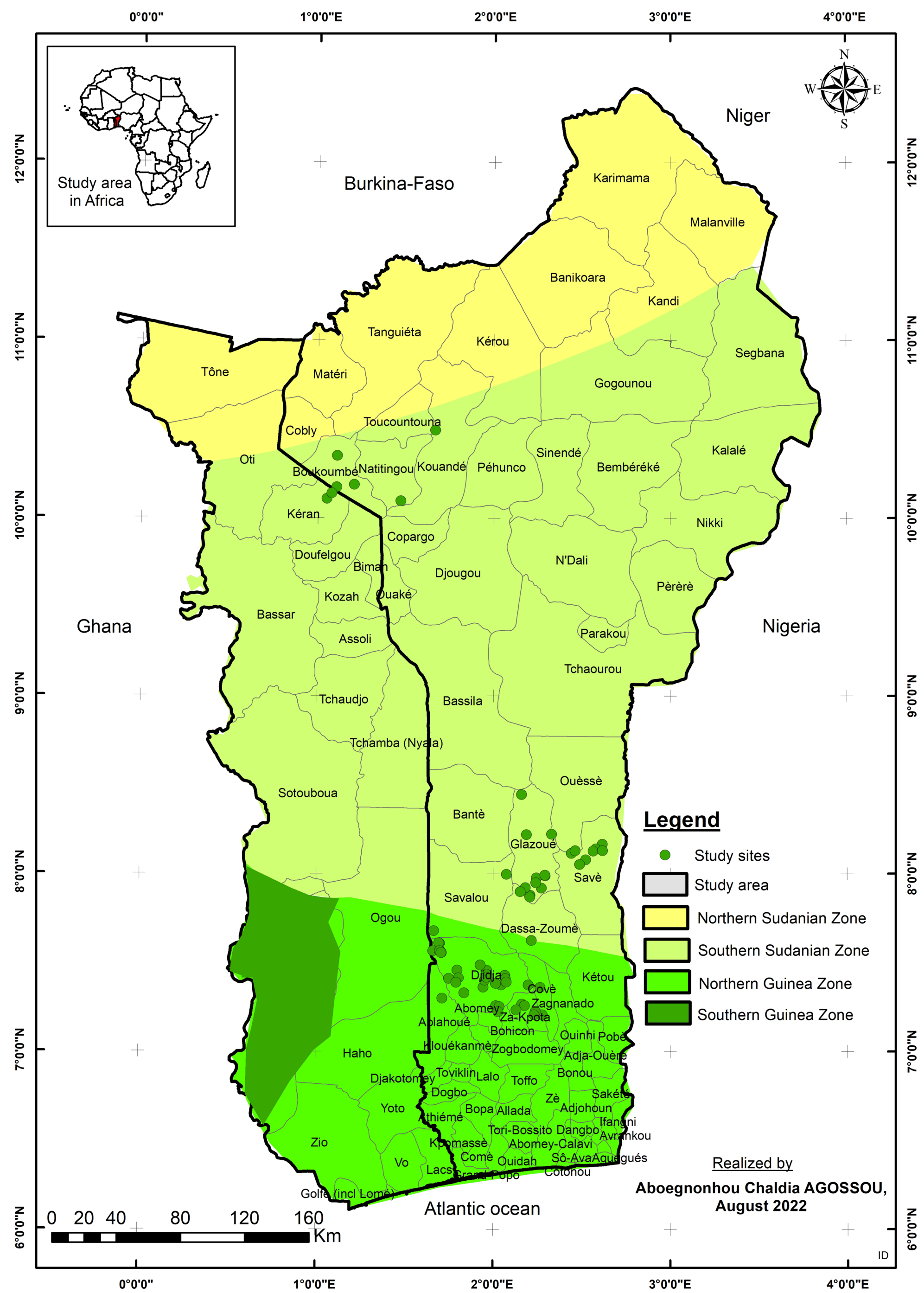

FIGURE 1
Map showing the study area.

experience in the *doyi* production, and household size) and qualitative data (access to agriculture extension services, nutritional quality of seeds, seed type, origin of seed used, availability of labor, degree of adoption of new varieties or technologies in agriculture, availability of agricultural inputs, and access to market to sale farm products) were also collected. The degree of adoption of new varieties was explained in four modalities: early adoption (when farmers adopted the seed at its initial stage), middle adoption (adopted the innovation before majority of the community people), late adoption (adopted the innovation after majority of the community people adopted it), and no adoption (when farmers prefer to use local landraces or practices).

3.3. Statistical analysis methods

All analyses were performed in R version 3.6.1 (Team RC, 2019). Descriptive statistics (mean, standard error, and frequency) were used for socio-economic and demographic data. A Spearman correlation analysis was used to test the relationship between variables while a Kruskal-Wallis, analysis of variance, Wilcoxon-test, and *t*-test (where necessary) were used to compare means of variables like agricultural income, income from *doyi* production based on the zone of the respondent, gender, and occupation. The economic value was analyzed through the selling price of the seed at sowing times, which was recorded per zone for each cultivar. A Spearman correlation analysis was used to test the correlation between the current yield of the crop and the expected yield of an improved variety for which the farmer is willing to pay. Student paired-test statistics were used to compare the freely proposed amount by farmers and the fixed proposed selling price of the seed of improved variety here called amount willing to pay (AWTP).

The explanatory variables included in the regression models were selected after testing the existence of multicollinearity through correlation tests among continuous variables and contingency coefficients. Supplementary Table 2 presents these variables and their *a priori* signs. Spearman correlation analysis was applied for the numerical data, whereas for dummy variables, a contingency coefficients method was used to check the independence between variables through Chi-square and Fisher-exact tests.

Classification trees and linear models estimated via ordinary least squared (OLS) tests were used to analyze the factors that can influence the willingness to pay for the seed. Whereas regression trees, the generalized linear model (glm), and Tobit regression (Tobin, 1958) were used to identify the factors that drove the farmers' amount willing to pay. The amount of deviance accounted by the glm model was calculated by using the Dsquared function of the package modEvA (Barbosa et al., 2016).

For all regression analyses we used the general equation $Y_i = \beta_0 + \beta_1 X_i + \varepsilon i$.

Whereas for the OLS, the Y_i used was the dummy dependent variable, which takes the value 1 if farmers are willing to pay and 0 otherwise. To implement the OLS in R, the command "lm" was used.

For the glm, Y_i was the amount willing to pay for improved seed freely proposed by farmers or fixed by the seed enterprise.

For all regression, β_0 was the intercept, β_1 was a vector of regression coefficients, and X_i was a vector of explanatory variables assumed to be correlated with the dependent variables (here WTP or AWTP). εi was an error associated with each regression.

For the case of the Tobit model, regression was based on the left censored and "vglm" function associated with the package VGAM used for this purpose in R (Yee, 2007).

For each regression model both continuous and categorical variables in Table 1 were initially used, followed by model simplification by elimination of variables. The classification and regression trees (CART) were performed using the ctree function of the "partykit" package in R (Hothorn and Zeileis, 2013) to select the most significant variables.

3.4. Concept clarification

AWTP, or **Amount willing to pay**, was evaluated through two methods: amount fixed by the seed enterprise and amount freely proposed by farmers.

Amount fixed by seed enterprise: This amount is fixed by the seed enterprise in the questionnaire for 1 kg of improved variety of *doyi*. This Amount varies between USD 13.23 and USD 1.15 [exchange rate of 21 April 2020 (1 FCFA for 0.0017 USD)].

Amount freely proposed by farmers: The maximum amount that farmers can allow to acquire 1 kg of improved variety of *doyi* when asked directly.

TABLE 1 Socioeconomic characteristics of respondents.

Characteristics	Modalities	Total	
		Size (*n*)	(%)
Number of respondents	Value	567	100
Number of villages	Value	80	
Sex	Male	379	66.85
	Female	188	33.15
Agro-ecological zones	Southern Sudanian Zone (SSZ)	200	35.27
	Northern Guinea Zone (NGZ)	367	64.73
Years in the cultivation of *doyi* (years)	Less than to 20	299	52.74
	20–40	205	36.15
	40–60	63	11.11
	Mean = 19.58		
Age	Below 20	5	0.85
	20–40	212	37.4
	40–60	269	47.45
	60–80	74	13.06
	80–100	7	1.24
	Mean	44	49
Instruction level	Illiterate	416	73.36
	Primary	81	14.28
	Secondary	51	8.99
	High school	13	2.29
	Undergraduate student	6	1.06
Marital status	Single	20	3.53
	Married	530	93.47
	Widowed	17	3
Linguistic group	Gur	65	11.46
	Kwa	430	75.85
	Songhai	2	0.35
	Yoruboid	70	12.34
Number of children in the household	Minimum	0	–
	Average	4	–
	Maximum	15	–
Household size	Minimum	1	–
	Average	8	–
	Maximum	25	–
Main occupation	Others	23	4.06
	Farmers	544	95.94
Migration	Native	433	76.36
	Migrant	134	23.63

4. Results

4.1. Socio-economic characteristic of respondents

A total of 567 respondents were interviewed in 80 villages across the two zones of the study with 65% of them living in the Northern Guinea zone and 35% of them in the Southern Sudanian zone. Most of the respondents are from Benin. The socio-economic characteristics of these respondents are summarized in Table 1. The typical respondents are 44 years old and is likely to be a man (66%). Most of the respondents did not attend western schools (73.17%) and most were married (93.21%). They had on average of four children and an average household size of eight persons.

The respondents belong to a total of 15 ethnic groups categorized in five different linguistic groups based on the grouping suggested by CENALA (2003). The majority of the respondents (75.85%) spoke Kwa and are from the Fon, Mahi, Agouna, Adja, and Ewe ethnic groups. This is followed by the Yoruboid linguistic group, which represented 12.34% of the respondents and included ethnic groups such as Idatcha, Tcharbè (Nagot), and Yoruba from Republic of Benin. Next, 11.46% of the respondents were from the Gur linguistic group, which includes the ethnic groups Ditammari, Obiaro, Yom, Temberma, and Warma. The Songhai linguistic group represents 0.35% of the respondents and includes the Dendi ethnic group.

4.2. Economic value of the crop in relation to cultivars and ecological zones

Most of the respondents (90.63%) who engaged in *M. geocarpum* production cultivated the white-seeded cultivars called doyiwé (*white doyi*) in the Fon and Mahi languages. Those two socio-linguistic groups that belong to the Kwa-linguistic group also referred to the species as doyikoun (literally meaning underground cowpea). The Idaasha and Tcharbè socio-linguistic groups from the Yoruboid linguistic group call the species Atchaka (High economic and nutritional legume), whereas Yoruba respondents call it Oyèyè. The Gur linguistic group use the names Issagnanré or Issanganané to identify the crop. The colored cultivars were found to be cultivated by few farmers (less than 10% of respondents) mostly in the Southern Sudanian Zone. Colored cultivars (Figure 2) included the white-seeded red-eye cultivars (WRC), the red-seeded cultivars (RSC) called *doyi-vovo*, the black-seeded cultivars (BSC) called *doyi-wiwi*, and the white-seeded black-eye cultivars (WBC), the latter being the most cultivated among the colored cultivars. All the existing cultivars are landraces, with the white, red, and black types cultivated in Northern Guinea whereas all five types are cultivated in the Southern Sudanian Zone. The comparison among the estimated seed yield of the five landraces by farmers did not show any significant difference ($p = 0.56$), and the estimated yield averages 480.2 kg.ha^{-1}.

There was a highly significant difference among the selling prices of different cultivars ($p < 0.0001$, df = 4, Kruskal-Wallis chi-squared = 102.76). The most economically valued cultivar by farmers was the white-seeded cultivar, which was also the most preferred by consumers. It cost 2.52 ± 0.058 USD in the Southern Sudanian Zone and 2.67 ± 0.031 USD in the Northern Guinea Zone with an average amount of 2.63 ± 0.028 USD. Other cultivars cost 1.65 ± 00 USD for the WRC, 1.72 ± 0.35 USD for WBC, 1.54 ± 0.109 USD for RSC, and 1.53 ± 0.076 USD for BSC.

4.3. Total agricultural and *doyi* revenues

The different types of incomes estimated by farmers (total agricultural and *doyi* incomes) varied significantly among respondents (Figures 3A–I). The average total income and agricultural income were USD 1,327 ± 72.63 and USD 1,171 ± 68.01, respectively. The income from *doyi* production represents about 17% of the total income of farmers with an average amount of USD 232 ± 12.41, which reached 3,308 USD for large-scale producers. Incomes were affected by gender (Figure 3A, W = 51,037; Figure 3D, 52,692; Figure 3G; W = 51,253) and agroecological zone (Figure 3F, W = 40,658; Figure 3I, W = 45,716). The average income provided by *doyi* to men was USD 282.09 ± 17.21 and USD 131.03 ± 10.82 for women (Figure 3G). The trend was the same for the agricultural income (Figure 3D) and total income (Figure 3A), which were higher for men than women. Farmers in the Northern Guinea Zone had the highest income (USD 246.32 ± 14.21) from the cultivation of *doyi* compared to the farmers of the Southern Sudanian Zone (206.49 ± 23.73 USD) (Figure 3I). Occupation was not found to have an effect on the incomes (Figures 3B,H) except for agricultural income (Figure 3E; df = 1, W = 8,087), which showed a significant difference with a higher average income of USD 1,191.88 ± 70.44 for farmers versus USD 700.28 ± 161.90 for other workers with farming as a secondary activity.

4.4. Dynamics and constraints for *doyi* production and perception of farmers of genetic erosion of the crop in the production systems

Table 2 shows that 67.78% of *doyi* farmers did not access agricultural extension services. Those who had access to extension services have it for a few major or staple crops like cotton, maize, and soybean. Farmers' knowledge about the cultivation of *doyi* was transmitted to them by their parents in 96.51% of cases. About 75.26% of the respondents produced the crop in the 2018 cropping season. Relative to the adoption rate of improved technology in agriculture, 48.95% of the respondents declared adopting it in early stages and 39.02% were in the category of middle-stage adoption. Only 3.31% declared they avoid changing practices and did not adopt new technologies or practices and preferred to use traditional knowledge.

About 17% of the respondents abandoned the cultivation of *doyi* due to some constraints (Figure 4), and the majority of the farmers thought that the cultivation area is declining and this favored depletion and even disappearance of the crop (Figure 4B) in some areas.

A total of 11 reasons were recorded as causes for the abandonment of the cultivation of the crop according to respondents. The three most important bottlenecks were (i) the poor quality of seed resulting in a low yield, which was estimated to be less than 500 kg.ha^{-1}; (ii) the high labor requirements and the age of farmers (mostly older people); and (iii) the difficulty to access the seed mostly due to the increasing cost of the grains at sowing time. The most important reasons for depletion include low productivity of the existing cultivars and low access to quality seed. Biotic and abiotic stresses impacting the productivity of

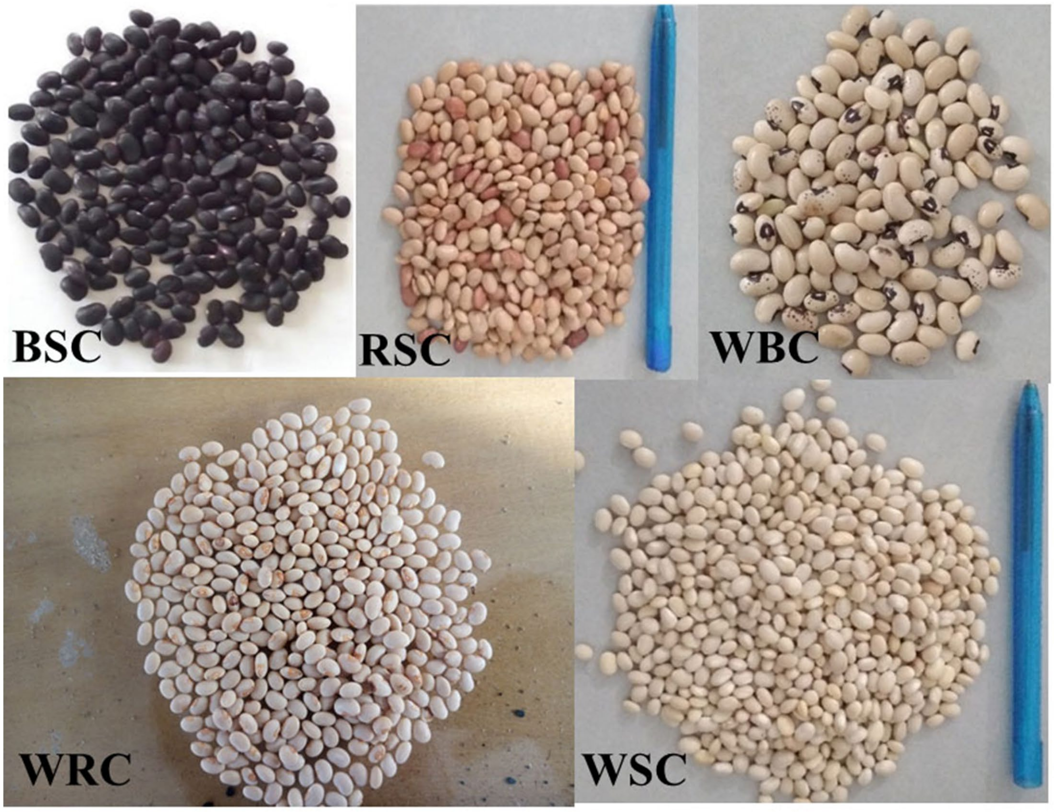

FIGURE 2
Various *Macrotyloma geocarpum* cultivars recorded in this study. BSC, Black seeded cutivars; RSC, Red seeded cultivars; WBC, White seeded with black eyes cultivars, WRC, White seeded with red eyes cultivars, WSC, White seeded cultivars.

doyi also promoted the decrease of the acreage farmers allocated to the crop and their decision to continue the cultivation of *doyi* or not. In the Sudano-guinean zone, the introduction of some competing crops like cotton and soybean, which are cultivated at the same time as *doyi*, also contributed to the crop's decreased production. Farmers' technical constraints in *doyi* production included harvest bottlenecks, high labor, and the fungal impact through seed and rot pod that can reduce the yield which was low naturally.

Many farmers have abandoned the cultivation after having lost their production due to abiotic stress factors like drought and flooding or biotic stress factors like pests and insect disease. It was only in the Djidja district that the transhumance was indicated to be a factor motivating farmers to stop the production of the crop. In the Sudano-guinean area, some farmers attributed the abandonment of the cultivation to the non-existence of fallow land in the area at the time. It seemed like un-fallowed land is not well suitable to produce *Macrotyloma geocarpum*. Despite all those constraints, 92.33% of the respondents that previously abandoned the crop were willing to restart its cultivation if the major constraints related to the low yield, access to quality seed, and sowing time on each type of land were solved.

4.5. Kersting's groundnut seed sources

Kersting's groundnut farmers got access to seeds via an informal seed system marked through three options: saving from previous harvests, purchase from a market, and seed exchange among farmers. Seed saving from previous harvests was practiced by 53.31% of respondents. According to farmers, they have difficulty maintaining the viability of the seed and protect it against post-harvest insects during storage, and they sell all their harvest after production to avoid loss. Seed purchases from markets occurred in 25.78% of cases with farmers going back to markets to buy their own production grain from sellers at sowing time. In this case, they have the option to pay directly to the seller or pay after harvest. They may also have a verbal contract with the seed seller and exchange part of their harvest with that person in November/December during harvest time. Seed exchange among farmers was observed with 1.4% of the respondent and was noticed in the Southern Sudanian Zone. About 18.81% of respondents not only saved their own grains but also went back to market to compete for seed needs if necessary.

4.6. Willingness to pay for improved *doyi* seeds and seed renewal rates

Most of the interviewed farmers (91.90%) were willing to pay for the improved seed of *Macrotyloma geocarpum*: of these, only 23.24% intended to renew the improved seed yearly, whereas 57.22% wanted to renew it just one time. About 11.44% of the respondents agreed to buy the improved seed at an interval of 3 years to renew their seeds every 3 years to ensure high yield.

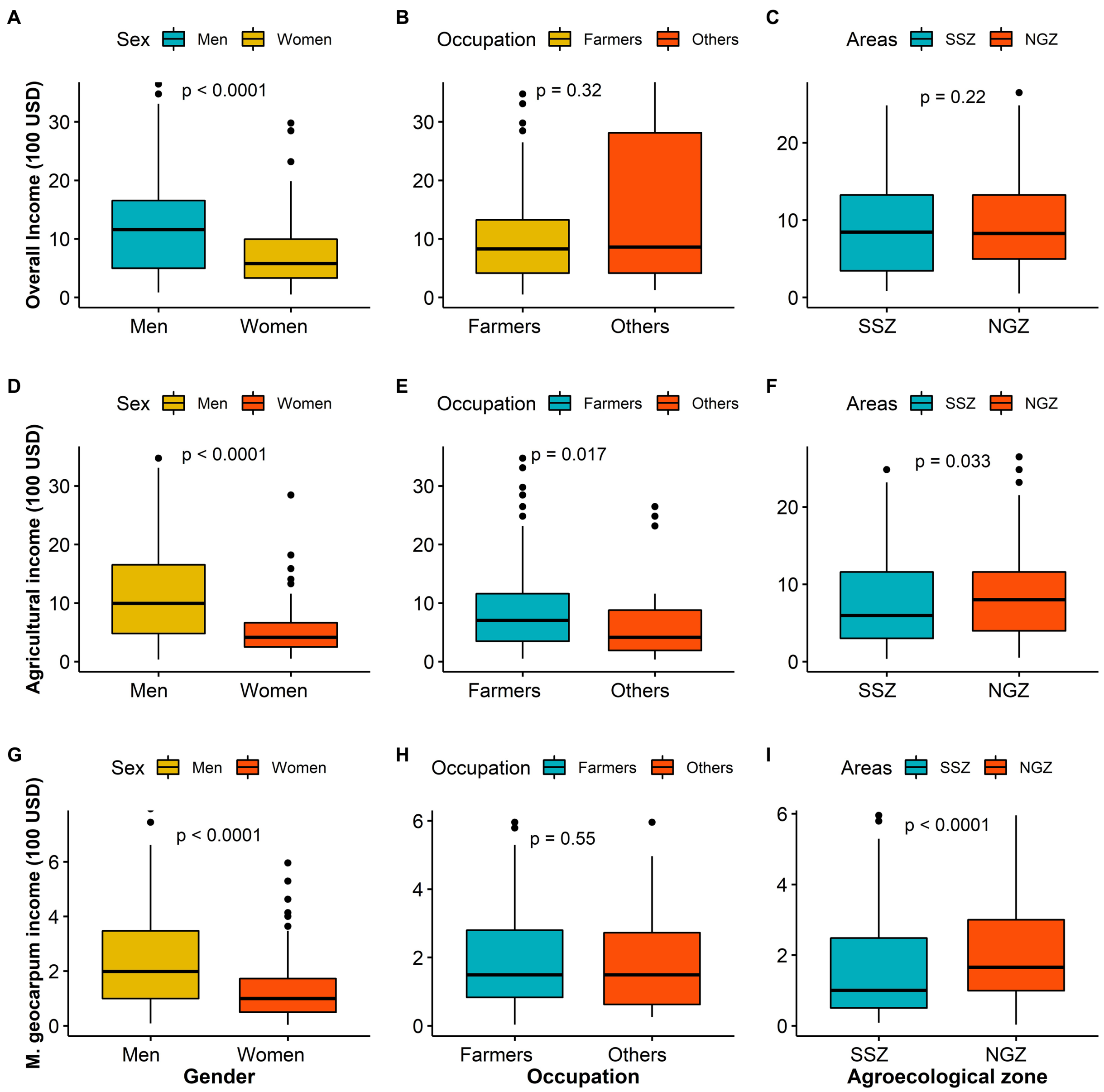

FIGURE 3
Total, agricultural, and *doyi* income earned by farmers in the survey areas. NGZ, Northern Guinea Zone; SSZ, Southern Sudanian Zone. **(A)** Overall income affected by gender; **(B)** Overall income affected by occupation; **(C)** Overall income affected by agroecological areas; **(D)** Agricultural income affected by gender; **(E)** Agricultural income affected by occupation; **(F)** Agricultural income affected by agroecological areas; **(G)** M. geocarpum income affected by gender; **(H)** M. geocarpum income affected by occupation; **(I)** M. geocarpum income affected by agroecological areas.

4.6.1. Factors determining the willingness to pay for the improved seed

By order of descending importance, the adoption level, the experience in *doyi* cultivation, and the cultivar type were the key factors out of the 14 tested variables that determined farmers' decision to pay for the seeds (Figure 5). The most influential factor is the adoption level. It explained with 100% confidence the willingness to pay for improved seed by a non-adopter and late-adopter farmers ($p = 0.027$).

Unsurprisingly, farmers with no adoption level were less willing to pay for improved seeds compared with later-stage adoption famers. For the middle-stage and early-stage adoption famers, the decision to pay was conditioned by their experience in the crop cultivation and the type of cultivar produced. Farmers' willingness to pay was at its highest level in less experienced farmers opting for the BSC, RSC, WRC, and WSC cultivars. In parallel, farmers with more than 52 years of experience in *doyi* production were less willing to pay for improved seed compared with their counterparts of <52 years of experience; those farmers opted for the WBC cultivar.

Based on the ordinary least squared method (Table 3) the WTP was affected by the estimated landrace yield, expected yield of the improved varieties, the income from the cultivation of the crop, and the adoption level of technologies. The result showed that the willingness to pay for improved seed was positively affected by the expected yield, the income from the crop and the middle-stage adoption level.

TABLE 2 Characteristics related to *doyi* production by respondents.

Variables	Modality	Unit	Frequency (%)
Decision about *doyi* production in the household	Production in the last season	% of yes	75.26
	Abandonment of the *doyi* cultivation	% of yes	16.9
	Planting in the future	% of yes	92.33
Access to agricultural extension services	Access to agricultural extension services	% of yes	32.62
Adoption level	No adoption	% of yes	3.35
	Late adoption	% of yes	8.3
	Middle adoption	% of yes	39.32
	Early adoption	% of yes	49.03
Knowledge on *doyi* transmission channel	Generation to generation	% of yes	96.51
	Neighbors	% of yes	3.49

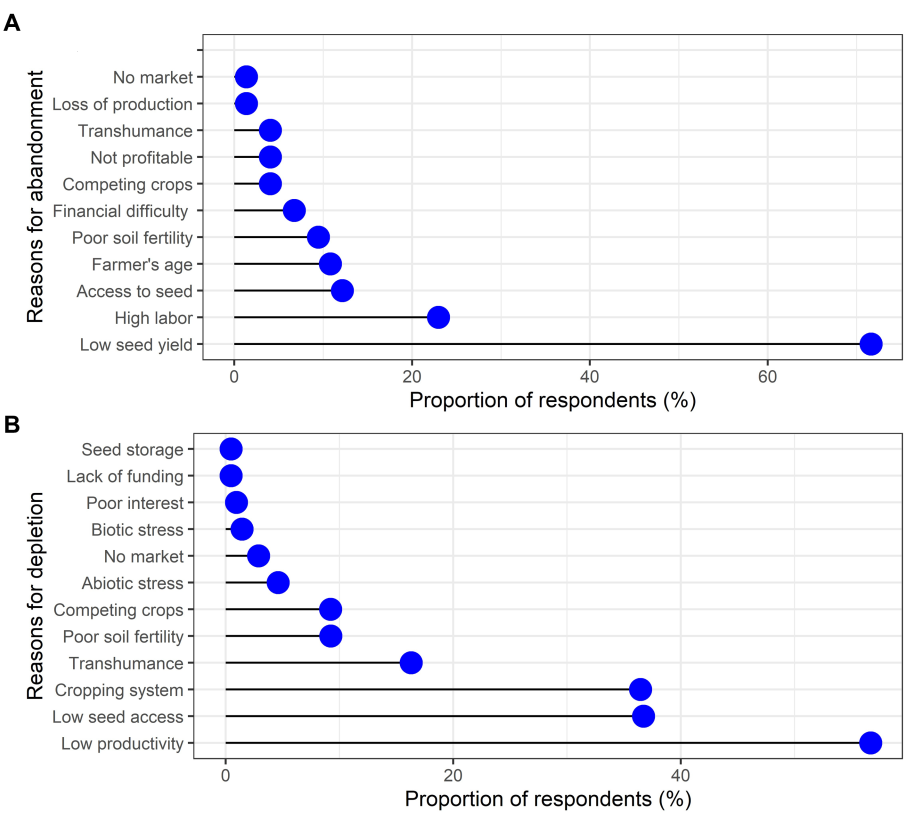

FIGURE 4
Abandonment **(A)** and depletion **(B)** factors of *M. geocarpum* production in Benin and Togo.

Conversely, the willingness to pay was negatively influenced by the farmers' current yield and the absence or the late adoption level. The coefficients for the variables were statistically significant (Table 3).

Both the classification tree model and the Logit regression model clearly concurred on the adoption level of technologies as the main factor which drove farmers to pay for improved *Macrotyloma* seeds.

4.6.2. Amount willing to pay for 1 kg of *Macrotyloma geocarpum* seed

- Amount freely proposed by farmers to buy 1 kg of improved seed.

The most commercialized cultivar was the white-seeded type in the two zones investigated. Farmers intentionally proposed to pay for that cultivar the amount of 5.2 ± 0.28 USD in SSZ and 4.75 ± 0.14 USD in NGZ. For other cultivars found only in SSZ, farmers proposed to spend for each kg of improved varieties the amount of 2. 20 ± 0.27 USD, 2.04 ± 0.106 USD, and 1.68 ± 0.098 USD for the red-seeded, white-seeded with black eyes, and black-seeded cultivar, respectively. The significant difference was revealed among those proposed amount within the Southern Sudanian Zone ($p < 0.0001$; df = 4; Kruskal-Wallis chi-squared = 68.341).

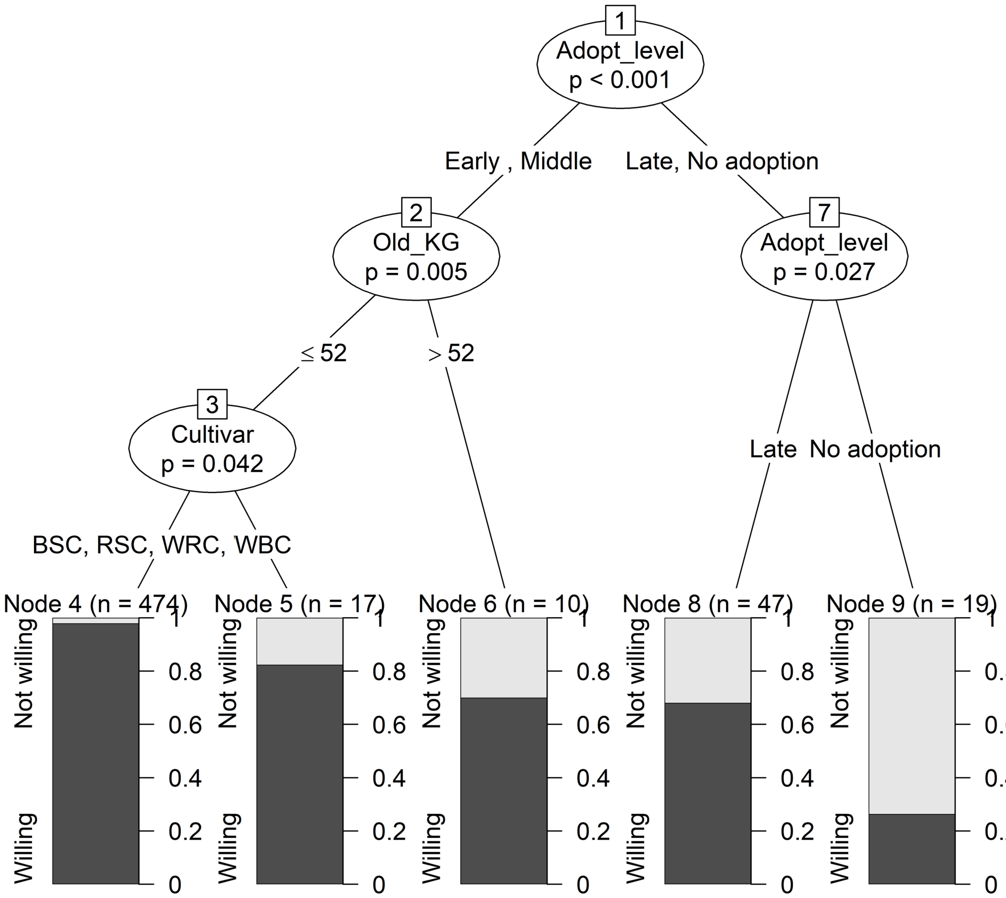

FIGURE 5
Classification tree showing the factors affecting the willingness to pay for *M. geocarpum* seed.

TABLE 3 Factors affecting willingness to pay (WTP) through linear model estimated via ordinary least squares.

WTP	Coef.	Std err.	*t* value	*p* > |*t*|
Constant	1.007e+00***	4.057–02	24.817	< 0.0001
Estimated yield	−1.168e-03***	8.818e-05	−13.249	< 0.0001
Expected yield	4.634e-04***	1.890e-05	24.523	< 0.0001
Income from *M. geocarpum*	6.616e-05**	2.259e-05	2.929	< 0.01
Adoption level: late	−9.485e-02***	2.628e-02	−3.609	< 0.001
Adoption level: middle	7.791e-03^{ns}	1.427e-02	0.546	0.58
Adoption level: no adoption	−3.270e-01***	4.078e-02	−8.019	< 0.0001
Multiple *R*-squared	0.665			
Adjusted *R*-squared	0.662			

***$p < 0.001$; **$p < 0.01$, ns, non significant.

- Amount fixed by seed companies for 1 kg of *M. geocarpum* seed.

Most of the farmers agreed to pay an amount between 3.309 USD and 8.27 USD. Less than 6% of respondents were willing to pay the maximum amount fixed (13.23 USD) for the improved *doyi* seed. Farmers were willing to pay variable prices for the different cultivars. An average of USD 1.68 ± 0.09 was indicated for the black-seeded cultivars and 2.55 ± 0.39 USD for the white-seeded with black eyes cultivars mostly cultivated in Southern Sudanian Zone. The average amount that farmers were willing to pay for the white-seeded cultivars was 5.65 ± 0.12 USD, whereas the red-seeded cultivars had the lowest price, 2.20 ± 0.27 USD.

The amount farmers were willing to pay differed significantly following the respondent's occupation ($p = 0.033$; W = 7,225) and highly significantly for agro-ecological zone ($p < 0.001$; W = 39,273), the sex of respondents ($p < 0.001$; W = 38,435), and the cultivars ($p < 0.001$; Kruskal-Wallis chi-squared = 101.14; df = 4) (Figure 5). The Northern Guinea Zone farmers were willing to pay a higher price

TABLE 4 Drivers for farmers' decision to pay for improved seed of *doyi* using GLM.

	Freely proposed amount by farmers				Fixed amount by seed enterprise			
	Coef.	Std err.	*t* value	$p > \|t\|$	Coef.	Std err.	*t* value	$p > \|t\|$
Constant	2.7546***	0.7155	3.850	0.0001	3.201***	0.746	4.287	< 0.0001
Sex: Women	−0.8433***	0.2397	−3.517	0.0004	−0.5774*	0.2538	−2.275	0.023
Estimated yield	−0.0108***	0.0016	−6.420	< 0.0001	−0.0084***	0.0017	−4.883	< 0.0001
Expected yield	0.0045***	0.0004	10.479	< 0.0001	0.0034***	0.0004	7.843	< 0.0001
Income from *M. geocarpum*					0.0009*	0.0003	2.463	0.0141
Adoption level: late					−1.4139**	0.4743	−2.981	0.0030
Adoption level: middle					−0.6538**	0.2292	−2.852	0.0045
Adoption level: no adoption					−0.7399^{ns}	1.1512	−0.643	0.5206
Linguistic group Kwa	2.5097***	0.3648	6.879	< 0.0001	2.9307***	0.3818	7.675	< 0.0001
Linguistic group Songhai	2.3383^{ns}	2.4480	0.955	0.3399	1.2797^{ns}	2.4953	0.513	0.6082
Linguistic group Yoruboid	3.1973***	0.4461	7.167	< 0.0001	3.1545***	0.4633	6.808	< 0.0001
Dsquared	0.27				0.27			
Adjusted Dsquared	0.26				0.25			

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ns, non significant.

(on average 5.69 ± 0.14 USD) for 1 kg of *doyi* compared with their counterparts, the Southern Sudanian Zone farmers, who were willing to pay 4.68 ± 0.22 USD ($p < 0.0001$; df = 1; $t = 9.0021$). While men were willing to pay 5.76 ± 0.15 USD, women proposed the amount of 4.42 ± 0.20 USD.

- Relationship between the amount fixed by the enterprise and freely proposed by farmers and the farmer's preferred mode of payments.

The maximum amount freely proposed by farmers to pay for the seeds was on average USD 4.63 ± per kg of seed and differed significantly from the average amount fixed by the seed enterprise to sell (USD 5.35) their seed ($p < 0.0001$; $t = -9.0021$, df = 521). Three modes of payments were proposed by farmers for the improved seed. About 50.4% of the farmers were willing to pay cash for the seeds once they sell their next harvest based on a contract, whereas 29.2% of them wanted a cash payment at sowing time, and 20.4% wanted to pay the cost of the seed through a contract which allows them to sell their own production to the seed enterprise or their proposed customers. Clearly, farmers face difficulties to afford seeds during sowing time as they may not have budgeted for seeds and may prefer alternative solutions.

4.6.3. Factors influencing the amount farmers are willing to pay for *doyi* seed

- Factors affecting the freely proposed prices by farmers.

The result of GLM applied to the freely proposed amount by farmers to pay for the improved varieties of *M. geocarpum* revealed four factors that significantly ($p < 0.001$) influenced the decision to spend specific amounts to buy improved seed (Table 4). Men were more willing to freely pay a higher price to access quality seed compared to women ($p < 0.0001$; $t = -3.517$). While the current yield negatively affected the amount freely proposed by farmers ($p < 0.0001$; $t = -6.420$), the expected yield from the improved variety rather positively influenced the amount freely proposed by farmers. ($p < 0.0001$; $t = 10.479$). With regards to ethnic groups, the Kwa and Yoruboid linguistic groups were likely to freely pay a higher amount compared to the Gur and Songhai groups (Table 4).

- Factors affecting fixed prices by seed enterprises.

The generalized linear model analysis on the amount willing to pay fixed prices for Kersting groundnut improved seed revealed six factors that significantly affected the respondent decision to allocate any amount for 1 kg of improved seed of *doyi*. Those factors included linguistic group, adoption level, the expected yield of improved varieties, the estimated yield, the income from the crop, and the gender (Table 4). Women were willing to pay less money compared to men. The higher the expected yield of improved varieties, the more farmers wanted to invest to have access to them. Early adopters were also more willing to pay higher prices for seed of improved varieties compared to farmers with late and middle adoption levels ($p < 0.01$, $t = -2.981$). The greater the income that farmers earned from the sale of *doyi*, the higher the amount they are willing to pay to access quality seed.

As revealed in Table 5, the Tobit model suggested that five factors determined the amount farmers were willing to pay: estimated yield of farmer's landraces, expected yield of new varieties, cultivars type, adoption level, and the income from the crop. The expected yield and the income had significant and positive relationships with the amount that farmers were willing to pay. The higher the yield of improved varieties and the income from the crop the more farmers may pay for improved varieties.

The correlation between the predicted and observed values of AWTP is 0.63, indicating that the predicted values share 40% of their variance with the amount farmers were willing to pay.

- Tree-based methods to identify the factors driving farmers' decisions on the amount to pay for seeds of improved varieties.

TABLE 5 Estimated coefficients for significant explanatory variables of amount willing to pay for improved seed with Tobit model regression.

	Coef.	Std err.	*Z*	*p* > |*Z*|	[95% Conf. Interval]		*p* value	Wald stat	LogLik	Pr(>Chi)
Constant	2.307**	0.829	2.783	0.005	0.6821	3.9322	< 0.001		−1227.62	< 0.001
Estimated yield	−0.0119***	0.0015	−7.821	< 0.0001	−0.0149	−0.0089	< 0.0001	−8.013	−1258.4	< 0.0001
Expected yield	0.0049***	0.0003	14.753	< 0.0001	0.0043	0.0056	< 0.0001	14.158	−1329.5	< 0.0001
Cultivars RSC	−0.237	1.564	−0.152	0.879	−3.3046	2.8292	0.879	−0.152	−1262.9	< 0.0001
Cultivar WBC	0.553	0.798	0.693	0.488	−1.0115	2.1181	0.488	0.690		
Cultivar WRC	0.245	2.598	0.094	0.924	−4.8479	5.3386	0.924	0.093		
Cultivar WSC	3.562***	0.549	6.484	< 0.0001	2.4855	4.6394	< 0.0001	6.515		
Income from *M. geocarpum*	0.0012***	0.0003	3.487	0.0004	0.0005	0.0019	< 0.001	3.448	−1234.3	< 0.001
Adoption level: late	−1.9238***	0.4347	−4.425	< 0.0001	−2.7759	−1.0717	< 0.001	−4.438	−1,243	< 0.0001
Adoption level: middle	−0.7329**	0.2276	−3.225	0.0014	−1.1784	−0.2874	< 0.001	−3.192		
Adoption level: no adoption	−2.7115*	0.9008	−3.012	0.0028	−1.4759	−0.9472	< 0.001	−3.541		
Sigma	0.900***	0.0315	28.562	< 0.0001	0.8386	0.9622	< 0.0001			
r	0.63									
R-squared	0.40									

Total observation: 568; left-censored from bellow observations: 46; uncensored observation: 522. ***$p<0.001$; **$p<0.01$; *$p<0.05$; $p<0.1$.

The regression tree model revealed that four factors influenced the amount farmers were willing to pay (Figure 6). These factors included the socio-linguistic affiliation of the respondent, the expected yield, income from the crop, and the respondent's adoption level.

The fixed amount the Gur and Songhai linguistic groups, both located in the Southern Sudanian Zone, were willing to pay depended on their current income from the crop. When the income from the crop is greater than 181.98 USD, respondents from the Gur and Songhai socio linguistic groups were willing to pay an average of 4.89 USD versus 2.04 when the income is lower or equal to 181.89 USD. Most Songhai and Gur linguistic group respondents had on average low income (100.37 USD) from the crop compared to the Kwa and Yoruboid socio linguistic groups who earned around 173.98 USD. This can be explained by the fact that the Songhai and Gur respondents are all located in the SSZ where it is noticed that the production is realized using small areas with food dietary diversification as the primary production objective. Conversely, their counterparts Kwa and Yoruboid produced the crop for market purposes and could have over time selected/retained high-yielding genotypes to maximize income. When it comes to the Kwa and Yoruboid linguistic groups, the most important factor determining the fixed amount they were willing to pay was the expected yield from the improved varieties rather than the yield. When this group's expected yield is greater than 1,140 kg.ha^{-1}, they were ready to pay on average USD 6.89. When the expected yield is lower than 1,140 kg.ha^{-1}, the amount that farmers were willing to pay depended on the adoption level with the non-adopter and late-adopter farmers being ready to pay less (USD 3.65) than early- and middle-stage adopters (USD 5.12).

4.6.4. Desired breeding traits for *doyi* improvement

As the farmers intended to buy the improved *doyi* seed, the improvement of the crop should be based on their preferred improvement traits. A total of 15 traits, categorized into breeding traits and agronomic research needs, were listed by farmers (Figure 7). The top five breeding traits were higher seed yield, high fungal resistance, high storage aptitude, high pest resistance, and high nutritional quality, while the top agronomic research needs included identification of crop fertilization schemes, the best sowing date on different type of soils, how to store the seed, and how to maintain good germination. Farmers expected the improved variety to be 1 ton.ha^{-1} against 500 kg. ha^{-1} for current landraces.

With the global challenges of agriculture nowadays (i.e., climate change, genetic diversity erosion, wars, and unrests), it is quite important to target all traits related to yield components improvement and tolerance of the crop to abiotic and biotic stresses. This includes the crop production cycle, which farmers want to be shorter. The normal current crop cycle goes up to 180 days, but farmers long for Kersting's groundnut cultivars with a production cycle of 75 to 90 days to face variations of climate.

5. Discussion

5.1. *Doyi* production, economic value, and contribution to household income

Areas previously described as being the production environments of the species (Akohoué et al., 2019) and favorable areas in the future for the cultivation of the species (Coulibaly et al., 2022) were investigated. Kersting's groundnut cultivation seems to be more intensive in the Sudano-Guinean region of Benin (here shared between the Northern guinea zone and the Southern Sudanian zone) compared to the department of Atacora in the Northern Sudanian zone. Mainly Northern Guinean and Southern Sudanian areas are included in the ecological areas where the crop must be well cultivated. Overall, men predominated in the *doyi* production as revealed by previous observations about the crop in Benin (Akohoué et al., 2019; Kafoutchoni et al., 2022; Vissoh et al., 2023). This fact is contrary to what we observed in Ghana and Burkina-Faso where women

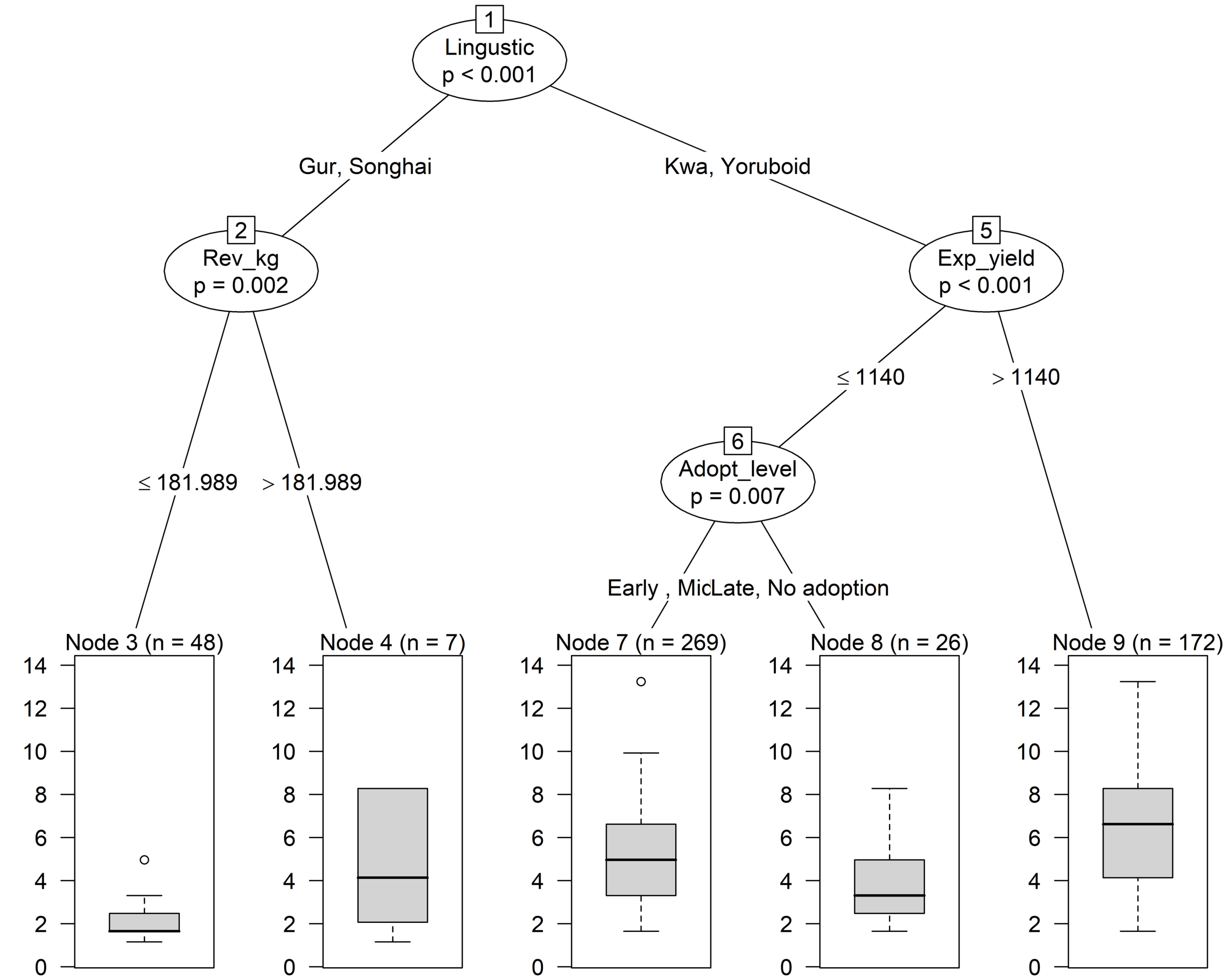

FIGURE 6
Conditional trees on AWTP for 1 kg of improved seed of *M. geocarpum*. MidLate: Middle, Late.

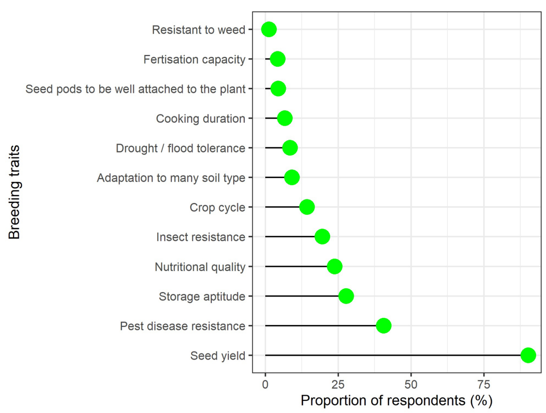

FIGURE 7
Farmers' desired traits for *doyi* crop improvement.

represented the main producers of the crop (Coulibaly et al., 2020). This variation in gender involvement may be linked to specificities in traditional land tenure and to the main objective of the production, which varied across regions and countries. Most women producer have as main objective sustained food security through diet diversification by planting *doyi* in Ghana, Burkina Faso, and the Sudanian area of Benin and Togo, whereas in Northern Guinea the production objective is mainly for income generation. It is also worth pointing out that women by default are part of their husbands' production unit and will not then have their own plot or a large plot unless they have money to hire land or labor for Kersting's groundnut cultivation; they may just cultivate small area for easy management at harvest time to avoid harvest losses because the crop required significant labor (Kafoutchoni et al., 2022).

The selling price of 1 kg of *M. geocarpum* varied considerably from one morphotype to another with the white-seeded cultivars being the most expensive and the most popular variant consumed in Benin. Its average price was 2.6 US (1,500 FCFA) per kg, and nowadays this price is more than the double and can sometimes hike to up to 10 USD. The average prices of other cultivars (RSC, BSC, WRC, and WBC) are less than 2 USD, but the cultivation of those cultivars is mostly for diet diversification. Based on farmers' estimation, the average yield for white cultivars is around 500 kg, which can bring around USD 1200, as reported by Vissoh et al. (2023), but the yield is mostly random according to many farmers due to the genetic potential of the cultivars and the stress during cultivation among other reasons. The average income of Kersting's groundnut of respondents was 232 USD, which is between the 100 and 300 USD previously revealed by Assogba et al. (2016).

Authors are of the opinion that the economic value of the crop is the highest among the grain legumes consumed in Benin. The challenge remains the genetic improvement of the performance of existing cultivars and their stability in appropriate growing areas. Despite the low and uncertain yield, the species' contribution to farmers incomes is relatively high and represents 17% of the agricultural income of producers. In contrast to small farmers, big farmers can get from the crop more than 3,300 USD annually. We found also that the income from the crop is higher for farmers of the Kwa and Yoruboid linguistic group compared to the Songhai and Gur linguistic group who had the lowest revenue from the crop. This can be explained by the fact that all the Songhai and Gur respondents are located in the SSZ where it is noticed that the crop was grown using small areas with food dietary diversification as the primary production objective (Akohoué et al., 2019). Conversely, their counterparts Kwa and Yoruboid, mostly found in the Northern Guinean zone, produced the crop for market purposes. The objective behind the production is explained by the level of income generated by each category of the socio linguistic group.

5.2. Kersting's groundnut production constraints and perception of farmers of genetic erosion

Many production constraints have been revealed by authors (Akohoué et al., 2019; Coulibaly et al., 2020; Kafoutchoni et al., 2022). Among them are the unavailability of quality seeds, the soil infertility, the unavailability of fertilizers for cultivation, transhumance, and the unstable yield; these have gradually contributed to the abandonment of the crop by some growers. With the new results and research focused on the species, there is renewed hope of seeing the sector be better organized and more beneficial for producers. Recently, for instance, it has been proven that the use of amendments based on *Tithonia diversifolia* has improved yield in the Southern Sudanian zone (Anani et al., 2020), thus opening up a route for *doyi* yield increase. The introduction of a new crop like soybean with higher yield and for which the market is very well organized contributed to the abandonment of *doyi* cultivation for some producers. The main production area in Benin is frequently invaded by herders who arrive in the area during the beginning of the dry season (*doyi* harvest time) for livestock feeding. Also, the high labor associate to the crop makes it hard and less attractive as workforces are also moving from production areas to towns, particularly when farmers need the labor force at harvest time.

All those production constraints strongly contributed to the decrease in size of the land allocated to the crop and even the abandonment of *doyi* production by some producers. Fortunately, at the same time, many farmers are trying to be guardians of their genetic resource conservation in different ways including crop regeneration. This has contributed to the fact that all the five cultivars already identified in the area by Akohoué et al. (2019) in Benin and Togo are still found in the production Zone. It proves that the genetic resources of *doyi* are still available even if some are increasingly less cultivated compared to others depending on the areas. So far, the white cultivars are widely cultivated and therefore the least susceptible to genetic erosion whereas other cultivars are much less cultivated. The white-seeded with black eyes, white-seeded with red eyes, and black-seeded cultivars are less cultivated but mostly exist in the upper Southern Sudanian zone. The cultivar most prone to genetic erosion appears to be the white-seeded with red eyes variety, which has been reported to be grown by only one farmer. For this same cultivar, in Ghana, only one sample was collected by Coulibaly et al. (2020) during their survey. This shows that this white-seeded with red eyes cultivar is not widely distributed and not well known by many growers.

5.3. Drivers of farmers' decision to pay for *doyi* seed

In agriculture, the quality of the seed determines the productivity and the income of farmers. Quality seed may always be adopted if it shows superiority over existing varieties or landraces. In the case of the orphan legume *doyi*, any improvement in seed quality will increase the yield and farmer income. So a study of the extent to which agricultural technologies is adopted by farmers is necessary for agricultural development. Adesina and Zinnah (1993) said that the perception of specific technological characteristics explained the adoption decision by farmers. In this paper, the high level of farmers' willingness to pay for the improved varieties were recorded. Indeed, more than 90% of the farmers were willing to pay for improved seeds including farmers who have abandoned the cultivation of the crop.

The factors that affect the willingness and the amount willing to pay for improved seed of Kersting's groundnut were identified. The study revealed that expected yield of improved varieties, linguistic group, adoption level, estimated yield of farmers cultivars, gender, income from Kersting's groundnut, type of cultivars, gender, and experience in the crop cultivation are the main drivers for *doyiwé* farmers to pay for improved seed. Those factors can be categorized into three major groups: socio-economic (gender and linguistic group), farming experience (number of years of experience in *doyi* cultivation, the estimated yield of the crop, and the income), and improved varieties characteristics through the expected yield.

The lower the estimated yield of the crop, the more farmers expect the improved variety to be high yielding and the higher their willingness to pay is. Farmers want the expected yield of the probable new variety of *doyi* to have a grain yield higher than 1,000 kg.ha^{-1} in the farmer's field.

The sociolinguistic group of the respondents is an important factor explaining farmers' decision. Local people from specific sociolinguistic areas develop specific behavior vis-à-vis specific plant genetic resources. Our study shows the Kwa linguistic group, which includes mostly Fon and Mahi ethnic groups, is well involved in *doyi* cultivation. Whatever the location of farmers from the Kwa linguistic group, they produce the crop. This could be attributed to the high economic value of the white-seeded cultivars largely cultivated by those farmers. Farmers were willing to pay more for the white cultivars compare to others. Such a situation is explained by the high demand for the white grain during celebrations at the end of year. Northern Guinean farmers from the Kwa linguistic group placed more importance on the crop and are involved in the cultivation of the crop. The importance of a crop within the sociolinguistic group of each area contributes to the farmers' decision to adopt or not the improved varieties of *doyi*. The years of experience in *doyi* cultivation were positively correlated with the age of respondents, which unfortunately was not among the important determinant of the willingness to pay for *doyi* seed. In contrast, age was directly reported to be an important driver for technology adoption for other crops (Fahad et al., 2018; Ullah et al., 2018). Regarding the experience with *doyi* production, farmers with a few years of experience (young farmers) are likely more willing to pay than older farmers with more experience. This supports the assertion that younger farmers show more willingness to accept and pay for change due to their knowledge relative to new practices (Polson and Spencer, 1991; Boadu et al., 2019). Vissoh et al. (2023) found that with the accumulation of experience years on *doyi*, old farmers may get high yields, and this can explain old farmers' motivations to pay less compared to young farmers who did not have as great a perception of the risk of high prices of inputs, as reported by Fahad et al. (2018). Regarding the adoption rate, which is essential for breeders, farmers defined specific criteria for adopting improved varieties. Those criteria could include the taste of the new variety, nutritional quality, yield potential, and others. These can be well evaluated only when the seeds are released or evaluated in farmer fields.

Both ordinary least square methods and classification and regression trees showed that the income from the crop affects the amount willing to pay for the improved seeds as also reported by Boadu et al. (2019) for Pona certified yam seeds in Ghana and Daniel and Teferi (2015) for agricultural extension services in Eastern Ethiopia. Our analysis shows that women proposed the lowest amount to pay for the improved seed compared to men. Vissoh et al. (2023) showed that gender has a negative impact on the *doyi* yield. This trend was also observed in the Northern Region of Ghana when Banka et al. (2018) evaluated the willingness of farmers to buy legume biofertilizer and revealed that men have greater power to buy legumefix. Additionally, we can pay attention to the objectives of the farming activities of women, which were more oriented to consumption of commodities such as legumes and vegetables.

A gap was found between the freely proposed purchase price by farmers and the fixed amount set by the seed enterprise to sell the improved seeds. The use of direct and indirect survey methods of stated preference to evaluate the amount willing to pay in our study showed that the direct amount proposed by farmers is less than the amount fixed for the quality seed.

5.4. Breeding implication

Seed is the most vital input of agriculture and without a guarantee for quality seeds, other inputs remain worthless. This can explain why farmers stated quality of seed as a primary need. High seed yield and early maturity with resistance to biotic stress (pest and disease) are needed to meet farmers' expectations. The most important among these agronomic traits was the yield potential, which should be greater than 1,000 $kg.ha^{-1}$ against the current cultivars (with a yield less than 500 $kg.ha^{-1}$). Beyond these criteria, resistance to abiotic stress, such as droughts, should also be considered (Maity and Pramanik, 2013; Hampton et al., 2016). Even if tolerance/resistance to drought was ranked ninth among farmers' desired traits, it is a crucial one that often impedes the top desired trait such as yield. Based on the farmers' preferences, strategies to ensure a consequent seed yield increase in *M. geocarpum* appears to be the next crucial challenge we face.

Recent development in *M. geocarpum* suggested challenges in hybridization in the species (Kafoutchoni et al., 2021), a situation that locks genetic variation creation. Such a bottleneck calls for the necessity to explore alternative diversity generation approaches such as mutation breeding by using physical and chemical mutagens. Moreover, the role of augmenting agronomic practices should not be underestimated, as it holds substantial potential to positively influence crop yield. This includes the implementation of plowing techniques tailored to the unique characteristics of each identified area, a notion previously suggested by Coulibaly et al. (2020).

The aspirations of farmers extend beyond mere improvement of crop performance. Ensuring the enhanced performance of the crop is accompanied by an organized market structure is paramount to guarantee a better profit margin for farmers. Without this, achieving a satisfactory adoption rate of newly released varieties may prove challenging.

6. Conclusion

This study reveals that farmers' purchase decisions for improved varieties are heavily influenced by market availability. Farmers anticipate that new varieties will outperform their current cultivars, with expectations centered around a higher yield of over 1,000 $kg.ha^{-1}$ with higher resistance to fungal pests, which triggers the most substantial challenges to the crop at harvest. Farmers proposed a purchasing price of USD 4.63 per kg of improved seeds while the input-dealers price was around USD 5.35. Farmers willingness to pay is influenced by the anticipated yield of the new variety, the level of adoption, and the income derived from the crop. Additionally, linguistic group membership plays a significant role in the amount farmers are willing to pay. Interestingly, the amount proposed by farmers is significantly lower than the amount they are willing to pay when evaluated against the bid fixed price during the survey, suggesting a propensity among farmers to propose lesser amounts for the same product. As a result, it may be worthwhile to consider additional studies using auction methods to accurately assess farmers' true purchasing capacity for the improved seeds.

Farmers require further education on the benefits of purchasing quality seeds consistently rather than making a one-time purchase, as indicated by 50.4% of respondents. The ongoing practice of saving past harvests for use as seed in the following cropping season also needs to be addressed. It is conceivable that farmers may be sensitive to the price of improved seeds, potentially impacting the adoption rate of future *doyi* varieties. However, if the new product can naturally demonstrate its superiority over local cultivars, a well-devised selling strategy and marketing plan by seed companies in rural areas could lead to its acceptance, increased willingness to pay, and, ultimately, successful adoption.

This study underscores the need for the improvement and development of high-quality *Macrotyloma geocarpum* seeds and their commercialization by seed companies to meet farmers' demands and address issues of seed access and low yield. Once the variety has been developed and released, experimental auction methods could be utilized to gauge farmers' preferences and the amount they would genuinely be willing to pay for the improved seeds.

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.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

AA and EA-D: conceptualization. AA: investigation, writing and editing, and data analysis. EA-D: validation. EA-D, SN, VF, HO, TK, and MC: review. All authors contributed to the article and approved the submitted version.

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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.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1180961/full#supplementary-material

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