



Article

Farmers' Perceptions, Preferences and Choices of Commercial Tea Clones in Uganda: From the Smallholder Out-Growers' Perspective

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Abstract

Tea (*Camellia sinensis* (L.) Kuntze) cultivation by smallholder out-growers has grown significantly. Recent government initiatives have expanded production from traditional tea growing regions. This study investigated how smallholder farmers perceive and prefer different commercial tea clones. It also looked at the factors that influence their choices across major tea-growing regions of Uganda. A structured questionnaire was administered to 324 randomly selected tea out-growers from Central, Western, Kigezi, and West Nile regions. Data was analyzed using descriptive statistics, a Tea Preference Index (rating clone attributes on a 1–5 scale), and a multivariate Probit (MVP) model to evaluate farmers' choices and preferences. Clone 303/577 is the most cultivated, accounting for 59%. Adoption rates were high in West Nile (98%), Kigezi (77%), and Central (67%) regions. Clone 6/8 ranked second at 47%, while clone 100/5 had the lowest cultivation rate at 10%. The ranking of clones by preference was 303/577, 6/8, 108/82, 31/8, and 100/5. Key attributes influencing preferences included, yield potential, canopy width, post-plucking/pruning recovery rate, shoot tenderness and cup quality. Results showed that a farmers' choice of clone 303/577 was significantly influenced by shoot density, gender and tea farming experience. For clone 108/82, the most important factors were quick recovery after plucking/pruning, education level and household size. This information is vital for agricultural policy, extension services, tea breeding and genetic improvement programs in the tea sector.

Keywords: tea clones; preference and choice; Uganda tea industry; smallholder out-growers



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1. Introduction

Tea production is a key driver of economic development in many Asian and African nations. In Uganda, tea ranks as the second-largest traditional cash crop foreign exchange

earner after coffee. As of 2022, Uganda had over 29,000 hectares under tea cultivation [1], producing 66,000 metric tons of tea in 2021, with projections estimating an increase to 68,000 metric tons by 2026 [2]. The tea industry supports more than 80,000 smallholder households and employs over 150,000 skilled and unskilled workers, making it a crucial sector for rural livelihoods and national economic stability [3,4]. Tea cultivation in Uganda traces its roots to early 1900s, gaining commercial significance from 1945 with the establishment of large estates by European and Asian settlers [5]. Today, Uganda's tea industry comprises large estates (33%) and smallholder farmers (67%), with the latter organized either as small estates supplying specific factories or as independent out-growers [6]. This dual system has evolved to create a robust supply chain that supports both domestic consumption and export markets [7]. Contextually, an out-grower is a farmer who participates in a contractual farming scheme with a tea processing factory/company, gaining access to markets, technical support and credit services while ensuring a steady tea leaf supply to the factory [8]. Although tea plant bushes can remain productive for over 100 years, peak yields are generally between the 30th and 50th years. Due to limited availability of suitable land in both commercial estates and smallholder sectors, producers have increasingly expanded cultivation into marginal areas where suboptimal soil and climate conditions pose significant challenges [9]. These challenges are exacerbated by changing climatic conditions which have introduced erratic rainfall and temperature patterns that negatively affect tea quality and yields [10]. This situation demands the adoption of modern agricultural technologies, particularly improved resilient and highly productive tea varieties.

Modern tea cultivation has progressed significantly from traditional seedling propagation to vegetatively propagation clones due to the latter's advantages in yield, uniformity and cost-effectiveness. Over 1500 tea clones are currently in use across 36 countries [11]. In Uganda, the transition from seed-based to clonal tea cultivation has been relatively low. While clonal planting materials could have been available, their demand by small holder farmers is still low due to the high cost of these plantlets. Promotion of clonal plantlets has been supported by government initiatives aimed at poverty alleviation and agricultural modernization [4].

Rwebitaba Zonal Agricultural Research and Development Institute (ZARDI), which is mandated to lead Uganda's tea research and equally hosts the national tea genebank with over 152 genotypes, has played a pivotal role in varietal development [12]. Through systematic clonal field trials assessing yield potential, cup quality and stress tolerance, four commercial clones (108/82, 100/5, 31/8, and 6/8) were released by the Tea Research Institute of East Africa. Clone 303/577 was later released by Tea Research Foundation of Kenya for commercial production [13]. These varieties have undergone extensive evaluation for key agronomic traits including soil adaptation, drainage adaptation, yield, canopy architecture, and resistance to various environmental stresses (ibid).

The adoption of agricultural technologies, including improved crop varieties, is significantly influenced by farmers' perceptions, preferences, and socioeconomic characteristics [14]. Variety choice, in particular, represents a technological evolution delivering utility in both production aspects (e.g., yield, labor efficiency, pest resistance) and market-driven characteristics (e.g., cup quality, market value and demand).

In Uganda, tea production plays a significant role in poverty reduction and rural development, not only by improving household incomes but also by contributing to rural infrastructure and employment opportunities [7]. While the government of Uganda agencies, stakeholders and development partners have promoted improved tea clones through various initiatives [4], limited research exists on how farmers perceive and make choices among these tea clones across Uganda's tea-growing regions. Understanding farmers' perceptions and choices, although subjective has been shown to be essential in decision

making on the adoption of new technologies and their improvement of the economic modeling outcomes [15]. Understanding these aspects is crucial for tea breeders, companies, agricultural policymakers, and extension services to enhance program efficiency and adoption rates. This knowledge gap is particularly significant given tea's status as a priority commodity in Uganda's agricultural transformation agenda [6]. Additionally, tea clone preference is critical for optimizing productivity and sustainability, as it guides breeding priorities, resource allocation, and supports policy alignment toward climate-resilient and market-responsive tea development [13]. Recent studies have increasingly emphasized the importance of understanding farmers' decision-making processes in the adoption of agricultural technologies [16,17]. Despite this growing body of research on tea crop [4,7,12,13], there remains limited empirical evidence on how specific crop attributes influence farmers' varietal choices where production cycles are long and investment decisions are irreversible. Addressing this gap is crucial, as clonal characteristics play a decisive role in shaping farmers' adoption behavior and the overall sustainability of tea cropping system.

This study contributes to the literature by examining how tea clone traits influence farmers' selection of commercial tea varieties in Uganda. The study offers an understanding of the behavioral and technical dimensions of technology uptake. The findings provide valuable insights for tea breeding programs, extension services, and agricultural policymakers, enabling them to design interventions that are more closely with farmers' preferences, production constraints, and market realities. The results will support efforts to promote farmer-centered innovation, improve the targeting of clonal dissemination strategies, and enhance the sustainability and competitiveness of Uganda's tea sector.

2. Theoretical Frameworks

The choice of tea clones can be conceptualized as a binary decision in which farmers seek to maximize their expected utility based on their heterogeneous characteristics [18]. This decision is influenced by uncertainty, as farmers form expectations regarding which clone and accompanying management package will yield the most favorable results. The study adopts an Integrated Technology Adoption and Utility Maximization Framework, which synthesizes insights from Random Utility Theory (RUT) [19], Rogers' Diffusion of Innovations Theory [20], and the Agricultural Innovation Systems (AIS) perspective [21,22]. This integrated approach provides a comprehensive lens for understanding smallholder farmers' decision-making processes concerning the adoption of improved tea clones. According to Random Utility Theory, farmers are rational agents who choose the option that maximizes their perceived utility. In the context of tea clone choice, a farmer may decide whether to choose or not to choose a particular clone depending on how its characteristics align with production goals, available resources, and market opportunities. Each tea clone offers a bundle of attributes such as yield potential, drought and pest resistance, input requirements, and cup quality that collectively determine its perceived utility. Conversely, some farmers may opt to continue cultivating seedling tea as a risk minimization strategy, especially when uncertain about their ability to meet the management demands of improved clones. In such cases, the decision not to adopt reflects a precautionary approach aimed at avoiding potential financial vulnerability associated with clone cultivation. Consequently, farmers' preferences represent a comparative evaluation of the benefits and constraints of available options, conditioned by household characteristics and local production contexts.

Rogers' [20] Diffusion of Innovations Theory complements this perspective by emphasizing that adoption is a gradual process shaped by individual perceptions and social interactions. Farmers' adoption behavior is influenced by the perceived relative advantage, compatibility, complexity, trialability, and observability of the innovation. For instance,

high-yielding or climate-resilient clones that demonstrate clear advantages tend to diffuse more rapidly among smallholders, while those requiring specialized management or higher investment are adopted more slowly. At a broader level, the Agricultural Innovation Systems (AIS) framework situates these individual decisions within the institutional and market environment. Adoption outcomes are determined by interactions among farmers, researchers, extension agents, policymakers, and market actors. This systemic view underscores how institutional support, market incentives, and value chain coordination shape the availability, accessibility, and desirability of specific tea clones. By linking farmers' varietal preferences to external drivers such as export quality standards, policy priorities, and consumer demand, the AIS perspective bridges the gap between production systems and market requirements.

Integrating these three theoretical perspectives enables the study to conceptualize tea clone selection as both a binary and multivariate decision-making process, where farmers evaluate options based on production-oriented traits (e.g., yield potential, pest and drought resistance, adaptability) and market-oriented traits (e.g., price premiums, cup quality, and demand trends). This integrated framework captures the complex interplay between individual choice behavior and the broader innovation ecosystem, offering a robust conceptual foundation for analyzing the drivers of smallholder farmers' preferences for commercial tea clones in Uganda.

3. Materials and Methods

3.1. Study Area and Survey Design

The study was conducted across Uganda's major tea-producing agroecological regions, namely the Western, Southwestern, Central, and West Nile zones. These regions represent the core of the country's tea production belt and are characterized by favorable climatic and biophysical conditions for tea cultivation. The areas experience a temperate climate with annual rainfall ranging between 1000 mm and 1500 mm, well distributed over at least 150 days per year, and average temperatures of 20 °C to 25 °C. Most of these regions lie at an altitude exceeding 1500 m above sea level, providing the cool and humid environment required for optimal tea growth and quality development [7]. A comprehensive cross-sectional field survey was carried out between January and December 2022. The extended data collection period was necessitated by resource and logistical constraints, which made simultaneous fieldwork across all regions impractical. However, this time spread did not affect the reliability of the results since the key variables of interest such as tea clone preference, farm characteristics, and household demographics were time-invariant and not influenced by short-term fluctuations. Before the main data collection, the research team conducted a pre-test of the questionnaire in Mubende District, one of the non-participating districts, to assess the instrument's reliability, clarity, and internal consistency. A total of 20 farmers participated in the pilot phase, and feedback from this exercise informed revisions to improve question wording, sequencing, and logical flow. The refined instrument ensured clarity and minimized response bias during the main survey.

The final structured questionnaire was administered to 324 smallholder out-grower household heads purposively and randomly selected across the different tea-growing regions. The survey captured detailed information on household composition, demographic and socioeconomic characteristics (including education, gender, age, and tea farming experience), land ownership and utilization patterns, and specific tea-related variables such as clone preference, agronomic practices, pest and disease management, soil fertility enhancement, and tea agroforestry integration. It also covered production costs, yields, revenue, access to extension services, institutional linkages, and marketing challenges faced by farmers. Data collection was undertaken by trained enumerators under the close

supervision of the research team to ensure accuracy and adherence to ethical standards. Enumerators received intensive training on the study objectives, interview techniques, and data quality control measures, including daily consistency checks and spot validations. The structured questionnaire and related field protocols are provided in the Supplementary Material for reference and replication. This methodological rigor ensured that the data collected was representative, reliable, and analytically robust, providing a sound empirical foundation for examining the determinants of tea clone choice and adoption behavior among smallholder farmers in Uganda.

3.2. Sampling Procedure

A multistage sampling approach was employed to select tea farmers for this study. In Uganda's tea industry, smallholder growers account for about 70% of the total acreage, while tea estates contribute the remaining 30% [5]. This survey covered smallholder farmers from all the four major tea-growing regions of Uganda, Western, Southwestern, West Nile and Central, representing the country's diverse agroecological and production conditions. Within each region, purposive sampling was first used to identify strategic tea processing companies, which provided lists of their affiliated out-growers. These farmer lists were then organized by district to create a clear sampling frame. To ensure representativeness, proportionate random sampling was conducted to select districts for inclusion in the study [18,19]. At the district level, simple random sampling was applied to draw farmers from the compiled out-grower lists. The selected districts were Kyenjojo, Kabarole, and Kikuube in the Western region; Bushenyi, Kanungu, Rukiga, and Rubanda in the Southwestern region; Mukono, Buikwe, and Mityana in the Central region; and Zombo in the West Nile region.

This sampling design ensured adequate regional representation and captured variability in tea production systems, farm characteristics, and market linkages. It also strengthened the reliability of the findings by integrating perspectives from both highland and mid-altitude tea-growing areas, which differ in climate, soil fertility, and access to processing facilities. The sample size for the study was determined using Yamane's [23] formula for finite populations, which provides a reliable method for estimating sample sizes where the population is known. The formula is expressed as

$$n = \frac{N}{1 + N(e)^2}$$

where n represents the required sample size, N is the total population, and e is the level of precision.

Given a total population of 2000 tea farmers, a 95% confidence level, and a 5% margin of error, the calculated sample size was approximately 324 respondents. The distribution of respondents across regions was as follows: Kigezi (41.4%), Rwenzori and Central (38.9%), and West Nile (12.7%). This sample size was considered sufficient to ensure representativeness and statistical reliability while maintaining feasibility in terms of time and resources. The approach allowed for adequate coverage of farmers across the four major tea-growing regions of Uganda, thereby capturing regional diversity in production systems and farmer characteristics [23].

3.3. Analytical Framework

All data were analysed using STATA software 18 [24]. Descriptive statistics, including means, percentages, frequencies, and standard deviations, were used to evaluate tea clone selection and describe the socio-economic characteristics of respondent households, particularly regarding their tea farming experience and the types of tea clones present

on their farms. Respondents were asked to rate the performance of different tea clones based on key agronomic and quality-related traits such as shoot density, shoot tenderness, recovery rate, drought tolerance, yield potential, and cup quality. Ratings were done using a five-point Likert scale where 1 = very poor and 5 = very good, allowing for a standardized comparison of farmer perceptions across clones. The resulting data were analyzed descriptively using means and standard deviations to summarize farmers' assessments and identify the most valued traits influencing clone preference. An overall weighted score was computed to capture the composite performance of each tea clone based on farmers' evaluations. This score was derived by dividing the total of the mean ratings across all assessed attributes by the number of traits evaluated, resulting in a single index that reflects farmers' overall perception of each clone. The weighted score served as a comprehensive measure for comparing tea clones using a combination of agronomic and quality traits, thereby providing an integrated view of clone performance from the farmers' perspective.

Multivariate probit model

Farmers' choice of tea clones was modeled using a multivariate probit (MVP) model [25,26]. This approach was selected due to its ability to simultaneously estimate multiple interrelated binary outcomes, considering potential dependencies between decisions or outcomes. The MVP model provides a more robust framework for analysis in studies where decisions are not independent, improving the accuracy of parameter estimates and inferences. The MVP approach simultaneously models the influence of explanatory variables on different tea clones while allowing for potential correlation between unobserved disturbances and the relationship between the choice option of different tea clones [27]. This method acknowledges that farmers typically adopt and adapt multiple technologies as complements or substitutes to address overlapping constraints, and that technology-adoption decisions are path-dependent, with recent choices partly influenced by earlier technology selections [28]. The Multivariate Probit model for this study is characterized by a set of m binary dependent variables y_m such that;

$$y_m^* = X_m' \beta_m + \varepsilon_m, y_m = 1 \text{ if } y_m^* > 0 \text{ and } 0 \text{ otherwise, } m = 1, 2$$

$$E[\varepsilon_m | X_1, \dots, X_M] = 0$$

$$Var[\varepsilon_m | X_1, \dots, X_M] = 1$$

$$Cov[\varepsilon_j, \varepsilon_m | X_1, \dots, X_M] = \rho_{jm}$$

$$(\varepsilon_1, \dots, \varepsilon_3) \sim N_M[0, R]$$

where y_m is the m^{th} dependent variable

X_m = Hypothesised determinant of choice of the tea clone

β_m = effect of selected determinant on the choice of the tea clone

ε_m = error term

4. Results and Discussion

4.1. Demographic and Socioeconomic Characteristics of Tea Farmers

The study revealed that tea farmers in Uganda have an average age of 49.7 years, indicating they are in their economically productive years for commercial tea cultivation [29]. This age group is typically associated with increased experience and resource accumulation, which can positively influence farm productivity and decision-making [30].

According to the study, tea farming is predominantly male-dominated, with 81% of the respondents being men (Table 1). This gender disparity reflects the traditional social structure where men are primarily responsible for income generation. However, the underrepresentation of women may limit sectoral inclusivity, despite evidence that women's participation in agriculture significantly improves productivity and household welfare [31].

The majority of respondents (90%) reported tea farming as their primary occupation, with an average of over 20 years of experience. This high level of specialization and long-term engagement suggests a deep understanding of tea cultivation practices and market dynamics. The average household was 7 members, which aligns with the labor-intensive nature of smallholder tea production in Uganda, where family labor is the primary workforce [32]. This reliance on family labor can be both an advantage in terms of cost-saving and a limitation when considering expansion or adoption of labor-intensive technologies [33].

Education and land holdings

The educational profile of tea farmers is relatively favorable, with over 50% having completed primary education and 27% attained secondary education. This literacy level facilitates the implementation of the best agronomic practices in tea cultivation, as well as for making informed decisions about clone selection and farm management [34]. Higher education levels have been associated with increased adoption of agricultural innovations, improved farm productivity and marketing strategies [35].

Land holdings among the surveyed farmers averaged 15 acres, with approximately 6 acres dedicated to tea cultivation. This allocation reflects the importance of tea as a cash crop in the region. The size of land under tea cultivation is a critical factor influencing production volumes and potential income [11]. Perera [36], noted that increases in cultivated land area correlate positively with productivity growth among smallholder tea farmers. However, the relationship between farm size and productivity is complex and can be influenced by factors such as labor availability, input use efficiency, and access to markets [37]. Also, land under tea is important for income generation and productivity [11]; however, productivity is not only dependent on land size but also on input efficiency, including soil fertility management, which remains an important but yet underemphasized aspect in many smallholder farming systems. Despite tea being a heavy nutrient demand crop, especially in the continuous plucking/pruning systems, only limited attention was reported by farmers regarding soil fertility enhancement practices, pointing to a key gap in sustainable intensification strategies.

Access to extension services and farmer preferences

The study found that 43% of farmers had access to extension services, primarily provided by tea companies supporting their out-growers. While this represents a significant portion of farmers, there is room for improvement in extension service coverage. Effective extension services are instrumental in facilitating knowledge dissemination, providing technical advice, and facilitating input access, all of which contribute to the adoption of improved tea production technologies and utilization of the best tea production practices [38].

Farmers preferred high-yielding tea clones, with over 90% of respondents prioritizing this trait. This preference is driven by the direct link between yield and market returns. High-yielding clones are characterized by quick recovery after plucking and pruning, high shoot density, wider canopy, and tender shoots that enhance plucking and tea quality [39]. However, it's important to note that while yield is a crucial factor, other traits such as drought tolerance, pest resistance, and quality attributes also play significant roles in the overall performance and profitability of tea production [40]. The focus on high-yielding varieties should be balanced with considerations of sustainability and resilience, especially in the face of climate change. Recent research has highlighted the importance of developing

and promoting tea clones that can withstand variable environmental conditions while maintaining yield and quality [41]. Additionally, integrating agroecological practices alongside high-yielding varieties can contribute to more sustainable and resilient tea production systems [42].

Table 1. Descriptive statistics for variables explaining choice and preference of tea clones.

Variable (Clone Traits)	Description	Mean	Std. Dev.
High Yielding	If clone is highly yielding (1 = Yes, 0 = No)	0.98	0.16
High shoot density	If clone has high shoot density (1 = Yes, 0 = No)	0.95	0.21
Wider canopy	If clone has a wider canopy (1 = Yes, 0 = No)	0.95	0.23
Quick recovery after plucking/pruning	If clone recovers quickly after plucking/pruning	0.96	0.21
Tender shoots	If the clone has tender shoots	0.93	0.25
Socio-demographic characteristics			
Sex	Gender of the household head (1 = Male, 0 = Female)	0.813	0.390
Age	Age of the household head (years)	49.69	14.14
Tea farming experience	Experience of the household head in tea farming (years)	20.07	17.13
Education level	Level of education of the household head		
No formal education (1 = Yes, 0 = No)		0.09	0.28
Primary (1 = Yes, 0 = No)		0.51	0.50
Secondary (1 = Yes, 0 = No)		0.27	0.45
University (1 = Yes, 0 = No)		0.13	0.34
Household size	Number of family members	7.08	3.37
Main occupation as tea	If the Main Occupation is tea farming (1 = Yes, 0 = No)	0.92	0.28
Asset ownership			
Farm size			
Small scale	Size of the farm (4 acres of less) (1 = Yes, 0 = No)	0.73	0.45
Medium scale	(4 acres but less than 10 acres) (1 = Yes, 0 = No)	0.13	0.33
Large scale	(10 acres and above) (1 = Yes, 0 = No)	0.15	0.36
Total land owned	Total area of land owned(acres)	15.86	46.51
Total cultivated land	Total area of land cultivated(acres)	10.06	21.81
Total tea land size	Total area of land covered by tea(acres)	6.43	16.42
Institutional variables			
Access to extension services	If the tea farmer accesses extension services (1 = Yes, 0 = No)	0.43	0.49
Access to credit	If the tea farmer accesses credit (1 = Yes, 0 = No)	0.22	0.42
Cooperative membership	If the tea farmer belongs to a farmer group (1 = Yes, 0 = No)	0.72	0.45

Source: Survey data (January–December 2022).

4.2. Tea Clones Cultivated by Farmers in Uganda

The analysis of tea clone distribution reveals distinct patterns in farmers' adoption preferences across Uganda's tea-growing regions (Figure 1). The results reveal that farmers in Uganda were found to have cultivated more than one tea clone, a practice that indicates diversification in tea production. This approach reflects farmers' efforts to reduce production risks and ensure consistent yields across seasons. The figure shows that clone 303/577 is the most widely cultivated (58.95%), followed by 6/8 (47.22%), while 108/82 (18.52%), 31/8 (14.2%), and 100/5 (9.57%) are less common. The dominance of clones 303/577 and 6/8 can be attributed to their superior agronomic performance, adaptability, and market preference. The widespread adoption of clone 303/577 can be attributed to its superior agronomic characteristics, particularly its high yield potential and resilience to environmental stresses. According to Sriyadi [43], an efficient plantation management requires planting clones with high yield potential. This clone exhibits remarkable drought tolerance [44] and demonstrates rapid recovery following pruning operations, traits that are particularly valuable for smallholder farmers operating under variable climatic conditions. These attributes align with farmers' economic objectives and risk management strategies. Clone 6/8's significant presence in tea plantations (47%) is primarily due to its superior quality attributes. The Government of Uganda, through the National Agricultural Advisory Services (NAADS), has actively promoted both clones 303/577 and 6/8, recognizing their

complementary advantages in yield and quality, respectively. This institutional support has played a crucial role in their widespread adoption.

The limited adoption of clone 100/5 (10%) reflects its less favorable agronomic characteristics. Its low shoot density, delayed recovery after plucking and susceptibility to drought contribute to reduced yield potential. These limitations make it less attractive to farmers who prioritize productivity and resilience in their clone selection decisions. It is probable that soil fertility plays a key role in the different clone performance; however, it is also notable that soil fertility issues are often not explicitly recognized by farmers as drivers of poor clone productivity, which suggests the need for greater awareness and soil testing services.

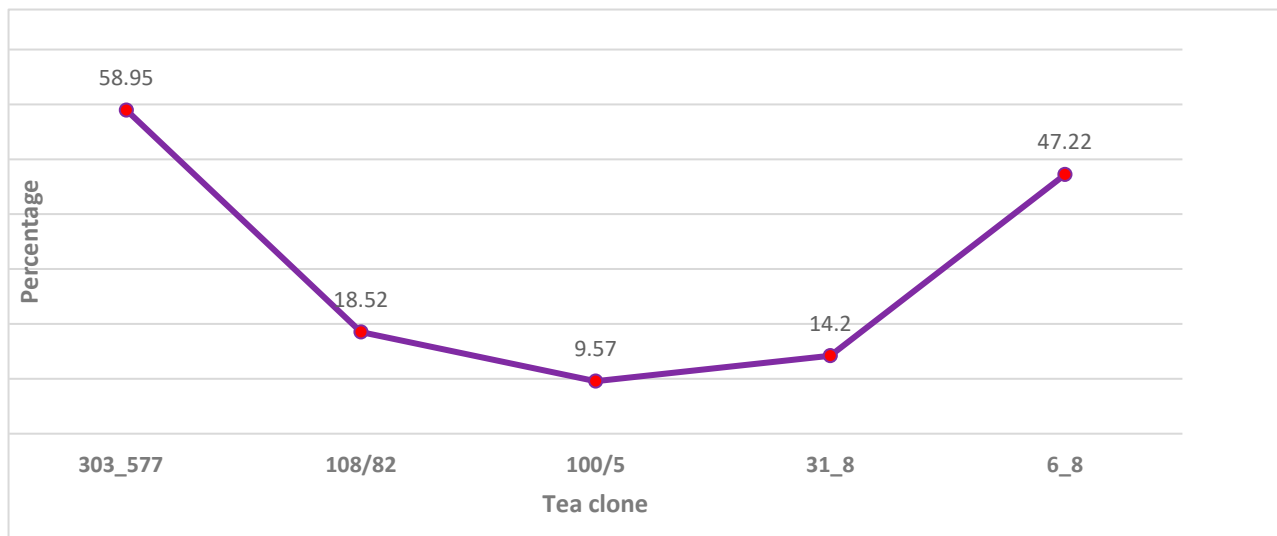


Figure 1. Tea clones cultivated in Uganda (Farmers cultivated more than one tea clone).

4.3. Tea Clone Prevalence in Selected Tea-Growing Regions of Uganda

The survey results revealed widespread cultivation of various tea clones across all regions, with the notable exception of clone 108/82, which was missing in the Central region. Clone 303/577 emerged as the most prevalent, particularly in West Nile (98%), Kigezi (77%), and Central (67%) regions (Table 2). The popularity of clone 303/577 in West Nile and Kigezi sub-regions can be attributed to the recent establishment of new tea fields and the promotion of this clone due to its high yield potential. As tea is sold by weight, farmers are incentivized to cultivate high-yielding varieties to maximize their income from green leaf tea sales. Interestingly, seedling teas continue to be grown by all farmers, with the highest proportions observed in the central and Rwenzori regions (Table 2). This persistence of seedling tea is primarily due to the presence of tea fields planted over 40 years ago; when seedlings and stumps were the predominant planting materials [7]. These aging tea fields often exhibit dead branches, which significantly compromise their yield potential. Despite the superior attributes of clonal tea varieties, the replacement of existing seedling tea fields with clonal tea is a costly endeavor, presenting a significant barrier to modernization [3]. The continued cultivation of seedling teas alongside newer clonal varieties reflects the complex interplay of historical planting practices, economic constraints, and the gradual adoption of improved cultivars in the tea industry. This situation is not unique to Uganda, as similar patterns have been observed in other tea-producing countries, such as Kenya and Sri Lanka [45,46]. The coexistence of older seedling teas and newer clonal varieties presents both challenges and opportunities for the tea sector, necessitating targeted interventions to improve overall productivity and quality [42].

To address the yield disparities between seedling and clonal tea, research efforts have focused on developing cost-effective strategies for gradual field renovation and the introduction of high-yielding, disease-resistant clones. Additionally, agronomic practices such as improved pruning techniques and fertilizer management have shown promise in rejuvenating older tea fields and enhancing their productivity [47,48]. These approaches offer potential solutions to bridge the gap between traditional seedling teas and clonal tea, ultimately contributing to the sustainable development of the tea industry.

Table 2. Distribution of tea clones grown by farmers across regions.

Region	No	303/577	108/82	100/5	31/8	6/8	Seedling Tea	Number of Varieties		
		Percentage (%) Distribution						Mean	Min	Max
Central	43	67.4	0	2.3	2.3	67.4	86	2.26	1	3
Kigezi	136	77.2	19.9	2.2	16.9	38.2	63.2	2.18	1	4
Rwenzori	115	36.5	18.3	26.1	16.5	54.8	81.7	2.34	1	6
West Nile	59	98.3	54.2	1.7	42.4	81.4	1.7	2.79	1	6

Source: Survey data (January–December 2022).

4.4. Farmer Perceptions and Choice/Preference of the Tea Clones

Among commercial tea clones in Uganda, a clear hierarchy of preference has emerged based on various attributes. Farmer preference rankings placed clone 303/577 at the top, followed by 6/8, 108/82, 31/8, and 100/5 (Figure 2). Clone 303/577 is highly favored due to its exceptional characteristics, including high yield potential, wider canopy, quick recovery after plucking and pruning, tender shoots for easy plucking, high shoot density, and moderate cup quality. Clone 6/8 follows closely in preference, appreciated for its high yield, wider canopy, tender shoots, quick recovery after plucking, and high cup quality. These findings align with a biochemical analysis of Ugandan tea clones conducted by [13], which confirmed the desirable quality attributes of clone 6/8.

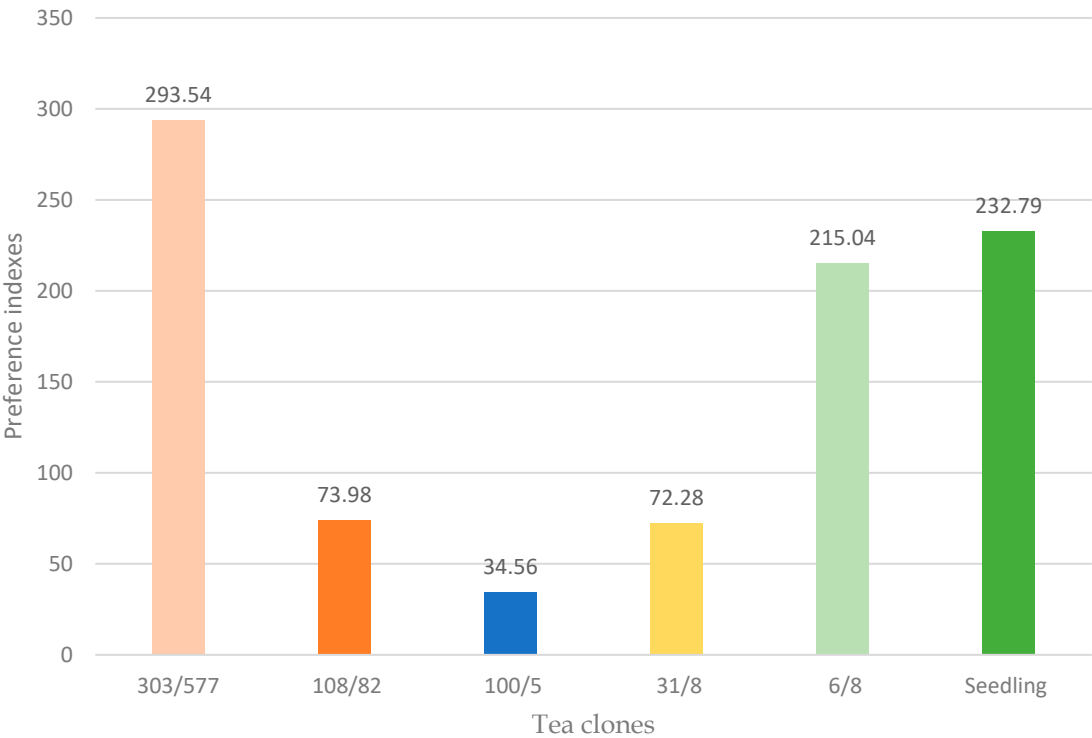


Figure 2. Farmers choice of Tea Clones, Uganda (n = 324).

Despite its high yield potential and wider canopy, clone 100/5 was the least preferred due to its susceptibility to pests and diseases, poor drought tolerance and underperformance in marginal soils and poor soil drainage conditions. Interestingly, seedling teas remained popular due to lower establishment costs and superior drought resilience attributed to possession of a tap root and better root development during growth. This preference for seedling tea persists despite the advantages offered by some clonal varieties. This analysis of farmer preferences provides valuable insights into the complex factors influencing tea clone selection in commercial cultivation, highlighting the balance between yield potential, quality attributes, and environmental resilience that farmers consider when choosing their tea varieties.

Farmers asked to score the desirable preferred attributes of the different tea clones on the scale of Preferences scale 5 = Very good; 4 = Good; 3 = Fair 2 = Poor; 1 = Very poor. Table 3 presents the average scores with regard to different attributes including High-yielding, a wider canopy, quick recovery after plucking and pruning, tender shoots for easy plucking, moderate cup quality.

Table 3. Preferential ranking of tea clone traits by farmers.

Attributes	Means					
	303/577	108/82	100/5	31/8	6/8	Seedling Tea
Tolerant to poor soils/low fertility	3.41 (1.08)	2.78 (1.00)	2.78 (1.26)	2.72 (1.04)	2.95 (1.06)	3.42 (1.21)
Tolerant to poor drainage	3.06 (1.14)	2.90 (1.02)	2.68 (1.14)	2.37 (1.08)	2.70 (1.06)	2.88 (1.19)
High Yielding	4.57 ** (0.67)	3.61 (0.91)	4.03 ** (0.78)	3.71 (0.92)	3.84 (0.95)	3.20 (0.62)
Wider canopy	4.04 ** (0.82)	3.48 (0.84)	3.90 (0.71)	3.55 (0.68)	3.75 (0.89)	3.31 (0.81)
Quick recovery after plucking	4.20 ** (0.75)	3.36 (0.85)	3.65 (0.84)	3.49 (0.92)	3.74 (0.88)	3.07 (0.74)
Quick recovery after pruning	4.05 ** (0.76)	3.38 (0.93)	3.65 (0.84)	3.45 (0.68)	3.73 (0.86)	3.10 (0.78)
Tender shoots	4.14 ** (0.79)	3.46 (1.00)	3.61 (0.88)	3.50 (0.77)	3.76 (0.88)	3.02 (0.72)
High cup quality	4.06 ** (0.83)	3.17 (0.99)	3.50 (0.86)	3.38 (0.78)	3.55 (0.86)	3.25 (0.77)
Tolerant to drought	3.10 (0.96)	2.98 (1.17)	3.10 (1.01)	2.96 (0.71)	3.13 (1.00)	4.20 ** (0.80)
Tolerant to nematodes	3.38 (1.06)	2.37 (0.93)	2.72 (1.14)	2.66 (1.26)	3.04 (1.08)	2.81 (1.23)
High shoot density	4.31 ** (0.70)	3.29 (0.93)	3.61 (0.83)	3.37 (0.83)	3.66 (1.00)	3.10 (0.78)
Tolerant to pests	3.33 (1.02)	2.85 (1.13)	2.93 (1.41)	2.76 (1.23)	3.13 (1.11)	3.15 (1.17)
Does not require a lot of management	3.14 (0.98)	2.83 (1.00)	2.63 (1.01)	2.77 (0.93)	2.93 (1.05)	3.47 (1.17)
Resistant to disease	3.33 (1.06)	2.68 (1.07)	2.83 (1.31)	2.67 (1.15)	3.10 (1.08)	3.11 (1.12)
Tolerant to termites	3.31 (1.20)	2.22 (1.24)	2.42 (1.25)	2.57 (1.34)	2.80 (1.17)	2.89 (1.29)
Weighted average	3.70 (0.90)	3.02 (1.00)	3.20 (1.02)	3.06 (0.95)	3.32 (0.99)	3.20 (0.96)

Standard deviation in parentheses ** high preference. Note: Farmer perceptions were captured using a five-point Likert scale: 5 = Very good; 4 = Good; 3 = Fair 2 = Poor; 1 = Very poor. The results suggest that among the commercial clones, farmers have a strong preference for clone 303/577. This is based on the highly scored attributes including; High-yielding, a wider canopy, quick recovery after plucking and pruning, tender shoots for easy plucking, moderate cup quality [13] and high shoot density. Results reveal that Farmers have a reasonable preference for clone 6/8, due to high yielding, wider canopy, tender shoots, quick recovery after plucking, and Moderate quality/cup quality. Despite the high yield and wider canopy attributes associated with clone 100/5 as indicated by farmers, overall, the results indicate that this clone is the least preferred. Farmers suggest that 100/5 is susceptible to pests and diseases, drought and does not do well in poor soils and drainage. The study revealed that farmers still prefer seedling teas due to tolerance to drought, an attribute associated with good root development during establishment.

4.5. Drivers of Clone Choice Among the Commercialized Tea Clones

A multivariate probit model was estimated jointly for six dependent variables: 303/577, 108/82, 100/5, 31/8, 6/8 and seedling tea. The results of the analysis are presented in (Tables 4 and 5). Several factors were found to have a significant relationship with the choice of tea clones. As shown in Table 4, the model's log-likelihood ratio (LR) is -3236.1075 , with a Wald $\chi^2(15) = 133.54$ and a Prob > $\chi^2 = 0.0000$, indicating statistical significance at ($p < 0.05$). This suggests that the model is a good fit. It is important to note that these findings are further discussed together with the marginal effects.

Table 4. Multivariate probit simulation results for adoption of the commercialized tea clones.

Variables	Clones					
	303/577	108/82	100/5	31/8	6/8	Seedling Tea
Clone traits						
High Yielding	−0.137 (1.232)	0.327 (1.612)	−14.55 (0)	−0.222 (3.605)	2.010 (1.889)	−0.929 *** (1.199)
High shoot density	0.879 (0.590)	0.180 (0.767)	−1.170 * (0.619)	−0.974 (0.654)	1.563 ** (0.709)	−0.614 (0.634)
Wider canopy	0.206 (0.597)	5.938 (0)	6.088 (0)	1.726 (2.052)	0.207 (0.660)	0.316 (0.664)
Quick recovery after plucking/pruning	−0.299 (0.849)	−6.558 *** (1.013)	4.185 (0)	0.764 (2.269)	−2.116 * (1.177)	6.173 (0)
Tender shoots	−0.081 (0.562)	0.407 (0.663)	5.049 *** (1.01)	0.441 (0.670)	0.510 (0.473)	0.514 (0.564)
Socio-demographic characteristics						
Sex	−0.537 ** (0.219)	−0.535 ** (0.217)	−0.395 (0.261)	−0.079 (0.223)	−0.193 (0.195)	0.613 *** (0.206)
Age (years)	−0.0044 (0.007)	0.008 (0.008)	0.009 (0.009)	−0.005 (0.008)	0.003 (0.007)	−0.008 (0.007)
Tea farming experience (years)	−0.033 *** (0.006)	−0.030 *** (0.008)	−0.001 (0.007)	−0.015 ** (0.007)	−0.007 (0.005)	0.039 *** (0.007)
Education level of household head						
Primary	0.134 (0.276)	0.211 (0.343)	5.260 *** (0.337)	−0.00623 (0.346)	0.0504 (0.265)	−0.581 * (0.345)
Secondary	−0.0137 (0.303)	0.532 (0.361)	5.427 *** (0.339)	0.348 (0.361)	0.0291 (0.289)	−0.656 * (0.366)
University	0.357 (0.350)	0.879 ** (0.433)	5.581 (0)	0.330 (0.415)	0.578 * (0.344)	−1.172 *** (0.407)
Household size	−0.002 (0.028)	0.069 ** (0.034)	0.031 (0.037)	−0.006 (0.0314)	−0.006 (0.025)	0.002 (0.029)
Farm size (acres)						
Medium scale	0.269 (0.250)	−0.603 * (0.342)	0.477 (0.301)	−0.045 (0.31)	−0.0355 (0.231)	0.2 (0.262)
Large scale	−0.338 (0.354)	−0.0536 (0.462)	0.533 (0.445)	0.321 (0.493)	0.232 (0.341)	0.141 (0.414)
Total land owned	0.009 (0.016)	−0.096 *** (0.035)	−0.032 (0.025)	−0.002 (0.007)	0.009 (0.015)	0.007 (0.009)
Total cultivated land	−0.002 (0.017)	0.086 ** (0.037)	0.022 (0.029)	−0.004 (0.014)	−0.00037 (0.016)	0.0125 (0.0124)
Total tea land size	0.006 (0.015)	0.029 (0.025)	0.009 (0.0242)	−0.002 (0.027)	−0.011 (0.015)	−0.044 * (0.025)
Institutional variables						
Access to extension services	−0.125 (0.166)	0.107 (0.186)	0.151 (0.224)	0.209 (0.189)	0.315 ** (0.155)	0.0242 (0.172)
Cooperative membership	0.155 (0.180)	−0.0304 (0.211)	−0.511 ** (0.233)	−0.101 (0.210)	−0.525 *** (0.177)	−0.1 (0.189)
Constant	1.012 (0.852)	−1.230 (0.997)	−6.33 *** (1.013)	−2.187 (2.112)	−1.825 (1.386)	0.745 (0.932)
Observations	353	353	353	353	353	353

log-likelihood ratio (LR) is −3236.1075, with a Wald chi2 (15) = 133.54 and a Prob > chi2 = 0.0000
 Notes: ***, **, * = significant at 1%, 5%, and 10% probability levels, respectively.

Table 5. Average marginal effects for the determinants of adoption of the commercialized tea clones.

Variable	Clones					
	303/577	108/82	100/5	31/8	6/8	Seedling Tea
Traits						
High Yielding	−0.042 (0.01)	0.077 (0.043)	−0.168 (0.458)	−0.049 (0.022)	0.717 (0.189)	−2.019 *** (0.66)
High shoot density	0.272 (0.062)	1.393 (0.786)	−0.174 * (0.117)	−0.216 (0.098)	0.558 ** (0.147)	−0.179 (0.059)
Wider canopy	0.064 (0.014)	1.393 (0.786)	0.907 (0.61)	0.383 (0.174)	0.074 (0.019)	0.092 (0.03)
Quick recovery after plucking/pruning	−0.093 (0.021)	−1.538 *** (0.868)	0.624 (0.419)	0.170 (0.077)	−0.755 (0.199)	1.799 (0.588)
Tender shoots	−0.025 (0.006)	0.095 (0.054)	0.752 *** (0.506)	0.098 (0.045)	0.182 (0.048)	0.150 (0.049)
Socio-demographic characteristics						
Sex	−0.17 ** (0.04)	−0.125 ** (0.07)	−0.06 (0.04)	−0.02 (0.01)	−0.07 (0.018)	0.18 *** (0.06)
Age (years)	−0.001 (0)	0.002 (0.001)	0.001 (0.001)	−0.001 (0.001)	0.001 (0)	−0.002 (0.001)
Tea farming experience (years)	−0.010 *** (0.002)	−0.007 *** (0.004)	0 (0)	−0.003 ** (0.002)	−0.002 (0.001)	0.011 *** (0.004)
Education level of household head						
Primary	0.042 (0.009)	0.049 (0.028)	0.784 *** (0.527)	−0.001 (0.001)	0.018 (0.005)	−0.169 * (0.055)
Secondary	−0.004 (0.001)	0.125 (0.07)	0.809 *** (0.544)	0.077 (0.035)	0.010 (0.003)	−0.191 (0.063)
University	0.111 (0.025)	0.206 ** (0.116)	0.832 (0.559)	0.073 (0.033)	0.206 * (0.054)	−0.342 (0.112)
Household size	−0.001 (0)	0.016 ** (0.009)	0.005 (0.003)	−0.001 (0.001)	−0.002 (0.001)	0.001 (0)
Farm size (acres)						
Medium scale	0.083 (0.019)	−0.141 * (0.08)	0.071 (0.048)	−0.010 (0.005)	−0.013 (0.003)	0.058 (0.019)
Large scale	−0.105 (0.024)	−0.013 (0.007)	0.079 (0.053)	0.071 (0.032)	0.083 (0.022)	0.041 (0.013)
Total land owned	0.003 (0.001)	−0.023 *** (0.013)	−0.005 (0.003)	0 (0)	0.003 (0.001)	0.002 (0.001)
Total cultivated land	−0.001 (0)	0.020 ** (0.011)	0.003 (0.002)	−0.001 (0)	0 (0)	0.004 (0.001)
Total tea land size	0.002 (0)	0.007 (0.004)	0.001 (0.001)	0 (0)	−0.004 (0.001)	−0.013 * (0.004)
Institutional variables						
Access to extension services	−0.039 (0.009)	0.025 (0.014)	0.022 (0.015)	0.046 (0.021)	0.112 ** (0.03)	0.007 (0.002)
Access to credit	−0.072 (0.016)	0.039 (0.022)	0.035 (0.024)	−0.017 (0.008)	0.010 (0.003)	0.034 (0.011)
Cooperative membership	0.048 (0.011)	−0.007 (0.004)	−0.076 ** (0.051)	−0.022 (0.01)	−0.187 *** (0.049)	−0.029 (0.01)

***, **, * = significant at 1%, 5%, and 10% probability levels, respectively.

4.5.1. Drivers of the Choice of Clone 303/577

The study revealed that farmers are more inclined to choose clone 303/577 primarily because of its high shoot density, a critical agronomic factor influencing tea yield (Table 4). Shoot density, defined as the number of actively growing shoots with at least one leaf per shoot [45], is widely recognized as a major determinant of tea productivity [46]. The marginal effects analysis showed that farmers' perception of high shoot density significantly increased the probability of selecting clone 303/577 by 27%, underscoring the economic rationality behind this preference. Since tea is traded based on weight, higher shoot density directly translates into greater yields, higher sales volumes, and increased household

income, which strongly aligns with findings from similar studies in Kenya, Sri Lanka, and China that highlight yield-related traits as primary drivers of clone adoption [3,13,41]. Among the socioeconomic factors, gender and tea farming experience emerged as statistically significant determinants. The analysis revealed a negative association between male farmers and the likelihood of choosing clone 303/577, indicating that female farmers are relatively more likely to adopt this variety. This trend may reflect men's dominant role in land ownership and allocation decisions, which can limit their willingness to establish new tea fields or replace existing ones, while women who often manage the day-to-day operations of tea farms may prioritize productivity-enhancing clones. The marginal effects analysis indicated that a 5% increase in male respondents corresponds to a 16% decrease in the probability of choosing clone 303/577. Similar gendered adoption patterns have been observed in smallholder systems elsewhere, where women's involvement in operational decisions has led to higher responsiveness to improved technologies [14,31]. This result suggests that yield-related perceptions, particularly shoot density, remain the most decisive factor in clone selection, implying that farmers' experiential knowledge plays a vital role in shaping choice behavior. Therefore, this calls for the need to integrate farmer-led evaluation into breeding and dissemination programs to enhance uptake. The results also reveal that socioeconomic heterogeneity, including gender and experience, significantly influences choice of tea clones. Designing inclusive tea breeding and extension programs that consider these dynamics can enhance equity and uptake, consistent with global calls for gender-responsive agricultural innovation systems [29,31]. The study contributes to the literature on technology adoption and sustainable intensification by highlighting how trait-based preferences and gender roles jointly shape adoption in perennial cash crop systems, a relatively underexplored area compared to annual crops [14,16]. It is also in line with ongoing discussions on climate-resilient and market-driven breeding that emphasize matching varietal traits to farmers' economic motivations and environmental realities [12,13]. By empirically linking farmer perceptions to clone selection decisions, the study advances understanding of the micro-level behavioral mechanisms underpinning agricultural technology adoption, offering lessons not only for Uganda's tea sector but also for other developing-country contexts striving to balance productivity, inclusiveness, and sustainability in crop improvement initiatives.

4.5.2. Drivers of the Choice of Clone 108/82

The multivariate probit analysis revealed that farmers are less inclined to choose clone 108/82, one of Uganda's commercially promoted tea clones, primarily due to its undesirable attribute of slow recovery after plucking or pruning. Quick recovery defined as the rapid emergence of new shoots from axillary buds below the plucking point is fundamental to the economics of tea estates, as it determines the frequency of harvests and overall productivity. The speed of canopy re-establishment following plucking directly influences both the yield and economic efficiency of tea production. Consequently, clones with longer recovery periods are generally classified as low-yielding [47]. The marginal effects analysis indicated that the probability of farmers adopting clone 108/82 decreases by approximately 1.55%, suggesting that this agronomic limitation remains a critical deterrent to its widespread adoption. Similar findings have been reported in Kenya, Sri Lanka, and China, where post-harvest recovery rate and shoot regeneration capacity have been identified as key determinants of clone performance and adoption [3,41,49].

In addition to agronomic attributes, socioeconomic factors significantly influence the choice of clone 108/82. Both gender and tea farming experience were found to have negative and statistically significant effects at the 5% and 1% levels, respectively. This suggests that male farmers and those with greater experience in tea cultivation are less

likely to adopt this clone, likely due to their familiarity with other, more productive or resilient clones such as 303/577 and 6/8. Experienced farmers may also be more aware of the yield trade-offs associated with slow-recovering varieties, leading them to prioritize clones with higher recovery rates and proven profitability [14,50].

Conversely, education level exhibited a positive and significant association with the likelihood of choosing clone 108/82. Educated farmers are better positioned to access, interpret, and act upon technical information about clone characteristics and management practices, increasing their willingness to experiment with varieties promoted through extension services and research institutions. Similarly, household size positively influences the probability of adoption, as larger households often have greater labor capacity to meet the intensive management demands of establishing and maintaining tea plantations. This finding echoes earlier evidence linking labor availability and human capital to technology adoption in perennial cash crops [15,16,31].

The analysis also revealed a relationship between land-related variables and the choice of clone 108/82. Land ownership negatively correlates with the likelihood of selecting this clone, implying that farmers with more land are less inclined to cultivate it possibly because they have access to alternative clones offering superior yield and quality performance. However, the total cultivated land area was found to have a positive and significant relationship with the probability of choosing clone 108/82. This outcome may reflect the clone's desirable attributes, such as being one of the first released commercial clones, its ease of establishment in both field and nursery settings due to high vigor, good cup quality, and its low mortality rate, which makes it a preferred option among nursery operators.

The findings underscore the importance of land suitability and management practices in enhancing the productivity of clone 108/82. Farmers cultivating larger tea areas may leverage its ease of establishment to expand acreage efficiently, despite its slower recovery rate. These insights suggest that clone 108/82 could remain relevant under specific agroecological and economic contexts, provided farmers receive adequate guidance on land selection, soil fertility management, and optimal pruning regimes to offset its limitations.

The study reveals a balance between agronomic performance, economic rationality, and farmers' capacity to manage labor and land resources in the choice decision making process. The findings also highlight the critical role of education and labor availability in shaping choice behavior, emphasizing the need for targeted extension strategies that enhance farmers' technical understanding of clone-specific management requirements. Additionally, land dynamics reveal that farm size and ownership can either facilitate or constrain choice, reinforcing the importance of integrating land-use considerations into tea breeding and dissemination programs.

These findings contribute to the broader discourse on technology adoption in perennial crops, where varietal preferences are increasingly understood through the lens of trait-based adoption behavior and context-specific performance [14,31]. The study strengthens the argument for farmer-centered and evidence-driven breeding strategies, which incorporate end-user preferences, land-use constraints, and socioeconomic heterogeneity into clone development and promotion. By situating Uganda's tea clone dynamics within these global conversations, the study advances the literature on sustainable intensification and inclusive innovation systems, providing actionable insights for breeding programs, policymakers, and extension agencies working to enhance productivity and resilience in smallholder tea production [12,13].

4.5.3. Drivers of the Choice of Clone 100/5

The analysis of clone 100/5 revealed that farmers preferred this variety largely due to its desirable attribute of tender shoots, as reflected by the positive and significant coefficient

at the 10% level. Tender shoots are highly valued in tea production because they are easier to pluck during harvesting, reducing labor effort and maintaining shoot quality [48]. Farmers interviewed in this study noted that clone 100/5 consistently produces tender shoots that remain pliable even during the dry season, enhancing its year-round plucking efficiency. This finding aligns with the results of Aaqil et al. [51], who demonstrated that the selective plucking of tender shoots yields high-quality teas with superior liquor, aroma, and taste, attributes that significantly enhance market value and export competitiveness. The marginal effects analysis further indicates that farmers who perceive tender shoot characteristics in a clone are 75% more likely to choose clone 100/5, highlighting the strong influence of sensory and physical attributes on adoption behavior.

However, the study also revealed a negative and statistically significant coefficient at the 1% level for high shoot density, indicating that farmers are less likely to choose clone 100/5 due to its lower shoot density relative to other commercial clones such as 303/577 or 6/8. This trade-off suggests that while tenderness promotes quality and ease of harvesting, the lower shoot density may constrain total yield. Similar yield–quality trade-offs have been documented in Kenya and Sri Lanka, where farmers often balance plucking convenience and leaf quality against volume output when making clone choice decisions [3,41].

In terms of socioeconomic characteristics, education level emerged as a significant determinant of clone choice. Both primary and secondary education levels showed positive and statistically significant effects at the 5% level. The marginal effects analysis revealed that a 1% increase in primary and secondary education levels among tea farmers corresponds to a 78% and 80% rise in the probability of choosing clone 100/5, respectively. These results reinforce the proposition that educated farmers are better equipped to comprehend and apply information related to clone characteristics, agronomic practices, and market opportunities. Education enhances farmers' ability to interpret extension messages, assess technological benefits, and integrate innovations into existing farm systems, factors consistently associated with technology adoption in smallholder agriculture [14,16,31].

The findings from the analysis of clone 100/5 highlight that perceived quality attributes, particularly shoot tenderness, can significantly shape farmers' clone preferences, often outweighing considerations of yield potential. This reflects a broader behavioral trend in which farmers value process-related efficiency and product quality alongside productivity especially in export-oriented crops like tea, where leaf quality directly affects price premiums. The results also show the importance of quality-driven adoption pathways, emphasizing the need for breeding programs and extension services to balance yield improvement with quality enhancement when developing and promoting new tea clones.

The results confirm the pivotal role of education and human capital in facilitating technology adoption. Enhancing farmers' knowledge through targeted training, field demonstrations, and participatory varietal evaluations could accelerate the diffusion of high-performing clones such as 100/5. These findings also contribute to ongoing discussions on farmer-centered innovation systems and sustainable intensification, showing that adoption decisions are not merely output-driven but also shaped by farmers' appreciation of quality, labor efficiency, and environmental adaptability [13,14,31]. The study advances the understanding that successful dissemination strategies must integrate both agronomic performance and user-perceived benefits, thereby aligning breeding priorities with farmer and market needs [12,51].

4.5.4. Drivers of the Choice of Clone 6/8

The analysis of clone 6/8 revealed a combination of agronomic and socioeconomic factors shaping farmers' choice decisions. The positive and significant coefficient for shoot density indicates that farmers are more likely to choose clone 6/8 because of its high shoot

density, a desirable attribute closely linked to tea yield and plucking frequency. High shoot density ensures a consistent supply of pluckable shoots, contributing to sustained productivity and economic returns. Conversely, the negative and significant coefficient for quick recovery after plucking or pruning suggests that farmers are less likely to choose clone 6/8 due to its longer recovery period, which can temporarily limit production cycles and affect harvest regularity. The marginal effects analysis showed that a 1% increase in perceived shoot density corresponds to a 56% rise in the probability of choosing clone 6/8, reaffirming that yield-related attributes remain the dominant driver of clone choice among smallholder tea farmers. This finding is consistent with evidence by Han et al. [41], who observed that clone 6/8 produces high-quality green tea with desirable liquor, flavor, and leaf characteristics, making it a commercially attractive option for quality-focused producers.

In terms of socioeconomic factors, the analysis demonstrated that university education has a positive and statistically significant effect on choice, suggesting that farmers with higher levels of education are better able to understand, evaluate, and utilize technical information about improved tea clones. Educated farmers are also more likely to interact with research and extension systems, enabling them to make informed decisions on variety selection and farm management. In addition, access to extension services emerged as a significant determinant, showing a positive association at the 5% level. Farmers who regularly engage with extension agents are more likely to choose clone 6/8 than those without such access, underscoring the vital role of information dissemination and technical backstopping in promoting technology uptake.

Extension services play a particularly pivotal role in enhancing awareness, building capacity, and improving management skills necessary for the successful adoption of improved tea clones. The study findings align with Dube and Guveya [52], who reported that smallholder tea farmers with reliable access to extension support achieve significantly higher yields than their counterparts lacking such assistance. Similarly, Yigezu et al. [16] highlights the contribution of extension systems in bridging information gaps and reducing uncertainty in technology adoption, particularly for perennial crops like tea, which require longer-term management and investment decisions.

The results from the analysis of clone 6/8 emphasize that farmers' choice behavior is guided by both agronomic perceptions and institutional support structures. While high shoot density remains a key incentive for clone choice, the slower recovery rate represents a trade-off that may limit the clone's appeal under intensive production systems. This duality illustrates the need for breeding programs to target multi-trait improvement, focusing not only on yield and quality but also on regrowth dynamics and resilience under varying climatic conditions.

The positive influence of education and extension access underscores the importance of strengthening human and institutional capacity within Uganda's tea sector. Building an effective knowledge transfer framework through farmer field schools, demonstration plots, and company-based advisory systems can accelerate the diffusion of improved clones and improve agronomic performance. This aligns with studies [14,31] emphasizing that information access and farmer empowerment are central to achieving sustainable technology adoption and productivity growth.

4.5.5. Drivers of the Choice of Seedling Tea

Seedling tea remains the predominant type in Uganda's traditional tea-growing regions, particularly in the Rwenzori and Central zones, where it has historically formed the backbone of production systems. However, the Multivariate Probit analysis revealed a negative and significant coefficient for yield at the 10% level, indicating that farmers are less likely to choose seedling tea over clonal varieties due to its inferior yield performance.

The marginal effects analysis showed that when farmers perceive seedling tea as having poor yield potential, the probability of choosing it decreases by 2%. Farmers consistently reported that seedling tea is more susceptible to pests and diseases, requires higher nutrient inputs, and performs significantly worse under limited management compared to clonal teas. These findings mirror those from Kamunya et al. [3] and Han et al. [41], who documented similar yield and disease susceptibility disadvantages in seedling tea systems relative to improved clonal cultivars in Kenya and China, respectively.

Among socioeconomic determinants, gender and tea farming experience were both found to be significant. The marginal effects analysis revealed that a 10% increase in male farmers corresponds to an 18% increase in the likelihood of maintaining or choosing seedling teas. Likewise, each additional year of tea farming experience increases the probability of selecting seedling teas by 1%. This trend suggests that experienced male farmers, who are often older and possess longstanding plantations, are reluctant to replace existing seedling fields due to the high replanting costs and the risk of short-term income loss associated with field renovation. Such path dependency has also been reported in other perennial crop systems, where established producers tend to resist transition to improved varieties despite long-term economic gains [14,31].

Conversely, education and total tea land size exhibited negative and statistically significant effects. This implies that more educated farmers and those owning larger tea estates are less likely to continue cultivating or expanding seedling tea plots. Educated farmers are more aware of the productivity and quality advantages of clonal teas, while larger landowners have greater capacity to invest in clonal replanting and intensive management systems. This finding aligns with evidence from Yigezu et al. [16] and Nalugo et al. [13], who emphasize that education enhances farmers' ability to access and interpret information about improved technologies, thereby increasing their likelihood of adopting innovations that improve profitability and resource efficiency.

Furthermore, farmers in this study associated seedling teas with lower shoot density and smaller plucking tables relative to clonal varieties, which directly affect labor productivity and overall yield potential. These perceptions reinforce the declining appeal of seedling tea, especially in regions where clonal varieties are increasingly available and supported through company-led outgrower schemes.

The results underscore a clear shift in Uganda's tea sector from traditional seedling-based systems to clonal tea cultivation, driven by yield differentials, pest and disease resistance, and market-driven quality preferences [3,13,41]. However, the persistence of seedling tea among experienced and male farmers highlights the role of financial and structural constraints in hindering technology transition [14,31]. Upgrading such plantations demands substantial upfront investment in replanting and maintenance, suggesting that targeted financing mechanisms, accessible credit schemes, and structured replanting incentives could be instrumental in accelerating the adoption and diffusion of improved tea clones [12,16]. As in other tea-producing countries, sustainable transformation of Uganda's tea industry will require not only varietal innovation but also inclusive support systems that address financial, gender, and institutional barriers.

The study extends the literature by illustrating how behavioral, economic, and institutional factors intersect to shape adoption patterns in perennial crops. Encouraging the replacement of seedling tea with high-yielding, resilient, and quality-enhancing clonal varieties can therefore significantly enhance productivity, profitability, and export competitiveness, contributing to Uganda's broader agricultural transformation agenda [12,13].

5. Conclusions

This study shows that smallholder tea farmers in Uganda exhibit strong preference for high-yielding, resilient and quality enhancing clones, particularly 303/577 and 6/8. Farmer choices are primarily driven by agronomic traits such as shoot density, recovery after pruning, shoot tenderness and cup quality, as well as socioeconomic factors including education, gender, farm size and access to extension services. The findings highlight the critical role of farmer perceptions and experimental knowledge in shaping clone adoption, underscoring the need for participatory and farmer centered approaches in tea breeding and dissemination.

Despite the clear advantage of clonal varieties, seedling tea remains prevalent, especially in older plantations, due to lower establishment costs and superior drought resilience. This persistence points to the financial and structural barriers that limit the full transition to improved clones. Gradual field renovation strategies, supported by accessible credit schemes and targeted replanting incentives, are therefore essential to enable farmers to adopt high-performing clonal varieties without compromising short-term incomes.

The study further emphasizes the importance of strengthening extension services and farmer education. Expanding technical support on clone-specific management, pruning, pest control and soil fertility management can enhance adoption and productivity. Additionally, incorporating gender-responsive approaches and addressing labor and land-use constraints can ensure that interventions are equitable and effective across diverse farmer groups. Integrating sustainable soil fertility practices and agroecological measures alongside high-performing clones can also improve resilience and long-term productivity.

In a nutshell, aligning tea breeding, dissemination and extension strategies with farmers preferences, regional agroecological conditions and socioeconomic realities offers a pathway towards sustainable intensification, increased profitability and market competitiveness in Uganda's smallholder tea sector. Supporting diversified clone cultivation, multi-trait improvement and inclusive adoption strategies will be key to enhancing productivity and ensuring the sustainable development of the tea industry.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/horticulturae11111401/s1>, Survey tool: title; Assessing tea production constraints, varieties grown and end user cultivar preferences in production systems of Uganda.

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Data Availability Statement: The data that support the finding of this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

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