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Farmers' preferred traits, production constraints, and adoption factors of improved maize varieties under South-Kivu rainfed agro-ecologies, eastern D.R. Congo: implications for maize breeding[1]

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ABSTRACT

The adoption rate of improved maize varieties (IMVs) is low among small-scale farmers in South-Kivu province, eastern Democratic Republic of Congo (DRC), despite extensive dissemination efforts by local and international research institutions and non-governmental organizations (NGOs). The level of understanding of farmers' preferences and needs for released IMVs, as well as socioeconomic factors influencing their adoption in South-Kivu, is still limited. This study aimed at assessing farmers' preference criteria for maize varieties and identifying factors driving the adoption of IMVs as well as major production constraints in South-Kivu, to guide varietal selection and breeding initiatives. Results showed that the most farmer-preferred attributes were high yield potential, early maturity, taste, and pest/disease resistance, with significant disparities across market segments. Socioeconomic factors such as the farmer's age, experience, membership of farmer organization, contacts with extension services, land ownership, seed availability, access to credits and labour availability bear significant influence on the adoption decision of IMVs. While experience and membership of farmers' organizations negatively influence the adoption of the combination of local and IMVs. Lack of land, pest and disease, lack of labour, and unavailability of quality seeds were the most important constraints faced by farmers. In addition to controlling negative socioeconomic factors and production constraints, it would be essential to initiate breeding initiatives that consider local farmers' preferences and needs, to boost IMVs uptake by farmers in South-Kivu.

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1. Introduction

Maize (*Zea mays* L) is the main cereal crop in the Democratic Republic of Congo (DRC) and a staple food for most households, it represents ~75% of the country's cereal production (Ndeko et al., 2024). In several regions of DRC, including the South-Kivu province, the maize production is mainly ensured by small-scale farmers on small plots (CAID, 2019). Because of its high productivity and nutritional value, the maize is an important source of food and income for a large proportion of Congolese farmers (Kulimushi et al., 2018; Maass et al., 2012). However, the national production of maize and the maize area drastically decreased by about 74,269 tons and 90,086 ha

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respectively between 2018 and 2020 (CAID, 2019; FAOSTAT, 2022). For instance, the average yield in farmer fields is ~0.8 t ha^{-1} compared to the potential (7 t ha^{-1}) (Kazige et al., 2022). This situation leads to high imports of maize products estimated at 121 thousand tons in 2019 (Mottaleb, 2022). Several factors are contributing to that production decline, including low soil fertility, inadequate farming practices, high pressure from diseases and pests, use of low productive varieties, and climate hazards (CAID, 2019; Kazige et al., 2022). In addition to environmental constraints, low maize yields are also attributed to a low adoption rate of new agricultural technologies, such as improved varieties (Dontsop Nguezet et al., 2016; Mondo et al., 2019). In such context, developing high-yielding maize cultivars with high nutritional qualities, adapted to environmental conditions, and resistant to diseases and pests, could be a better strategy to increase maize yields.

In DRC, there are maize breeding efforts focused at introducing and developing improved varieties to meet the above-mentioned challenges. For instance, more than 15 improved and high-yielding varieties have been developed and disseminated in different agro-ecological zones of the South-Kivu province since 2013 by international and national research institutions to increase maize yields. This is the case of the hybrid cultivars developed by the 'Institut National d'Etude et Recherche Agronomiques (INERA)' and the 'Université de Lubumbashi (UNILU)' in partnership with the International Maize and Wheat Improvement Center (CIMMYT) and biofortified hybrid cultivars containing high levels of iron and zinc, and those with a high concentration of provitamin A developedt by INERA in partnership with HarvestPlus (Seed system Group, 2019). However, to our knowledge, no study has been undertaken to understand how farmers reacted to their introduction, their adoption uptake rates, farmers' preferences, and major constraints related to their use in South-Kivu. Besides, the maize product scarcity persists, the yield is stagnant and the maize deficit has been estimated at ~11 million tons per year, due partly to low uptake of improved maize varieties (IMVs) by farmers and the persistent use of unproductive local varieties amongst farmers (CAID, 2019).

Adoption and use of improved varieties in agriculture play a crucial role in increasing crop yields, boosting food availability and alleviating poverty and food insecurity worldwide (Gyawali et al., 2007). Improved varieties offer the benefit of high yield potential, earliness, and high nutritional qualities compared to landraces. In contrast, these landraces are best adapted to local environments and are less susceptible to diseases and pests (Morris & Bellon, 2004). Recent research suggests that the adoption of improved varieties is a sustainable strategy for improving maize production (Rattunde et al., 2021). Furthermore, in most regions of the DRC, particularly in South-Kivu, the adoption of improved varieties is still low despite significant investment in dissemination. This limits agricultural performance in this region (Mondo et al., 2019). In addition to socioeconomic, demographic, environmental, and institutional factors, many researchers attributed the low adoption rate of improved varieties to the lack of adequacy between farmers' expectations and breeding programs' priorities (Mansaray et al., 2019; Marenya et al., 2021). For instance, Mondo et al. (2019) showed that improved cassava varieties introduced in South-Kivu had all the traditional desirable traits prioritized by breeding programs but were lacking local/regional farmers' preferences. For maize, hence, to improve the impact of breeding programs, developing new maize varieties should consider local preferences of farmers and other end-users (Gyawali et al., 2007; Witcombe et al., 2005). This implies that farmers' preferences and needs must be clearly identified through close collaboration and interaction between researchers and farmers.

Farmers' preferences and priorities for maize variety attributes differ from one farmer to another and from one agro-ecological zone to another (Mansaray et al., 2019; Witcombe et al., 2005). For example, the work of Mafouasson et al. (2020) showed that in Cameroon, farmers' preferences are oriented towards varieties with large grain size, soft grain texture, large ear size, high prolificacy, early maturity, short plants, resistance to lodging, resistance to diseases and reduced post-harvest losses. While in South Africa, the preferred characteristics of maize varieties include high yield and prolificacy, disease resistance, early maturity, white grain colour, and drying and shelling qualities (Sibiya et al., 2013). In contrast, the study by Asrat et al. (2010) that examined farmers' preferences for cereal crop varieties, suggested that yield stability and environmental adaptation are the main preferred varietal attributes in Ethiopia. In Kenya, Marenya et al. (2021) concluded maize breeding programs should focus on drought and striga tolerance and on traits related to grain characteristics that provide better storage ability.

Abera et al. (2020) suggested that adoption of maize varieties is not only related to variety-specific traits, but also to other factors related to production and market constraints such as soil fertility, fertilizer cost, seed cost, and market appreciation.

As above-mentioned, several IMVs have been released or introduced in South-Kivu province, eastern DRC. However, their adoption rate by farmers, farmers' preferences and faced constraints to their use have not yet been investigated. In this study, we assessed (i) farmers' preferences for attributes of introduced IMVs, (ii) socio-economic factors driving adoption, and (iii) farmers' perceptions of constraints to the IMVs use. This study will be a useful guide for breeding programs, seed companies, and farmer-support structures in understanding farmers' needs and environment, which are critical for successful varietal development and dissemination.

2. Literature review

2.1. Agricultural technology adoption

The adoption of agricultural innovations is a complex and crucial process for the development of agriculture and the improvement of agricultural production (Ruzzante et al., 2021). It offers significant potential to enhance the productivity and resilience of farms, but their adoption by farmers often remains limited and is influenced by various internal and external factors related to the farm (Ndeko et al., 2024). Recent studies have identified key factors that influence the adoption of agricultural innovations. Among these factors, farmers' socio-economic characteristics, such as the level of education, access to information, financial resources, farm size, non-agricultural income, and the development of income-generating activities, as well as sectoral factors, play a determining role (Maligalig et al., 2021). For example, farmers with better access to information and financial resources are more likely to adopt new technologies (Adams & Jumpah, 2021). Kumar et al. (2019) found that farmers' experience positively influences the adoption of agricultural technologies. Similarly, Ndeko et al. (2024) showed that the farmer's age, linked to their experience, membership in a farmer association, access to agricultural credit, and contact with extension services, determines the adoption of technological packages in agriculture, particularly plant protection, the use of organic and/or chemical fertilizers, and the use of improved maize varieties. In this context, the study conducted by Makate et al. (2019) showed that the number of agricultural innovations adopted largely depends on the level of education of the farmers. Furthermore, Ruzzante et al. (2021) highlighted the role of land ownership in the adoption of agricultural innovations. According to these authors, land ownership could encourage farmers to adopt more agricultural innovations. However, it should be noted that most of the determinants of agricultural technology adoption largely depend on the proposed technology, the cultural context, and the geographical location (Ruzzante et al., 2021).

The impact of adopting agricultural innovations on farmers' well-being and agricultural production has been well documented. For example, the study by Wordofa et al. (2021) reported that the adoption of improved agricultural technologies positively influences agricultural productivity and household income levels. In Benin, the adoption of improved rice varieties has significantly and positively contributed to increasing rice productivity and reducing poverty among farming households (Alene & Coulibaly, 2009). Regarding maize cultivation, the adoption of improved maize varieties (IMVs) has increased household income levels by 30–33% compared to non-adopters (Adams & Jumpah, 2021). Similarly, Merga et al. (2023) showed that IMV adoption considerably improves the well-being of smallholder farmers by reducing food insecurity and increasing their average caloric intake as well as the net value of their crops. Finally, the study by Jaleta et al. (2018) reported that IMV adoption has a robust and positive impact on per capita food consumption and significantly increases the probability of a smallholder being in food surplus.

The identification of factors influencing the adoption and use of new varieties is carried out using various approaches based on theories related to the adoption and diffusion of agricultural technologies. Recent research on the adoption of agricultural technologies highlights factors such as the role of economic incentives, agronomic knowledge, social networks, and farmers' perceptions of risk. Theories such as Rogers' diffusion of innovation theory, the sustainable livelihoods framework (Bass, 1969), and models of rational behaviour and innovation adoption (Ajzen, 1991) are often used to explain how and why farmers adopt new varieties or technologies. These theories allow for a more in-depth analysis of the underlying mechanisms of adoption and an exploration of the contextual factors that influence farmers' decisions.

2.2. Preference and perceptions of improved varieties

Studying farmers' varietal preferences is very important for improving the utilization of new varieties and guiding plant-breeding programs. It has been reported that farmers' preferences and perceptions of improved varieties are key factors influencing their adoption and long-term use. These preferences are often shaped by a specific set of criteria, such as agronomic characteristics, economic performance, and sociocultural aspects of the varieties. Additionally, Asrat et al. (2010) found that among the various varietal attributes, environmental adaptability and yield stability are important factors in farmers' crop variety choices. Besides these criteria, Semahegn et al. (2021) and Marenya et al. (2021) identified resistance to biotic and abiotic stresses as the primary attributes driving varietal choice. Similarly, Regena et al. reported early maturity, red seed colour, and high market prices as the most important attributes for groundnut varieties. In the South Kivu province, Mondo et al. (2019) identified several key varietal attributes for cassava, including yield potential, taste, high disease resistance, and early maturity. However, for maize, there is still a lack of information on varietal preference criteria as well as the adoption rate of new varieties.

It has been demonstrated that other farm characteristics, such as household resource endowments (particularly land holdings and livestock ownership), farming experience, and contact with extension services, can influence farmers' preferences for the attributes of improved varieties. This may lead to heterogeneity among farmers regarding varietal preferences (Asrat et al., 2010). Analyzing this heterogeneity among South-Kivu farmers would help identify priority selection criteria for each group and provide guidance for breeding programs (Maligalig et al., 2021).

3. Materials and methods

3.1. Study areas

The study was conducted in South-Kivu province, eastern DRC, from September to December 2020. Three territories of South-Kivu (Kabare, Walungu, and Uvira) were selected and surveyed (Figure 1). These areas are located in two different agro-ecological zones where maize is extensively cultivated by smallholder farmers (CAID, 2019; Mushagalusa et al., 2020). These three zones cover an area of 6906 km^2, which represent 10% of the total area of the province. These territories were chosen due to the importance of maize cultivation, as they represent the main maize production areas in South Kivu. Kabare territory is located between 28°45′ and 28°55′ E (longitude), 2°30′ and 2°50′ S (latitude) and between 1460 and 3000 m above sea level. It has an average annual rainfall of 1601 ± 154 mm and average monthly temperatures of 19.67 ± 2.3°C (Chuma et al., 2022). Walungu territory is located between 28.44 and 28.758° E (longitude), 2.692 and 2.625° S (latitude) and between 1000 (at Kamanyola) and 3000 m above sea level. It is characterized by a mean annual rainfall of 1600 mm and average maximum and minimum monthly temperatures of 25°C and 18°C, respectively (CAID, 2019; Pypers et al., 2011). Uvira territory is located between 29 and 29°30′ E (longitude), 3°20′ and 4°20′ S (latitude) and between 800 and 900 m above sea level. It has a mean annual rainfall of 1500 mm and average maximum and minimum monthly temperatures of 30.5–32.5°C and 14.5–17°C, respectively. Uvira has a semi-arid climate according to the Köppen Wladimir climate classification.

The Kahuzi Biega National Park borders Kabare and Walungu territories, while the Itombwe Forest Reserve overhangs the Uvira and Walungu territories. On the other hand, the Kabare and Uvira territories are bordered by Lake Kivu and Lake Tanganyika, respectively (Chuma et al., 2022; Mugumaarhahama et al., 2021). The existence of lakes and forests determine a bimodal rainfall with an equatorial climate characterized by two seasons. First is a long rainy season, which runs from September to June followed by a short dry season, from July to August. The rainy seasons determine two subsequent cropping seasons. The first one starts from mid-September to mid-January, and the second cropping season starts from mid-February to mid-June (Chuma et al., 2022; Pypers et al., 2011). In this zone, maize is the most cultivated cereal crop with an estimated cultivated area of ~151,627.27 ha during the 2018/2019 cropping season (CAID, 2019). These areas are densely populated and agriculture and livestock farming are the main sources of income for the majority of their populations.

3.2. Sampling and data collection procedures

A multi-stage random sampling method was used to select farmers in the study area, as explained by Semahegn et al. (2021). For the first stage, three territories

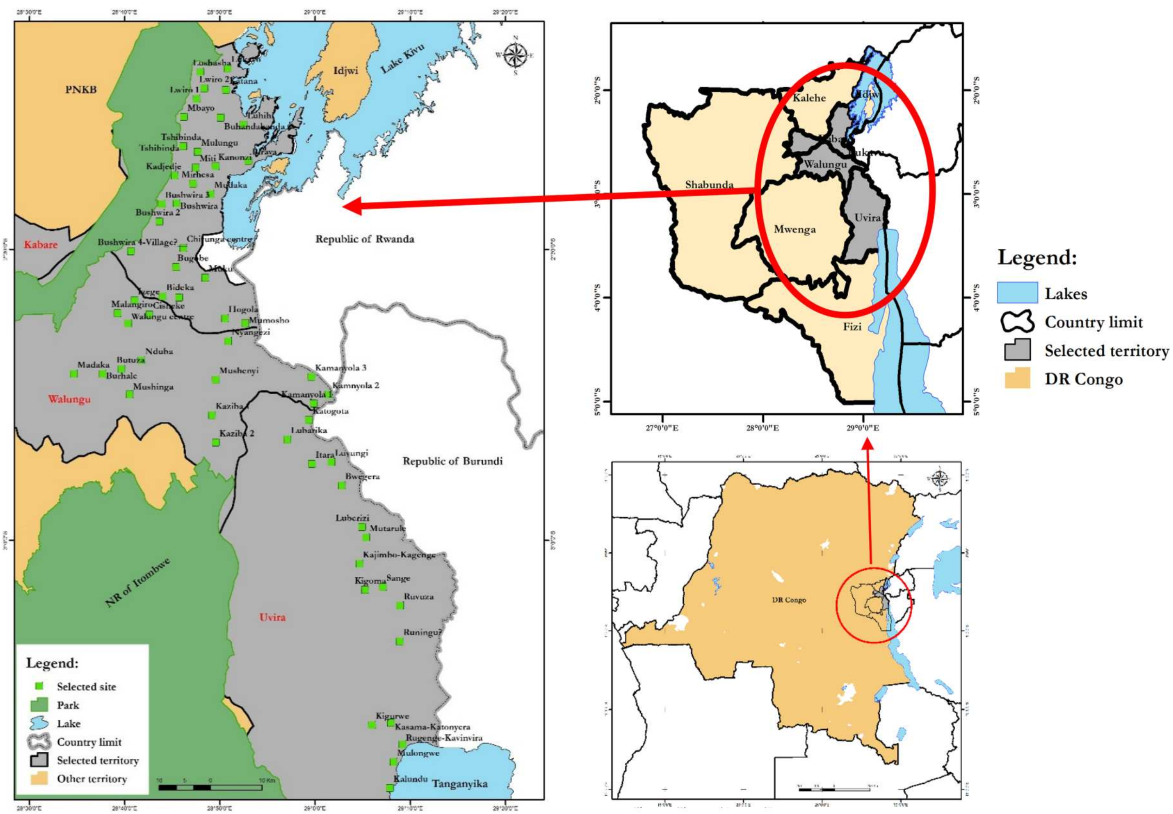

Figure 1. Map of the South-Kivu province showing selected territories (Kabare, Walungu, and Uvira) and localities covered by the study.

in the South-Kivu province were selected as representatives of the major maize production areas in South-Kivu. The second step was selecting villages in each territory or agro-ecological zone (AEZ). This selection was made to avoid a wide distribution of villages across the territory and to ensure greater representativeness of the territory. The choice of these territories and villages was dictated by the economic, social, and nutritional importance played by the maize crop in those areas. These areas also represented the operating sites of several NGOs and local, national, and international research centres such as the International Institute of Tropical Agriculture (IITA), Harvest-Plus, INERA-Mulungu, that are involved in disseminating improved varieties of different crops, including maize. For the third sampling step, the method was used to randomly select maize farming households within selected villages (Figure 1). In summary, four villages were selected per territory and 25 households were randomly selected from each village, resulting in a total sample size of 300 households.

Data were collected using a household survey method during which heads of households were interviewed using a semi-structured questionnaire. Individual interviews were coupled with focus group discussions (FGDs) with local resource-persons, including traditional authorities, village/territory agronomists, and leaders of farmer-based organizations (FBO). This survey was preceded by consultations with key individuals in each village before starting the actual data collection. This allowed us to accurately gather information on the attributes of maize varieties and to create the choice sets for the Best-worst scaling (BWS) method. Ethical approval to conduct research involving human participants was granted by the CNES Ethics Committee. Before conducting the interview, the formal process of seeking written consent from each farmer was undertaken and the purpose of the interview was explained. The survey and FGDs were conducted during the 2020/2021 cropping season and discussions with farmers focused on their experience of the two previous cropping seasons, i.e.

the 2019/2020 season B (February 2020 to June 2020) and the 2020/2021 season A (September 2020 to January 2021). The survey questionnaire was designed with three main sections. The first section focused on (1) demographic and socio-economic characteristics of the farmers' households (i.e. age, gender, household size, experience in maize cultivation), (2) farm characteristics (farm size, total farm area, field size, and maize field size, cropping system, type of varieties grown, access to credit, access to land, labour force), and (3) different constraints to maize production in the study area. The second section was devoted to the analysis of farmers' preferences for introduced IMVs' attributes in the environment. These criteria allowed us to investigate the heterogeneity of preferences among farmers and to properly classify maize farmers according to their preferences. A hierarchical ranking of these criteria using the Best-Worst Scaling (BWS) approach allowed the identification of the most relevant criteria that could, in the future, guide maize improvement programs in South-Kivu, with the aim of creating varieties meeting the needs and expectations of farmers. The third section examines the various constraints related to the use of VMIs and maize production in the study area.

3.3. Methods for data analysis

Statistical analysis of both quantitative and qualitative data was performed in R version 3.5.1 (R Core Team, 2018) using different R packages. XLStat version 2020 was used for descriptive statistics.

3.3.1. Descriptive statistics

Descriptive statistics were applied on the farmers' demographic and socio-economic characteristics by summarizing answers into means (±standard deviations) for quantitative variables and into frequencies for qualitative variables. T-student and Chi-square tests were used to assess differences between adopters and non-adopters of maize varieties based on the means (quantitative data) and frequencies (qualitative data).

3.3.2. Best-worst scaling (BWS) method and ranking of variety attributes

A well-structured analysis of farmers' preferences for variety attributes is always of great interest in plant breeding programs to determine the attributes that influence the variety choice (Asrat et al., 2010). In this study, the BWS method was used to investigate farmers' preferences for attributes of maize varieties grown in South-Kivu. This BWS considers data collection technique and/or how respondents rank the most important items on a list. It is, therefore, a stated preference approach to understanding choice processes (Flynn et al., 2007). For this study, we considered 13 different varietal attributes, selected based on the preliminary survey results and existing literature (Mafouasson et al., 2020; Marenya et al., 2021; Sibiya et al., 2013). The attributes selected for this study include those for both improved and local varieties and encompass various options that farmers might consider within the maize cultivation system, based on local knowledge. To conduct a complete analysis of farmers' preferences, we considered both adopters and non-adopters of improved varieties. Attributes considered in the BWS analysis and their descriptions are presented in Table 1, while the model matrix for the created choice sets is presented in Supplementary Table 1. Its shows how the choice sets were actually presented to the farmers.

Table 1. Description of maize attributes used in the farmer preferences analysis and created choice sets.

Attributes	Description of attributes
Yield potential	Quantifies the best possible output of IMVs grown in local environments
Taste (palatability)	Describes the acceptable or agreeable taste of cooked maize varieties and quality of food sub-products
Seed price	Describes the best possible price to receive or give for IMVs seeds
Early maturity	The time it takes from planting to when the maize can be harvested for cooking or roasting
Drought tolerance	Describes the ability of IMVs to stay green and fertile despite a mid-season dry spell
Low input use	Describes the ability of an IMV to grow with less farm inputs, such as fertilizers, pesticides, etc.
Pest/disease resistance	Describes the ability of IMVs to cope with unexpected pests and diseases
Seed longevity	Quantifies the total time span during which seed is viable and able to easily germinate under suitable conditions
Fertilizer responsiveness	Describes the maize's response to various levels of nitrogen, phosphorous, and potassium fertilizers
Environment adaptation	Describes the ability or the extent to which IMVs can adapt to the different maize ecologies
Seed accessibility	Refers to the availability of the seed of IMVs in the farmer vicinity
High flour density	Describes the ability of an IMV to accumulate high dry matter content and provide a higher flour yield after processing
Resistance to storage pests	Describes the ability of a maize variety to maintain seed quality under storage even in the presence of storage pests

The BWS approach was based on a balanced incomplete block design to develop a model containing 13 choice sets with four attributes in each set. Farmers were then asked to simultaneously choose, from the 13 sets (corresponding to the 13 attributes), the most important (best) and the least important (worst). All attributes had independent and equal occurrences. We considered the number of occurrences that an attribute was indicated as very important (best; Bi) and the number of occurrences that it was indicated as least important (worst; Wi) to obtain the frequencies for 'best' and 'worst' for all choice sets. To calculate individual frequencies for each attribute (BWi), we subtracted Wi from Bi, according to the following formula: $BWi = Bi - Wi$. We then summed the BWi values of each attribute from the set of 300 farmers to obtain the aggregate score for each attribute as directed by Jin et al. (2020). This score allowed us to prioritize the attributes according to their importance by farmers. The higher and positive the BWi value is, the more important the attribute is considered. Furthermore, it is noteworthy that a negative score for an attribute does not mean that this attribute negatively influences the farmer's (respondent's) choice, but it was less frequently cited as 'best' compared to others.

3.3.3. Analysis of the preference heterogeneity

The Latent Class Model (LCM) was applied to analyze the heterogeneity of farmers' preferences for attributes of improved and local maize varieties. This model has been used in several studies to identify underlying subgroups of farmers classified according to their preferences based on varietal attributes (Jin et al., 2020; Kikulwe et al., 2011; Maligalig et al., 2021). It is conceptually based on Lancaster's theory of consumer choice, which states that 'consumers derive satisfaction not from the goods themselves, but from the attributes they offer' (Lancaster, 1976). LCM is a statistical method used to identify a set of discrete latent classes, based on participants' responses to a set of observed categorical variables. This method estimates both the probability of choices and group membership. Segmentation is performed simultaneously on the basis of a choice model to identify groups of participants with homogeneous preferences within the group and heterogeneous between groups (Craft et al., 2020). In this study, the individual preference scores (BWi) of 300 farmers were considered in the model for the 13 attributes as described by Jin et al. (2020). The resulting classes were analyzed based on two main parameters of the model; these are the class occurrence (expressed in terms of % of the sample) and the probabilities that the members of a class choose an attribute. Several models, up to ten, were developed and evaluated to determine the optimal number of classes. To select a good model, the Bayesian information criterion (BIC), the Akaike information criterion (AIC) and the log-likelihood (LL) were used. Class size and data quality were also taken into account. The model with the lowest Bayesian Information Criterion (BIC) value was selected (Craft et al., 2020; Jin et al., 2020). An analysis of the criteria for maize variety preferences among farmers was conducted based on the classes generated by the LCA (see Supplementary Table 2).

In this study, two steps of the LCM were applied. It is the estimation of the LCM and assigning subjects to latent classes, as described by Vermunt (2010), assuming the LCM for a set of K categorical responses (items). Subject i response to item k is identified by Yik, and the full response vector by Yi. The discrete latent class variable is denoted by X, a particular latent class by t or s, and the full response vector by Yi, and the total number of classes by T. The latent class model for P(Yi) can be described as follows:

$$\mathrm{P}\ (\mathrm{Yi}) = \sum P\ (X = t) P\ (Yi \backslash X = t) \tag{1}$$

In the LCM, categorical responses are assumed independent of class membership, as presented here (2)

$$\begin{aligned} \mathrm{P}\ (Yi \backslash X\ =\ t) &= \Pi\ \ P\ (Yik \setminus X\ =\ t) \\ &= \Pi\quad \Pi\ \ \theta I(Yik = r) \end{aligned} \tag{2}$$

where I(Yik = r) = 1 if subject i gives response r on item k and 0 otherwise. The parameters to be estimated are the class proportions $\Pi_t = P(X = t)$ and the multinomial parameters $\theta_{ktr} = P(Y_{ik} = r \setminus X = t)$. Maximum likelihood estimation of these parameters involves maximizing the following log-likelihood function:

$$\begin{aligned} \log \mathrm{LSTEP1} &= \sum_{i=1}^{N} \log\ \ P\ (Yi) \\ &= \sum \log\ \ \left[\sum \pi\mathrm{t}\ \ \Pi\quad \Pi\ \theta\ I(Yik = r) \right] \end{aligned} \tag{3}$$

In the second step, one assigns subjects to latent classes based on their observed responses Yi and the parameter estimates from the 1[st] step. The assigned class membership of subject i is denoted by *Wi*. The key quantity for the class assignment is the probability of belonging to class t given the observed responses Y_i, or the posterior class membership probability $P(X = t \setminus Y_i)$, which can be obtained by the Bayes rule, as showed below;

$$P(X = t \setminus Yi) = P(X = t)\, P(Yi \setminus X = t) / P(Yi)$$

After this, the multinomial logistic regression model was used to determine the influence of socio-demographic and economic factors on farmers' preferences.

3.3.4. Multinomial logistic regression model

The multinomial logistic regression model (MNLR) is more commonly used to isolate the residual effects of explanatory variables on an interest variable by considering the other explanatory variables included in the model (Senyolo et al., 2021). We used this model because it is particularly well-suited for modelling choice behavior, where perceived outcomes are modelled based on the characteristics of individuals, in our case, smallholder farmers. In this study, we used the MNLRM to determine the effects of explanatory variables on the adoption of IMVs in South-Kivu. We have considered that a farmer may decide to use either a local variety only, or an improved variety only, or a combination of these two types of varieties. In such a context, a multinomial logistic model is very suitable for investigating the effects of explanatory factors on the adoption of the different choices mentioned above. Before running the model, the independent variables hypothesized in the study were evaluated for potential statistical issues in order to validate the model. Particularly, multicollinearity among the continuous explanatory variables was assessed using Variance Inflation Factor (VIF) analysis. Only variables with low collinearity, as indicated by a VIF value of less than 10, were retained. The VIF values were checked using the 'check collinearity' function from the 'performance' package in R. Compared to the binary logistic model; in the multinomial logistic model we have F levels of choice or modalities instead of two levels of choice, as in the binary logistic model. Each modality of the interest variable will be compared to the reference modality. For this model, the choice of reference category does not affect the model. Thus, in this study, the modality 'choice of local variety' was previously designated as the reference category against which we compared farmers' choice to use either improved varieties or both local and improved varieties on the same farm. We employed the multinomial logit because it can easily integrate the socio-economic characteristics of the farmers and evaluate their effects on the interest variable (Danso-Abbeam et al., 2017). The use of the multinomial logistic model is explained by its widespread use as a model to evaluate the adoption of technological innovations and its convenient application.

The explanatory variables of the model were specified on the basis of previous studies that described the variables influencing the adoption of agricultural innovations in general, including improved crop varieties. According to Danso-Abbeam et al. (2017) and Mugumaarhahama et al. (2021), adoption of agricultural innovations, particularly improved varieties, is largely explained by farmers' socioeconomic characteristics and institutional factors such as age, gender, level of education, the existence of functional extension services, membership of farmers' organizations, availability of seeds, price of improved variety seeds, household size, and farm size. Table 2 presents a brief description of the explanatory variables selected for this study as well as the expected effects for each of them.

Information related to maize production constraints was analyzed using the Rank Based Quotient (RBQ) method. Ten constraints were predefined and farmers evaluated the severity of each one as high (1), medium (2) or low (3) based on their perceptions, designated by ranking as first, second or third, respectively. RBQ method allowed us to identify the most important constraints for maize production in the South-Kivu province. To achieve this, the following formula was used;

$$RBQ = \sum fi\,(n + 1 - i) \times 100/N \times n$$

where i = concerned ranks, N = number of farmers, n = number of ranks, and fi = frequency of farmers for i^{th} rank.

4. Results

4.1. Socio-economic characteristics of maize farmers in the South-Kivu province

Results on the farmers' characteristics are presented in Table 3. This study revealed that the proportion of female farmers was higher than that of male farmers. Sampled maize producers included 36% of male farmers and 64% of female farmers. In general,

Table 2. Definitions and expected effect of variables used in the Multinomial Logistic Regression (MNLR) Model.

Dependent variables	**Description of variables**	**Expected effect**
Adoption of IMVs/Local and IMVs over only local maize varieties		
Independent variables		
Age	Age of the household (HH) head in years	+
Gender	1 if HH head is male, 0 if otherwise	+/−
Marital status	1 if married, 0 if single	+/−
Education level	Years of HH head formal education	+
Farming experience	Years of HH head experience in maize production	+
Household size	Number of persons in the HH	+/−
Landholding size	Total land owned by the farmer in are	+
Farm size	Total land allocated to maize by HH, in are	+
Land tenure	1 if the farmer owns the cultivated land, 0 if otherwise	+
Cropping system	1 if maize is grown in pure cropping, 0 if otherwise	+/−
Farm-based organization (FBO)	1 if HH head belongs to a FBO, 0 if otherwise	+
Off-farm income (salary)	1 if farmer gains some off-farm income, 0 if otherwise	+
Monthly income	Monthly HHIc, 1 if there is some monthly income, 0 if otherwise	+
Seed availability	1 if the farmer has access to IMV seeds, 0 if otherwise	+
Access to credit	1 if HH has access to credit, 0 if otherwise	+
Field-to-house distance	1 if the farm is far, 0 = if otherwise (based on farmers appreciation)	+/−
Contact with extension service	1 if at least one visit per year from extension services, 0 if otherwise	+
Disease constraint status*	Disease score ranging from 1 to 3	+/−
Soil fertility status**	Soil fertility score ranging from 1 to 3	+/−
Labor availability	1 = if labor is readily available; 0 = if otherwise	+/−

* and ** and other production constraints (Table 7) are based on farmers' appreciation, * Score ranging from 1 to 3: 1 = Weak; 2 = Medium; 3 = High, ** Score ranging from 1 to 3: 1 = low; 2 = Medium; 3 = High. HH = household, IMV = improved maize variety. Expected effects of variables were fixed based on the literature.

the average maize farmers were aged 39.12 years old and had an average of 6.1 household members. Maize farmers had an average of 6 years of formal education and ∼20 years of farming experience, suggesting that many of the farmers have low level of formal education. There were significant differences amongst the adopters and the non-adopters of IMVs in the majority of farmers' characteristics, with the exception of household size, marital status, off-farm income, cropping systems, field-to-house distance, receipt of a monthly income (salary), soil fertility status, and disease severity status (Table 3). Maize farmers' experience in farming activities was 29 years for adopters and 11 years for non-adopters. Significant differences amongst adopters and non-adopters in terms of land holdings and area of land allocated to maize cultivation were observed. Adopters of IMVs owned an average of 36.79 ares of land under cultivation and allocated half of it (∼19.8 ares) for maize cultivation, while non-adopters had smaller landholdings (22.73 ares) than adopters and allocated only 5 ares for maize cultivation. Results revealed also significant differences between adopters and non-adopters for the membership of a farm-based organization (FBO) and farmers' contact with extension services.

Adopters (45%) had more farming experience, a higher affinity to farmer-based organizations than non-adopters (10.62%) and had regular contacts with extension services (82.19%) than non-adopters (14.17%). Contact with extension services and membership in farmer-based organizations allowed adopters to be more exposed and receptive to agricultural innovations. Regardless of the adoption level, most farmers had off-farm incomes (57.53 and 55.12% for adopters and non-adopters, respectively) and a monthly income (10.31 and 14.17%, respectively). However, as for the access to credit, the majority of adopters (87.67%) had access to credit than non-adopters (17.32%). These credits allowed adopters to rent additional land for maize cultivation, as they had poor land ownership (11.02%) than non-adopters (56.16%). Likewise, these credits allowed affording the cost of IMVs seeds and farm labour that are more available to them (89.41 and 90.1%, respectively) than to non-adopters (14.96 and 27.55%, respectively). Results showed that the cropping system and the distance from the house to the field did not vary with the level of IMVs adoption. Intercropping was the most widely practiced cropping system by maize farmers in South-Kivu, on relatively small plots of ∼5–19 acres, with a medium to low soil fertility levels. Crop pests and diseases had a medium to high severity statuses among both adopters and non-

Table 3. Differences between adopters and non-adopters of IMVs based on socio-economic characteristics in South-Kivu.

Farmer characteristics	Adopters (**n** = 111)	Non-adopters (**n** = 189)	Total **n** = 300	*p*-value
Age (years)	42.13 (4.3)	37.02(3.8)	39.12 (3.2)	0.00036***
Education level (years)	7.3(1.1)	3.9(1.6)	5.6(1.4)	0.0012 **
Farming experience (years)	28.84(3.4)	10.88(2.31)	19.86(6.12)	<0.0001 ***
Household size	8.63(1.18)	4.46(2.61)	6.17(3.11)	0.222
Land holding size (are)	36.79(4.3)	22.73(2.5)	34.4(1.3)	0.0425 *
Farm size (are)	19.8(1.2)	15.59(1.8)	17.59(1.3)	0.0218 *
Dummy variables (%)				***Khi² p-value***
Gender				0.035 *
Female	47.97	75.14	64.0	
Male	52.03	24.86	36.0	
Marital status (% married)	87.67	77.16	81	0.0913
Membership of FBO (yes)	43.57	6.28	21	<0.0001 ***
Extension services (yes)	82.19	14.17	39	<0.0001 ***
Off-farm income (yes)	57.53	55.12	56	0.765
Land ownership (yes)	11.02	56.16	27.75	<0.0001 ***
Cropping system (monoculture)	21.91	18.89	19	0.457
Field-to-house distance (far)	57.5	59.05	58.5	0.88
Seed availability (yes)	89.4	14.96	42.5	<0.0001 ***
Monthly income (yes)	10.31	14.17	13	0.11
Access to credit (yes)	87.67	17.32	43	<0.0001***
Labor availability (yes)	90.41	27.55	50.5	<0.0001***
Pest constraints status				0.050*
Low	2.34	2.68	5.02	
Medium	16.72	31.10	47.83	
High	22.07	25.08	47.16	
Soil fertility status				0.60
Low	9.7	6.69	16.39	
Medium	20.74	31.44	52.17	
High	10.7	20.74	31.44	
Disease status				0.78
Low	4.01	2.34	6.35	
Medium	21.74	31.44	53.18	
High	15.38	25.08	40.47	

Note: Quantitative variables are presented as mean ± standard deviation. For all maize production constraints and other qualitative variables, *p*-value was obtained after a χ^2 test or Fisher Exact Test, while for quantitative variable, *p*-value was obtained after a t-student test at significance level of 5%. Signification codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

adopters and were among major constraints limiting maize production in South-Kivu.

4.2. Types of maize varieties grown and sources of seeds in South-Kivu

South-Kivu farmers grow both local and improved maize varieties (Figure 2). However, the adoption and utilization rate of maize varieties depends on varietal characteristics and farmers' preferences. We found that 16.9% of farmers grew improved varieties that they did not know by name, while 83.08% were able to name varieties they grew. Farmers used either local varieties alone (59%), either improved varieties alone (21.33%) or both local and improved maize varieties (19.67%). These results showed that the adoption of IMVs was low in the study area (41%), and most farmers (59%) preferred to use local varieties over improved ones. The main source of seeds was the recycling of local or improved seeds. The recycled seeds were acquired either from the farmer-saved seed or from neighbours or friends, referred to as farmer seed exchange (57.01%). Other farmers obtained maize seeds from farmers' organizations (21.35%), NGOs (12.80%) and research centres, mainly INERA (8.83%). We noted that for local varieties, seeds were mainly sourced from farmers' organizations and from the recycling of seeds (farmer-saved or farmer-seed exchange), while for improved varieties, seeds were sourced from the research centres, NGOs, recycling, and farmers' organizations.

4.3. Farmers' preferences for attributes of IMVs in South-Kivu

4.3.1. Farmers' preferences and ranking of preferred maize attributes

The analysis of attributes of the IMVs allowed us to rank them according to their importance in order to

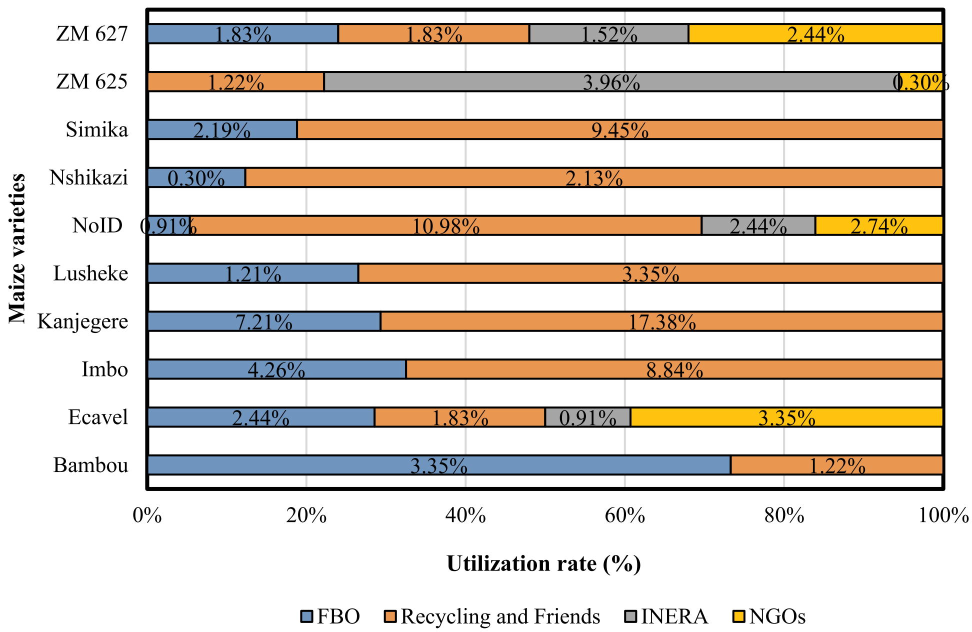

Figure 2. Sources of used seeds and utilization rate of local and IMVs in South-Kivu in 2019/2020 cropping season. **Legend**: For the source of seed: FBO = farmer-based organizations, friends = recycled seed obtained from friends (farmer-seed exchange), NGOs = non-governmental organizations, INERA is a public research centre.

better assess farmers' preferences. The results from best-worst scaling analysis (Table 4) showed that variety's potential yield, early maturity, taste, disease resistance/tolerance and adaptation to environmental conditions were the top five preferred attributes by farmers. Fertilizer response, storage pest resistance, seed availability, drought tolerance, and high flour density were the second most important preferred attributes. In contrast, the need for less farm inputs, seed price, and seed longevity were the least important attributes when selecting preferred IMVs in South-Kivu.

The relative importance was determined for each attribute in order to better categorize them. In this study, the attribute 'potential yield' (100%) was rated as the most important attribute preferred by farmers in South-Kivu, while seed longevity was rated as the least. The attribute 'early maturity' showed a small difference (3.98%) compared to the potential yield and may have equal consideration in the selection of IMVs in South-Kivu. The attributes 'taste' was 0.572 time, 'pest/disease resistance' was 0.557 time, 'environment adaptability' was 0.478 time, 'fertilizers response' was 0.434 time, and the attribute 'resistance to storage pests' was 0.374 time more important for farmers compared to the potential yield. Results showed that according to their importance, the attributes 'seed price', 'drought tolerance', 'less input needed', 'seed longevity' and 'high flour density' were not very important for maize farmers in South-Kivu and, therefore, may not be prioritized when evaluating an IMV. However, a deep analysis of preference heterogeneity could unpack the different attributes for the different categories of farmers. Results from the best-worst scaling model revealed some heterogeneity in maize variety preferences among maize farmers in South-Kivu. This suggests that an analysis of this heterogeneity would be important to understand the farmers' profile based on their preferred attributes and thus objectively suggest relevant market segments to breeding programs.

4.3.2. Farmers' preference heterogeneity for IMVs attributes in South-Kivu

The latent class model was used to identify the different latent classes that exist among maize farmers in South-Kivu, based on the farmers' preferences of maize variety attributes. It allowed us to determine which group of farmers preferred which type of maize variety. Six models were tested to determine the optimal number of

Table 4. Results of best-worst scaling analysis and ranking of farmers' preferred attributes.

Attributes	*Best (Bi)*	*Worst (Wi)*	*B-W*	*BWS ranking*	*Std. BWi*	*Bi/Wi*	*sqrt.BWi*	Relative importance
Potential yield	572	71	501	1	0.42	8.06	2.84	100
Taste	340	129	211	3	0.18	2.64	1.62	57.20
Resistance to storage pests	176	156	20	7	0.02	1.13	1.06	37.42
Seed price	28	193	−165	12	−0.14	0.15	0.38	13.42
Early maturity	520	70	450	2	0.38	7.43	2.73	96.02
Drought tolerant	108	173	−65	9	−0.05	0.62	0.79	27.84
Less inputs needed	48	188	−140	11	−0.12	0.26	0.51	17.80
Pest/disease resistance	272	132	140	4	0.12	2.06	1.44	50.57
Seed longevity	24	194	−170	13	−0.14	0.12	0.35	12.39
High flour density	52	187	−135	10	−0.11	0.28	0.53	18.58
Fertilizer response	220	145	75	6	0.06	1.52	1.23	43.40
Environment adaptation	252	137	115	5	0.10	1.84	1.36	47.78
Seed accessibility	132	167	−35	8	−0.03	0.79	0.89	31.32

classes (Table 5) based on the Bayesian Information Criterion (BIC). After testing, the third model was selected because it had a low BIC value compared to the other models. The results of this model identified three classes of maize farmers based on their preferences for attributes of IMVs. The size of these different classes as well as the frequencies of maize variety attributes per class are presented in Figure 3.

These results indicated a high inter-class heterogeneity among farmers based on their preferences for IMVs attributes. For example, class 2 was more represented (43% farmers) when compared to the other two classes in terms of number of farmers. It was followed by class 3 (37.33% farmers) and then class 1 (19.67% farmers). In the class 1, the choice of IMVs was mainly based on the attributes 'potential yield' (10.3%), 'fertilizer response' (12.33%), 'pest/disease resistance' (17.0%), and 'early maturity' (18.0%). On the other hand, in class 2, three attributes were considered for the choice of maize varieties, including 'early maturity' (9.33%), 'potential yield' (7.3%) and 'taste' (5.67%). Class 3 was characterized by farmers who used several attributes to select maize varieties. These attributes were 'potential yield' (31%), 'taste' (22.33%), 'resistance to storage pests' (14.33%), 'early maturity' (16.0%), 'drought tolerance' (6.33%), 'fertilizer response' (6%), 'environmental adaptation' (16%), and 'easy seed access' (11%).

4.4. Factors affecting the adoption of IMVs in south-kivu

The multinomial logistic (MNL) regression analysis for adoption of IMVs were performed after a perfect fit of the model for the significant covariates. The results of the MNL model used to determine the factors influencing the adoption of IMVs are presented in Table 6. According to the model results, the Wald test was highly significant ($p < 0.001$) with X^2 $(245) = 988.45$. This allowed us to confirm the adequacy of the model to the data collected by rejecting the hypothesis that all the coefficients of the regression were equal to zero. The reference variable was the adoption of local maize varieties alone, from which comparisons were made.

The results of this study showed that the farmer's age was significantly and positively affecting the probability of farmers' decision to grow IMVs alone as well as the combination of improved and local varieties over growing local varieties alone. The odds ratio for the variable age was 1.19 for adopters of improved varieties alone and 1.11 for adopters of both improved and local varieties (Figure 4). The obtained results suggest that the probability of

Table 5. Methods for defining optimal latent class number.

Models	Number of Class	LL	BIC	BIC (L^2)	L^2
Model 1	1	−1498.354	3227.845	3091.585	1119.462
Model 2	2	−1276.417	3256.994	2841.877	675.587
Model 3	3	−1336.469	3140.587	2864.898	795.692
Model 4	4	−1231.387	3403.447	2848.900	585.527
Model 5	5	−1196.288	3569.763	2875.788	515.331
Model 6	6	−1171.588	3756.875	2923.470	465.930

Source: Authors' computations. LL: Log-Likelihood, BIC: Bayesian information criterion, L^2: Square of the likelihood.

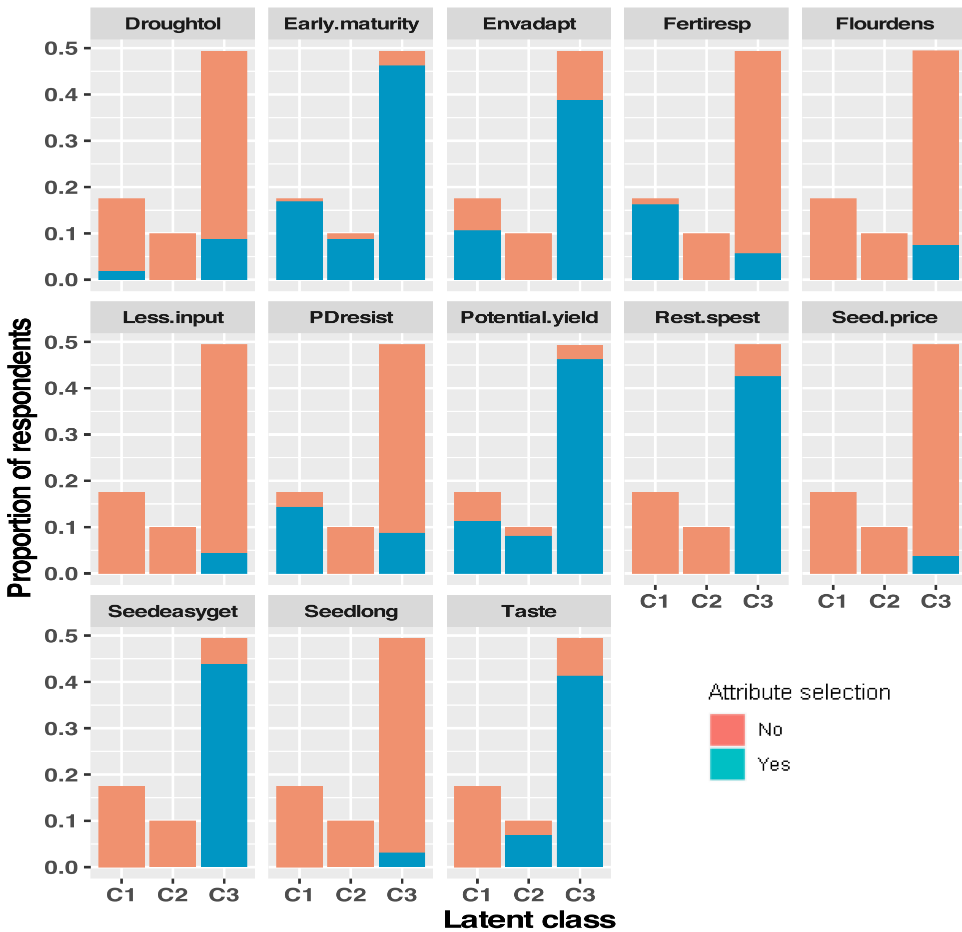

Figure 3. Bar plot of the IMVs attributes defining a profile of latent class. **Legend**: Droughtol = drought tolerance, Early.maturity = early maturity, Envadapt = environment adaptation, Fertiresp = fertilizer response, Flourdens = flour density, Less.inpu = less input, PDresist = pest/disease resistance, Potential.yiel = potential yield, Rst.spest = resistance to storage pests, Seed.price = seed price, Seedeasyget = seed accessibility, and Seedlong = seed longevity. Barr plots show cluster proportion for attribute choice (Coloured bar, yes or no). C1, C2, C3 refer to the class 1, class 2, and class 3.

adopting IMVs alone as well as the combination of local and improved varieties over local varieties alone increased with farmers' age. In other words, older farmers preferred to grow IMVs and the combination of local and improved maize varieties than growing local varieties alone.

Farmers' experience in farming activities significantly and positively affected the probability of IMVs adoption, but significantly and negatively affected the probability of combining improved and local varieties over local varieties. The odd ratio of 1.38 for the variable farmer experience indicates that farmers with more experience in farming and maize production have a higher probability of adopting IMVs compared to local varieties alone than less experienced farmers. However, this considerably reduced the probability of adopting the combination of local and improved maize varieties. These results indicate that there was 1.38 time more probability of adopting IMVs alone among the more experienced farmers than among novices. Similarly, the odd ratio of 0.98 showed that the more experienced farmers were, 0.98 time less they were interested in adopting both improved and local maize varieties than the less experienced farmers.

Membership of FBO positively and significantly affected the probability of adopting IMVs alone compared to local varieties. With an odd ratio of 24.11, membership in farmers' organizations increased the probability of adopting IMVs alone by a factor 24.11. However, its contribution to combining local and improved maize varieties was negative but not significant. Similarly, contact with extension services

Table 6. Multinomial logistic regression of socioeconomic factors influencing adoption of IMVs or both local and IMVs over local varieties in South-Kivu.

	Probability of adopting IMVs over local variety			Probability of adopting both improved and local varieties over only local variety		
Factors	Coefficient	Std. Error	***p*-value**	Coefficient	Std. Error	***p*-value**
Age (years)	0.174	0.078	0.026**	0.109	0.045	0.016**
Farming experience	0.326	0.081	<0.0001***	−0.017	0.042	<0.0001***
Household size	−0.694	0.374	0.063	−0.013	0.214	0.94
Membership of FBO	3.182	3.182	0.039*	−2.295	1.343	0.087
Contacts with extension services	4.90	1.938	<0.0001***	3.842	1.003	<0.0001***
Land ownership	3.494	1.814	0.0024**	2.131	1.1001	0.0527
Field-to-house distance	−2.005	1.241	0.1062	0.8234	0.775	0.288
Seed availability	5.984	2.983	<0.0001***	4.646	1.135	<0.0001***
Access to credit	3.597	1.547	<0.0001***	3.358	1.247	<0.0001***
Labor availability	2.714	2.223	<0.0001***	2.095	1.194	<0.0001***
Number of observations = 300						
LR χ^2 (12) = 143.53						
Prob.< χ^2 = 0.0000						
Pseudo R^2 = 07902						

Note: Significance level at 5% *p*-value threshold. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

positively and significantly affected both the adoption of improved varieties alone and the combination of local and improved maize varieties. The obtained odd ratios of 134.28 and 46.61 imply that with all other variables remaining constant, increasing the contact with extension services would increase the probability of adopting IMVs alone and the combination of local and improved varieties by 134.28 and 46.61 times, respectively.

We also observed a positive and significant relationship between land ownership and the probability of adopting IMVs alone over local varieties. Farmers owning farmland were 32.9 times more likely to adopt improved varieties compared to local varieties. Similarly, easy access to seeds of improved varieties significantly and positively affected their adoption as well as the adoption of combined local and improved maize varieties. Labour availability significantly and positively affected the probability of adopting both improved varieties alone (odd ratio = 15.05, $p <$ 0.0001) and the combination of local and improved maize varieties (odds ratio = 8.11, $p < 0.0001$) compared to local varieties. Findings indicated that having access to credit positively and significantly affected farmers' decision to grow improved varieties alone and the combination of local and improved varieties compared to local varieties alone. In fact, farmers who had access to credit were 36.48 times more likely to adopt improved varieties alone and 28.73 times more likely to adopt the combination of local and improved varieties over local varieties alone when compared to those who had limited access to credit.

4.5. Maize production constraints in south-kivu province

Constraints to maize production in South-Kivu were analyzed based on farmers' perceptions by specifying the relative importance on a scale of 1–3, as described in the Materials and Methods section. Table 7 presents the ranking and the hierarchy of maize production constraints according to their degree of importance. The results showed that, in general, ten constraints were recognized by farmers as obstacles to maize production in South-Kivu. These included crop diseases, unavailability of farm inputs, post-harvest losses, lack of improved variety seeds, lack of labour, lack of farmland, lack of market, low soil fertility, tax hassles, and difficulty of weeding.

The RBQ result indicated that lack of farmland, lack of labour and high disease pressure were the first, second, and third ranked production constraints as recognized by farmers. Other constraints perceived by farmers were, by the order of importance, the unavailability of improved variety seeds, unavailability of farm inputs (especially fertilizers, pesticides, etc.), lack of market demand, difficulty in weeding, low soil fertility, post-harvest losses and tax hassles.

5. Discussion

5.1. Farmers' preferences for IMVs attributes

This research provided an overview of farmers' preferences for attributes of IMVs, factors influencing their adoption, and maize production constraints in

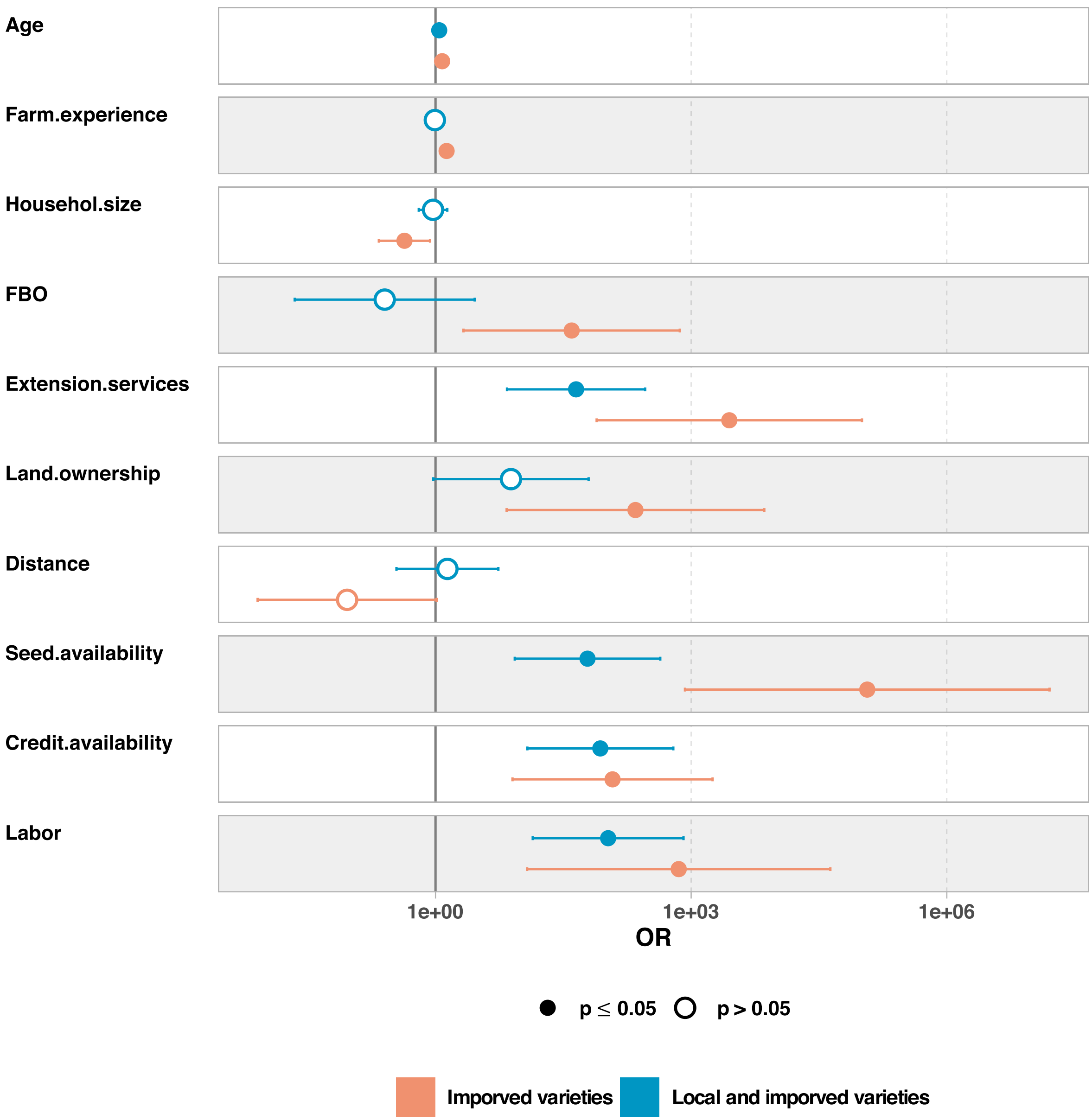

Figure 4. Forest plot summarizing multinomial logistic regression models (odds ratio) combining the contribution of multiple factors to the adoption of IMVs in South-Kivu. **Legend:** The *x*-axis shows odd ratios (OR) and the error bars show 95% confidence intervals, while the *y*-axis presents all factors used in the MNLRM. The red and the blue dots indicate the adjusted OR for the listed variable according to the adoption of both local and IMVs and IMVs, respectively. Coloured lines indicate 95% confidence intervals. OR to the right of the midline (where OR = 1) indicate higher odds of IMVs adoption while OR to the left of the midline indicate lower odds of IMVs adoption.

South-Kivu. The results of the BWS analysis showed that farmers ranked several IMVs attributes. These results are consistent with recent studies on farmers' preferences for IMVs attributes (Dao et al., 2015; Mafouasson et al., 2020; Yin et al., 2020). These studies suggested that yield is not the only criterion for farmers while selecting a variety. Other criteria included early maturity, adaptation to environmental conditions, response to fertilizers, resistance to diseases and pests, availability of improved variety seeds, price of improved variety seeds, and sensorial and nutritional qualities (Dao et al., 2015; Rattunde et al., 2021; Semahegn et al., 2021; Sibiya et al., 2013). The latent class modelling indicated a

Table 7. Farmers' perceived constraints to maize production in South-Kivu.

Production constraints	Number of farmers	Ranking 1	2	3	RBQ	Rank
Low soil fertility	300	31.3	52.0	16.7	23.8	8
Unavailability of quality seeds	300	40.3	53.1	6.6	25.8	4
Unavailability of farm inputs	300	43.3	40.7	16.0	25.2	5
Lack of farmland	300	47.0	47.6	5.3	26.8	1
Lack of labor	300	44.3	49.3	6.3	26.4	2
Lack of market demand	300	25.0	68.0	7.0	24.2	6
Post-harvest losses	300	8.3	76.7	15.0	21.5	9
Tax hassles	300	11.6	45.3	43.0	18.7	10
Difficulty in weeding	300	37.0	42.0	21.0	24.0	7
Disease constraints	300	40.3	53.0	6.6	25.9	3

Note: RBQ indicates Rank Based Quotient, data presented the frequency of farmers for the i^{th} Rank. Ranking scale from 1 to 3: 1 = High, 2 = Medium, 3 = Low.

difference in farmers' preferences and needs in terms of maize variety characteristics, seed technologies, and environmental conditions. Three preference classes, which can also be considered as market segments, were identified. The preference criteria varied from one class to another. These results agreed with other similar studies that revealed differences in farmers' preferences for maize variety attributes (Mafouasson et al., 2020; Yin & Yu, 2022). The study by Morris and Bellon (2004) reported that crop variety preference varies among farmers and that variety attributes affect adoption of improved varieties. These criteria are closely correlated with adoption factors and can be helpful in identifying economic, technical, and institutional challenges in developing participatory approaches that integrate end-users into plant breeding programs at both local and national levels. This outcome could be related to the production objectives of maize, which vary from farmer to farmer. Some farmers are the main consumers of their production, others may opt for maize processing, and others may sell their production. All farmers are subject to the preferences of final consumers (Rattunde et al., 2021).

High preference for the potential yield was listed as the most important attribute when selecting a maize variety. This attribute would be closely related to the performance of varieties currently used by farmers in South-Kivu and suggests that farmers really want to increase their yields by adopting varieties with high yield potential. Farmers use local varieties, which are often degenerated, exchange seeds among themselves, and do not purchase seeds from accredited seed distributors. Consequently, the average maize yield (~ 800–1200 kg/ha) is very low in the study area (CAID, 2019; Mushagalusa et al., 2020; Kazige et al., 2022). Adoption of high-yielding varieties would allow farmers to increase maize production and achieve their goals (Qaim, 2020). In South-Kivu province and the DRC in general, maize is the main cereal crop. Its demand is higher and often exceeds production due to the use of degenerated varieties and other technical constraints (CAID, 2019).

Early maturity, drought tolerance, and environmental adaptation were also ranked as key attributes looked for in IMVs. The preference for early maturity is related to the climatic disturbances that currently occur in the South-Kivu province and that impact on the duration of cropping seasons, the frequency and distribution of rainfall, the cropping calendar (Balasha et al., 2021). In this region, maize cultivation is dependent on the environmental conditions, so that climate disturbances could negatively impact maize yields, especially for smallholder farmers who cannot afford control and adaptation measures. Several research studies indicated the susceptibility of maize to climate change. Predictions by Knox et al. (2012) suggested that maize yields will decrease by 5% in Africa by 2050, mainly due to an increase in temperatures and solar radiation, which interact with precipitation to create more stressful conditions for maize plants, and therefore, lead to lower yields. In China, climate change has resulted in a decrease in maize yield of 1.7% due to increased temperatures (Wu et al., 2021). The preference for early maturity and adaptation was reported to be related to the environment that farmers face and the resilience of varieties to extreme conditions and disruptions that would arise in the environment (Jin et al., 2020). This could explain the low level of adoption of IMVs in South-Kivu, even though they are supposed to perform better than local varieties. Development and dissemination of varieties adapted to prevailing climatic conditions would be important to ensure the resilience of maize to climatic disturbances and guarantee yield stability in South-Kivu.

Disease resistance and storage pests were ranked 4^{th} and 7^{th} most preferred traits, respectively. The preference for these attributes would be related to the occurrence of several diseases that are prevalent on maize in South-Kivu as well as to crop pests such as the fall armyworm (*Spodoptera frugiperda*) and other stock pests. An invasion of the *S. frugiperda* was recently reported in South-Kivu with an incidence of about 57% in maize fields. According to Cokola et al. (2020), the incidence level of *S. frugiperda* in terms of leaf damage and larval density is about 65% in South-Kivu, causing considerable yield losses because all varieties currently grown are susceptible (CAID, 2019). The lack of disease/pest resistant maize varieties is a major constraint in South-Kivu where more than half of the population depends directly or indirectly on maize for their subsistence.

Varietal response to fertilizer was reported as the sixth most important attribute in farmers' varietal choice. This trend is linked to the fact that in South-Kivu, soil fertilization is essentially based on the use of various forms of organic matter, since mineral fertilizers are not widely used in the study area (Heri-Kazi & Bielders, 2020). Only a limited number of farms use mineral fertilizers. The scarcity of organic fertilizers in this region and the high costs of mineral fertilizers limit their use by local smallholder farmers (Mushagalusa et al., 2020; Ndeko et al., 2019a). Farmers prefer to grow varieties with high nutrient-use efficiency to maximize maize productivity at low production costs. It would be very important to focus breeding programs on selecting for nutrient-use efficiency, since currently available improved varieties require more nutrients. It has been reported that the use of high nutrient-use efficient varieties can reduce mineral fertilizer inputs and ensure efficient and sustainable management of natural resources (Ali et al., 2018). In addition to the varietal selection approach, the exploitation of other strategies based on the use of beneficial microorganisms found in the rhizosphere of plants such as arbuscular mycorrhizal fungi (AMF) and plant growth promoting bacteria (PGPB) could also increase the nutrient-use efficiency of crops (Adesemoye et al., 2008 ; Meena et al., 2017 ; Ndeko et al., 2019b, 2019a, 2022).

The preference for high seed availability and reasonable seed price of improved varieties is related to the lack of breeding programs and functional seed delivery systems in DRC in general and in South-Kivu in particular. The market for improved variety seeds is not well coordinated and their price is very high and fluctuates widely (Seed systems Group, 2019). Jandrain (2020) reported that in DRC and South-Kivu in particular, farmers are suffering from seed insecurity because they have lost their seed autonomy and are now struggling for access to high-quality seeds. Furthermore, the Congolese seed policy would be the result of instructions from funding organizations and not the result of the needs of the population. This situation would be the main reason for the low rate of adoption of improved varieties and the persistence of local varieties that are often degenerated in the region. However, the availability and affordability of improved seeds are key factors in influencing the adoption of improved varieties (Mafouasson et al., 2020). On the other hand, the preference for seed longevity would be explained by farmers' seed management practices. Farmers save part of their harvest that will be used as seed for the next season. Farmers may exchange seeds among themselves, leading to a mixture of varieties. For an improved variety, high yields and a longer storage period are the qualities most desired by farmers (Manandhar et al., 2018; Mushagalusa et al., 2020). The study by Jin et al. (2020) showed that this seed management method reduces production costs by increasing seed availability. Actions should, therefore, be taken to improve farmers' practices of seed storage to ensure they can effectively save quality seed from their harvests to increase availability of seed in the absence of a functional seed delivery system. Studies in Ethiopia, Cameroon (Mafouasson et al., 2020), Burkina Faso (Dao et al., 2015), Ghana (Danso-Abbeam et al., 2017) and Uganda (Mastenbroek et al., 2021) have also demonstrated the importance of maize variety attributes such as yield, disease resistance, early maturity, response to fertilizer, improved seed availability and price of improved seed, in farmers' varietal preference and choice.

Preferences for cooking quality and taste were important for farmers in classes 2 and 3. In both classes, these attributes were related to other criteria such as potential yield, early maturity, environmental adaptation, seed longevity, and pest/disease resistance. Other studies have reported the preference for these attributes and have emphasized the relevance of considering yield and crop consumption criteria in breeding programs (Jin et al., 2020; Teeken et al., 2018). In South-Kivu, the preference for cooking qualities and taste would be explained by the fact that subsistence farming is the most predominant production model. Most farmers are consumers of their own products and only a limited quantity participate to market (Ansoms et al., 2012; Cirimwami et al., 2019). Therefore, the introduction and dissemination of biofortified varieties in the province should be accompanied by the investigation of the sensory qualities. Thus, participatory selection is encouraged to ensure farmers' preferences are met, and consequently, increase the probability of IMVs adoption by farmers.

5.2. Factors influencing the adoption of improved maize varieties

Several groups of factors influence the adoption of improved varieties in rural areas, including demographic, socio-economic, and variety-specific factors. These are often then farmer age, level of education, household size, farmer experience, membership of a farmer's organization, access to credit, availability of labour, availability of improved seeds and prices of improved seeds (Danso-Abbeam et al., 2017 ; Jin et al., 2020 ; Mafouasson et al., 2020 ; Mugumaarhahama et al., 2021). In addition to these commonly studied factors, other research has reported that adoption of agricultural innovations could be explained by institutional factors such as the existence of effective extension services and regular contacts of farmers with these services (Sisay et al., 2015).

The results of this study showed a positive relationship between the age and the adoption of IMVs. This result confirmed our expected positive effect of age on the adoption of improved maize varieties in South-Kivu, but strongly disagreed with previous results by Lunduka et al. (2012) and Danso-Abbeam et al. (2017) that showed that older farmers generally prefer to grow local varieties and that age negatively influences the IMVs adoption. In contrast, Islam (2014) showed that age was significantly and positively correlated with the adoption of high-yielding rice varieties. The positive relationship between age and adoption of improved maize varieties in the study area could be attributed to the fact that older farmers have some experience in maize production. This category of farmers prefer either the improved varieties or to combine the two types of varieties in order to avoid the risk of yield loss by using the local varieties alone. In addition, older farmers have access to production resources and information and are inclined to easily adopt the IMVs (Asante et al., 2017).

Farmers' experience in maize production showed a significant influence on the adoption of IMVs. Consistent with this study, Danso-Abbeam et al. (2017) found a significant positive relationship between farmers' experience and IMVs adoption. The positive relationship between farmers' experience and IMVs adoption would be explained by the fact that the more experienced farmers become, the more they would have acquired greater knowledge about profitable farming activities and maize production practices. Therefore, they easily understand the challenges related specifically to the use of local varieties as opposed to improved varieties (Mastenbroek et al., 2021; Rattunde et al., 2021). This category of farmers are more interested in boosting their yields through the use of improved varieties than less experienced farmers (Abebe et al., 2013; Byerlee et al., 2008). It also explains the negative relationship between farmers' experience and the adoption of the combination of local and improved varieties, because farmers tend to discard local varieties for improved ones.

Institutional factors such as membership in the farmers' organization and contact with extension services were significantly and positively correlated with the probability of adopting IMVs. The first reason may be that there are several agricultural development projects in the region collaborating with FBOs to disseminate new technologies. The members of the FBOs receive training and seminars on best agricultural practices and new technologies. Secondly, FBOs also increase farmers' contact with extension services and consequently increase farmers' exposure to agricultural innovations and their uptake of improved varieties (Danso-Abbeam et al., 2017; Mugumaarhahama et al., 2021). Rattunde et al. (2021) reported that membership in farmers' organizations and contacts with extension services are important sources of useful information that can stimulate adoption of IMVs.

We also observed a positive and significant relationship between land ownership and adoption of IMVs. This result is consistent with findings by a study by Ogada et al. (2014) in Kenya that showed that land ownership security is a very important parameter in the adoption of IMVs, which can increase the probability of adopting the varieties by more than 4% compared to households without land ownership security. The relationship between land ownership and adoption could be explained by the land conflicts that prevail in South-Kivu and the limited availability of farmlands (Angélique et al., 2022; Mushagalusa et al., 2020). Because of this situation, sharecropping is the most common mode of land acquisition in the study area. In addition, security of land tenure could allow households to rent part of their land in exchange for some money to purchase improved technologies. Land ownership also stimulate the producer to invest in more demanding or long-term agricultural technologies than if not owned. However, these results disagreed with Mansaray et al. (2019) and Mugumaarhahama et al. (2021) who showed that farmers who cultivated their own land had a higher tendency to remain non-adopters of improved varieties, but those who rented farmland or were engaged in sharecropping had higher adoption rates of improved rice and potato varieties to make the investment profitable. Access to agricultural credit positively and significantly influenced the adoption of IMVs. This result aligned with the study by Danso-Abbeam et al. (2017) who found that farmers with access to agricultural credit were 7.7 times more likely to adopt IMVs either alone or in combination with local varieties compared to those without access to agricultural credit. Access to agricultural credit allows farmers to cover additional production costs and to invest more in research and purchase of improved maize seeds (Lunduka et al., 2012).

In this research, we showed evidence that access and availability of improved seeds influence the adoption of IMVs among farmers in South-Kivu. This result could be linked to low availability of improved seeds, high prices of improved seeds and the absence of a functional seed delivery system (Rattunde et al., 2021; Semahegn et al., 2021). Therefore, the majority of farmers recycle their own seed. This result is in accordance with Ogada et al. (2014) and Lunduka et al. (2012) who showed that seed availability is an important factor in the adoption of improved varieties. Based on Lunduka et al. (2012), the adoption rate was higher among farmers who received the maize seed vouchers, which give a short-term effect. Labour availability positively and significantly affected the adoption of IMVs alone or in combination with local varieties. It is closely related to household size. According to Abebe et al. (2013), large family size means high labour force, which could positively influence the adoption decision of agricultural innovations.

5.3. Farmers' perceptions of the maize production constraints

In South-Kivu province, farmers face several production constraints that affect maize production. Results of this study showed that crop diseases and pests, lack of cultivable lands, lack of labour, lack of seeds of improved varieties, lack of farm inputs, and low soil fertility are the most recognized constraints by farmers. However, among all these constraints, crop diseases, lack of land and lack of labour are the three most important constraints for small-scale maize producers in South-Kivu. Previous studies have mentioned crop diseases and pests as one of the most production-limiting constraints (Mafouasson et al., 2020; Semahegn et al., 2021). Disease and pest pressure on maize, especially the invasion by the *S. frugiperda*, would explain the particular importance that farmers accorded to this constraint in the study area. The lack of land is also mentioned as a major constraint because land is the most important factor in agricultural production but which is increasingly scarce because of the high population density that characterizes the eastern DRC. Walungu and Kabare territories covered by this study are the highest densely populated areas of DRC (~300 habitants per km^2) (Mugumaarhahama et al., 2021), with farm size being on average less than 0.5 ha per household. Low land ownership could impact both the agricultural production of households and their food security status (Ogada et al., 2014). The other constraint reported by farmers is the unavailability of labour, especially in Ruzizi plain where youths are not attracted by agriculture, considering it as less productive and burdensome (Furaha et al., 2016; Mondo et al., 2020). Consequently, farmers are importing labour from neighbouring countries Rwanda and Burundi to ease the labour shortage in the area (Mondo et al., 2020). The lack of farm labour for the most important work may limit the technical efficiency of the farm, and therefore, decrease crop yields or increase significantly the production cost as in the Ruzizi plain (Dahlin & Rusinamhodzi, 2019; Mondo et al., 2020).

5.4. Implications for maize breeding programs and seed policies

In this study, we found poor adoption of IMVs compared to local varieties, which are still widely used among farmers. Despite the dissemination efforts of IMVs during the last five years, farmers prefer to use local varieties that are lower yielding and degenerated compared to improved varieties. This would be related to several institutional factors listed in the previous sections that constitute barriers to the adoption of IMVs in South-Kivu. Due to the absence of a reliable seed delivery system and the absence of effective seed policies, farmers consider local varieties to be easily available and well adapted to their environmental conditions (Jandrain, 2020). In addition, breeding programs do not consider farmers' local/regional preferences, which would be the main determinants of the adoption of improved maize varieties in South-Kivu, as Mondo et al. (2019) noted for cassava varieties in the same study area.

According to the findings of this study, the low adoption rate of improved maize varieties in the study area is explained by a lack of collaboration between farmers, extension services, and variety improvement programs. Table 8 shows the different implications of the study and the potential interventions to be considered according to the model of Kuivanen et al. (2016), in order to improve the level of adoption of IMVs in South-Kivu. Results showed that farmers are classified into three classes (market segments) according to their preferences. This implies that interventions planned for new variety development should be adapted to this classification.

Table 8. Main implications of preference criteria analyses of maize variety attributes and production constraints for appropriate varietal improvement strategies and interventions in South-Kivu and DRC.

		Market segment		
Preferred traits of IMVs	Implications in targeting breeding programs and policies	C1	C2	C3
High yield potential	Develop high-yielding maize varieties, specific to different environments, adopt participatory varietal selection, consider conducting trials with farmers for quick IMVs uptake	x	x	x
Taste, high flour density	Targeting improvement objectives for the sensory characteristics of the final products with regard to the grain quality	x	x	x
Resistance to storage pests	Improving varietal resistance to storage pests			x
Seed price	Subsidize farm inputs and ensure the availability of high-quality seeds to farmers, support research programs			x
Early maturity	Develop new short-cycle varieties which adapt to changing environmental conditions	x	x	x
Drought tolerance	Develop drought-tolerant varieties that adapt to changing environmental conditions	x		x
Pest/disease resistance	Develop new varieties with multiple resistance to major maize diseases and pests, emphasizing the fall armyworm	x		x
Seed longevity	Improvement of seed storage aptitudes, establishment of conservation infrastructures for plant genetic resources in the short- and long-time frames in an effort to better preserve agricultural biodiversity			x
Fertilizer responsiveness / Environment adaptation	Develop new varieties tolerant and adapted to changing environmental conditions	x		x
Seed availability	Ensure the seed's availability to farmers by subsidizing them and developing an effective pro-poor seed delivery system across the territory			x
Production constraints and adoption factors of IMVs				
Lack of farmland	Increasing access to land, promoting agricultural intensification, promoting high yielding varieties for food crops, and reducing inequalities in land ownership	x	x	x
Low availability of labor	Develop family labor experience and enhance indigenous resources or mechanize some labor-intensive operations.	x	x	x
Crop disease	Develop varieties combining high yield potential and resistance to major diseases	x	x	x
Unavailability of IMVs seed	Consolidate and transform the traditional seed system, improve collaboration between farmers and breeding programs, improve the public extension service for effective dissemination of agricultural innovations, especially IMVs registered in the national catalog, create sale ponys in different locations, support acquisition of new varieties' seeds	x	x	x
Unavailability of farm inputs	Promote the use of local resources in the control of crop diseases and pests, soil fertility, etc.	x	x	x
Lack of market demand	Encourage the value addition of harvests by developing processing facilities in the production areas	x	x	x
Low soil fertility	Promote the use of leguminous crops for biological nitrogen fixation, the use of green manure, burying crop residues and promoting the integration of agriculture and livestock	x	x	x
Post-harvest losses	Improve post-harvest storage to reduce yield losses and maximize farmers' profits.	x	x	x
Access to credit	Facilitating access to agricultural credits, creating funds to subsidize agricultural inputs through refundable or non-refundable loans	x	x	x
Age	Encourage more youths in agriculture and train them in agricultural activities through practical sessions and accompaniment, developing income-generating activities and processing of agricultural products	x	x	x
Membership of FBO	Encouraging farmers to join farmers' based organizations, strengthening the capacity of farmers' organizations through regular training	x	x	x
Extension service	Restructure extension services, tighten collaboration with farmers and crop improvement programs	x	x	x

Therefore, a particular effort should be made to develop a seed policy, a functional seed delivery system and an effective extension service by decision-makers at all levels. This will boost the dissemination and use of improved seeds in the study area. At the same time, special emphasis should be placed on research in order to develop new varieties that meet farmers' expectations. It will be necessary to improve relationship between farmers and extension services in the South Kivu region.

It was reported that farmers should have access to information about new technologies before they adopt them (Lunduka et al., 2012). This increases the level of exposure and awareness of farmers to agricultural innovations. Breeding programs should therefore adopt the participatory plant breeding approaches. As defined by Morris and Bellon (2004), this approach has several advantages over traditional methods because it is well adapted to developing varieties that are more adaptable not only to physical environment but also to human preferences and needs, increases breeding efficiency and empowers rural communities. However, the application of this method requires overcoming several technical, economic and institutional challenges in order to achieve the best results.

Therefore, developing improved high-yielding maize varieties that meet farmers' needs and expectations should be integrated into the breeding objectives for South Kivu. The use of these varieties by farmers will increase maize production in the area. Breeders must work with extension specialists to ensure that the developed varieties are grown with the appropriate technical packages for successful results and a satisfactory adoption rate. This research will provide guidance for future breeding programs in order to increase the use of IMVs and hence, maize productivity in eastern DRC. Specifically, it is also essential to focus on enhancing the nutritional qualities of the varieties being developed. This approach would more effectively meet the actual needs of farmers and improve the acceptability and adoption of new varieties, as well as the health and food security of consumers. Moreover, it is crucial to develop varieties that are resilient to the biotic and abiotic factors affecting maize cultivation. Policymakers should promote agricultural intensification and improve farmers' access to land to address the issue of land scarcity, which is a significant limiting factor in the adoption of improved maize varieties. One proposed solution is to mobilize and incentivize young people to engage in agricultural activities, thereby enhancing access to labour in rural areas. This could be achieved by creating income-generating activities and implementing local projects to attract them, encouraging them to remain in their communities, and reducing the rural exodus currently observed. Finally, policymakers could encourage farmers to join farmer-based organizations (FBOs) to acquire essential skills for promoting improved varieties, ultimately boosting maize production.

In this study, we did not assess the fatigue of respondents or interviewed farmers during data collection, which constitutes a significant limitation (Adzawla et al., 2024). Indeed, fatigue could have led to response biases, where participants might provide less thoughtful or inconsistent answers, thus affecting the quality and reliability of the data (Jeong et al., 2023). However, it is important to note that the observed rate of non-response was relatively low, suggesting that the majority of participants were able to answer all the questions posed. This indicates that, despite potential fatigue, the collected data are representative and the study's conclusions remain valid. Additionally, we used a self-reported method for data collection, which could be a potential source of bias (Koller et al., 2023). It has been shown that surveys on agricultural operations relying on self-reported and memory-based data from farmers often suffer from systematically inaccurate reporting. This could constitute a source of bias due to measurement errors in the collected data (Abay et al., 2022). For example, Koller et al. (2023) observed that a standard questionnaire format led to much higher reported behaviours compared to a more anonymous and covert questionnaire condition. This effect appeared to be influenced by participants.

The Best-Worst Scaling (BWS) method has limitations for evaluating farmers' preferences, particularly when dealing with a large number of options, which can make the method complex and affect the quality of responses. Presentation bias and the difficulty in capturing the complexity of preferences, influenced by various contextual factors, can reduce the accuracy of the results (Ahoudou et al., 2023). Additionally, by focusing only on the best and worst options, BWS may limit the richness of the data, and responses could be subjective. Interpreting the results can also be challenging when differences are minimal or data are dispersed. Therefore, it is important to combine BWS with other approaches for a more precise evaluation (Bir et al., 2022). However, compared to other methods, BWS provides better estimates of varietal choices (Burton et al., 2021). In our study, we limited the number of options to 13 varieties to assess farmers' preferences, which helped reduce the complexity of the Best-Worst Scaling (BWS) method. By limiting the number of options, we simplified the decision-making process for respondents, making it easier for them to make meaningful choices between varieties. This approach helped reduce the cognitive load associated with evaluating many options while maintaining the methodological rigor of BWS. As a result, the quality of the collected data is improved, reducing potential biases and allowing for better interpretation of farmers' preferences.

The results of this study are based on data collected from three territories in the South Kivu province, where maize cultivation is particularly important for the survival of farming households. These territories were carefully selected to represent varied contexts within the province, thus capturing significant aspects of local agricultural practices (Ndeko et al., 2024). The representativeness of these territories is supported by their central role in maize production and their diversity in terms of agro-climatic conditions and agricultural practices. However, for a comprehensive generalization of the results to other regions or contexts, it is essential to consider certain limitations. Taking into account local specifics, such as climatic conditions and available resources, which can vary from one region to another, is necessary as these factors could influence farmers' preferences and practices (Asrat et al., 2010).

6. Conclusion and outlook

This study on farmers' preference criteria of IMVs attributes, factors influencing their adoption and major production constraints provided valuable insights on drivers of IMVs choices and uptake in South-Kivu, essential for guiding breeding programs and agricultural policies at national and regional levels. This study showed that IMVs are still poorly adopted in South-Kivu due to some varietal attributes and socioeconomic factors that need to be addressed. Traits like high yield potential, early maturity, taste, resistance to maize diseases and pests, environmental adaptation should be prioritized when introducing or breeding new varieties in eastern DRC, while strategies should devised to ensure seed availability and awareness of farmers on already disseminated varieties. In addition to developing new varieties and strengthening the seed delivery system, other agronomic packages should be introduced to control major production-limiting factors, such as diseases and pests, farmland scarcity, labour shortage, noxious weeds, post-harvest losses, and low soil fertility, to boost maize production and to release its potential for food security and poverty alleviation in rural South-Kivu.

Abbreviations

CIMMYT: International Maize and Wheat Improvement Center, CAID: « Cellule d'Analyse d'Indicateurs de Développement », ANOVA Analysis of variance, FAO: Food and Agriculture Organization, FBO: Farmers Based Organization, IMV: Improved Maize Varieties; INERA: « Institut Nationale pour l'Etude et la Recherche Agronomiques », IITA: International Institute of Tropical Agriculture, NGO: Non-governmental organization, SSA: Sub-Saharan Africa

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Authors' contributions

ABN designed the research; ABN and GBC performed the field experiment, did data collection, performed the analysis, interpreted data, and wrote the original manuscript. GBC, JMM, LMK, and YM assisted in the data analysis and interpretation. GNM, EBB, and RC revised the manuscript. All authors read and approved the final manuscript.

Availability of supporting data

Raw and treated data generated during study are available from the corresponding author on reasonable request.

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