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A cost–benefit analysis of the production system with improved and climate-resilient sorghum varieties in southern Mali

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Given the persistently low adoption rate of improved sorghum varieties over decades, it is relevant to assess whether it is profitable or not to grow these varieties in Mali. Over the past years, little evidence has demonstrated the profitability analysis as decision-support information regarding the adoption of improved sorghum varieties. This study used cost-benefit analysis to assess the profitability of two Improved and Climate-Resilient Sorghum Varieties (ICRSVs), "Soubatimi and Tiandougou-coura" compared to the "Local" ones, using three years of average yield data (2017, 2018, and 2020) in Sikasso region, Mali. The objective was to perform a consistent cost-benefit analysis through net income, cost-benefit ratio, and gross profit margin. The study used a farm partial budget framework, sensitivity analysis, and stochastic dominance analysis methods. A final sample of 31 farmers' on-farm trials under the fertiliser package of "100 kg complex cereal and 50 kg urea" per hectare was held as the agronomic package. The key findings showed that both varieties were profitable, with 79,661 CFA (123.56 USD) and 45,073 CFA (69.91 USD) average net incomes corresponding to 1.54 and 1.32 CBR, and 34 and 24 percents average gross profit margins, respectively, while growing the "local" varieties was not profitable, with an average loss of 12,113 CFA (18.79 USD) with 0.91 CBR and 10 percent average gross profit margin. In light of these results, the study suggests a large dissemination of the ICRSVs in Mali. Policy-makers should facilitate the implementation of outreach programs to inform smallholder sorghum farmers on the ICRSVs' traits and profitability information as decision support tool for a larger adoption.

KEYWORDS

CBA, profitability, stochastic dominance, improved and climate-resilient sorghum, Mali

1 Introduction

Raising productivity on existing farmlands is a key driver for sustainable agricultural transformation in sub-Saharan Africa (Akpo et al., 2021). To achieve this, the adoption of improved and climate-resilient cereal and legume varieties plays an important role. This idea is also supported by Akpo et al. (2021) stating that agricultural productivity is highly dependent on quality inputs most importantly, quality seeds of modern high-yielding crop varieties. On the other hand, smallholder farmers in sub-Saharan Africa (SSA) particularly in Mali faced many challenges in adopting promising improved crop varieties and farming systems. Amongst several constraints hindering the adoption of improved crop varieties, we mention the high risk and uncertainty in the face of a changing climate and its variabilities, decreasing soil fertility, lack of appropriate improved seed delivery system, and limited information on their traits and profitability. Another key constraint is the unaffordable price of certified seeds and other basic inputs such as chemical fertilisers remained crucial (Akpo et al., 2021; Smale et al., 2016).

In Mali, 80 percent of the active population depends on agriculture basically family farming and the allied sector (INSTAT, 2022)[1]. Therefore, information regarding the performance and profitability at the early stage of the dissemination process of new agricultural technologies such as Improved and Climate-Resilient Sorghum Varieties (ICRSVs) could provide more incentives to rural farmers (Alvarado, 2013; Gittinger, 1982; Miklyaev et al., 2017a,b). So, engaging in the adoption of improved crop seeds is a double risk for smallholder farmers. First, the new testing variety is sometimes associated with the risk of new agronomic practises (application knowledge and its effectiveness). Second, the uncontrolled rainfall pattern throughout the growing season is also challenging continuously. Thus, when a smallholder farmer decides to engage in growing the ICRSVs, this will undoubtedly incur additional costs to his/her farm budget. This derives from the fact that most of the recently released ICRSVs impose the use of a particular input package. For instance, in Mali, the production of a released sorghum variety “Seguifa” in 2008 required a package of “6 kg of Seeds, 100 kg of NPK, and 50 kg of Urea” for 1 ha with an average cost of 52,600 CFA[2]/ha (USAID, 2010)[3]. This average cost presents more than half of the annual average income *per capita* 85,322 CFA in rural areas of Mali (INSTAT, 2020).

Gittinger (1982) reported that cost–benefit analysis (CBA) will allow the farmers to allocate efficiently scarce resources in the production area once they are well informed on the costs and benefits. In addition, ranking different agricultural technologies (particularly, the ICRSVs) based on their profitability information is vital for farmers’ decision-making. Moreover, the efficient use of improved seeds, and organic and inorganic fertilisers are recognised preconditions for achieving productivity growth in SSA including Mali (Jayne et al., 2021; Sanchez, 2019). More recently, the cultivation of local and improved sorghum varieties induced an incremental total cost of 19,531 CFA/hectare[4] in Mali (Miklyaev et al., 2017a,b). Such an additional cost can be an impediment for farmers to adopt improved sorghum varieties. Given that concern, the present study performs a cost–benefit analysis of the ICRSVs which benefit farmers more with the dual-purpose (food and feeds) trait.

Beyond their dual-purpose nature, the ICRSVs incorporate important climate resilience features, such as drought tolerance and early maturity. They were disseminated in 2017 and 2018 under the Africa Research in Sustainable Intensification for Next Generation project and again in 2020 under the Enhancing Crop Productivity and Climate Resilience for Food and Nutrition Security project in Mali. The gap in 2019 was due to the conclusion of the Africa RISING project. Activities resumed in 2020 under the APSAN-Mali project, guided by the principle of building on existing efforts for continued sustainability. This study supports the findings of Kouyate (2020) highlighting the need for consistent profitability of improved varieties over time, given Malian sorghum farmers’ increasing vulnerability to climate change and variabilities in recent decades. The analysis also tracks the consistency of benefits within a stochastic farming environment to provide evidence of sustainable sorghum farm profitability independent of seasonal variation. This cost-benefit analysis can, therefore, guide farmers, sorghum breeding programs, and policymakers.

Several authors (Afreen and Haque, 2014; Arayaphong, 2012; Beshir and Nishikawa, 2012; Katungi et al., 2011; Kuwornu et al., 2018; Miklyaev et al., 2021; Al Rawahy and Mbaga, 2019; Sgroi et al., 2015; Vidogbéna et al., 2015) performed the CBA. However, these studies mainly focussed on plants and vegetables rather than cereal crops known as the major staple food in sub-Saharan Africa (SSA) including Mali. On the other hand, other authors have conducted the CBA with agricultural improved technologies (improved rice, maize, millet, and sorghum), policies, and crop value chains. For example, most recently, authors (Jenkins and Miklyaev, 2018; Miklyaev et al., 2017a,b, 2021) performed CBA for decision-making for both governments and individual farmers. However, those analyses focussed on the value chain approach and research investment with the net present value (NPV) appraisal and provided less detail on individual farmers’ profitability concerns. Nonetheless, individual farmers’ profitability appraisal analysis can be a pattern for the widespread adoption of ICRSV technologies.

The findings of the CBA of Mali sorghum and millet value chains were also reported under the Africa RISING project (Miklyaev et al., 2017a,b). The authors used the Economic Net Present Value (ENPV) as the evaluation criterion and mainly focused on the project’s initial investment. They did not closely consider the farm’s profitability with free seasonality. It is worthwhile noting that the promotion of improved sorghum varieties namely “Grinkan” and “Seguifa” by the USAID research project in the 2008–2009 agricultural season required the conduct of CBA. Then, the analysis revealed that both varieties had cost–benefit ratio (CBR) of less than one (USAID, 2010). Gierend et al. (2014) recommended using panel data to assess consistent sorghum farm profitability. This gives consistent CBR which is less sensitive to seasonal variation. However, we are not aware of any study that used panel yield data in that sense. So, given that concern the present study used 3-year yield data to perform the profitability analysis of on-farm trial plots. This provides reliable information to farmers, sorghum breeding programme, and policymakers contributing to reversing the lagging adoption rate of ICRSVs in Mali.

In the same vein, authors (Gierend et al., 2014; Kraybill and Kidoido, 2009) also studied in detail the profitability of improved sorghum varieties in Uganda. Admittedly, Gierend et al. (2014), considering the low and high input regimes with improved and local sorghum varieties, reported that the sorghum production system might be profitable mostly under high input use and not necessarily with improved varieties standalone without using any fertiliser package. On the other hand, Kraybill and Kidoido (2009) also pointed

1 Institut National de la Statistique/the National Institute of Statistics.

2 “Franc de la Communauté Financière d’Afrique,” currency in used in the West African Economics and Monetary Union (WAEMU) area.

3 United States Agency for International Development.

4 32.5 USD exchanged to CFA on Internet at today exchange rate of 600.94 for 1 USD.

out the low profitability (and highly inconsistent with one-season data) of improved sorghum amongst its competing cereal crops such as maize and millet. This implies that considering only 1-year yield effect, growing these improved sorghums was not profitable for farmers. Consequently, that could impede a wider acceptance of promoted improved sorghum varieties by smallholder farmers. In contrast, the ICRSVs have a competitive advantage with higher fodder yield which can also be commercialised. The present study was built upon that literature issues to know how much the ICRSVs are profitable under a fair agronomic fertiliser package of "100 kg complex cereal and 50 kg Urea" per hectare? The objective of the study is to assess the profitability through net income, cost–benefit ratio, and gross profit margin. We hypothesise that ICRSVs are higher yielding and generate greater benefit than local varieties to farmers. The analysis is performed with 3-year adjusted yield data to investigate the consistency of the profitability of improved sorghum production system in Mali.

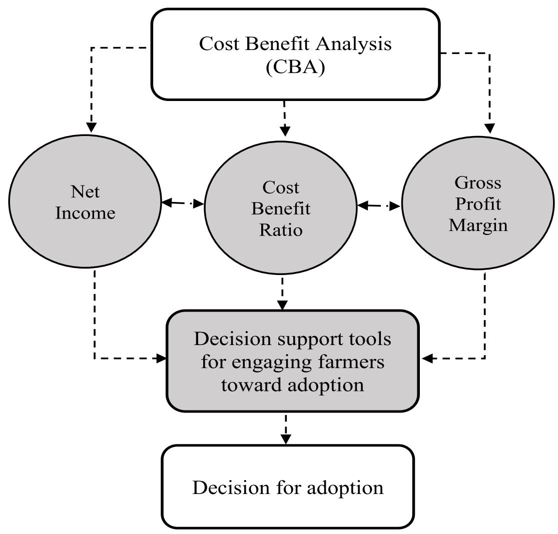

FIGURE 1
CBA conceptual framework for the ICRSV adoption decision in southern Mali. Source: authors' conception.

2 Conceptual framework and methodology

2.1 Conceptual framework

This sub-section presents the conceptual framework of the study in Figure 1 as follows.

The study's conceptual framework is based on the theory of change that farmers are more likely to adopt a particular improved sorghum variety when it is higher yielding. This means the variety generates a marketable surplus with greater net benefit than the local varieties. This is also supported by Amponsah et al. (2013) with the assertion that a positive gross margin increases the chance for farmers to adopt improved agricultural technologies. Most of the ICRSV cultivation requires a certain agronomic or fertiliser package (e.g., this analysis used "100 kg complex cereal and 50 kg urea") to achieve the expected yield. Farmers are most often confident when they are informed of the profitability of such a required package. So, the present study conceptualises that CBA results provide information to farmers through net income, cost–benefit ratio, and gross profit margin on the ICRSV production system under the abovementioned fertiliser package. These profitability indicators help farmers as supporting tools to engage in the adoption decision process. Such profitability information can also serve public policymakers to set relevant outreach programmes for the large dissemination of ICRSV technologies in Mali.

2.2 Methodology

2.2.1 Cost–benefit analysis model

Generally, two basic approaches are used in the literature concerning profitability analysis. On the one hand, the CBA is suitable where all cost and benefit items can be monetised. On the other hand, cost-effectiveness may be better when there are difficulties in transforming some of the cost and benefit items in monetary values (Gittinger, 1982). For instance, the cost-effectiveness approach is mostly applied in the environmental and health sectors where there are quite difficulties to assign monetary value to all the cost and benefit items. In this analysis, the CBA approach is used as all costs in the sorghum production system can be measured in monetary value and at the market and/or farm gate prices. This analysis used the average farm gate price as sorghum grains are mostly sold by farmers at gate price during harvest period in Mali. Most recently, a generalized Risk Opportunity Analysis (ROA) approach emerged, but it is applicable only when the economy exhibits dynamic and strong path dependence, fundamental uncertainty, and stakeholder heterogeneity (Mercure et al., 2021). This focuses on the agricultural sector, where stakeholders are relatively homogeneous, unlike the heterogeneity stipulated by the authors, and does address the entire complex economy. ROA might be more suitable for climate change policy analysis within a broader multilateral dimension.

Subsequently, the primary analysis methods applied were mostly financial and economic analyses. The financial analysis utilized a farm partial budget framework with net income and CBR evaluation criteria, while the economic analysis employed discounting techniques with Net Present Value (NPV) and internal rate of return (IRR) evaluation criteria. The study applies the farm partial budget analysis technique within the Malian sorghum production system, using net income, CBR, and gross profit margin as profitability measures for the ICRSVs. Recognizing some limitations of CBR, such as the potential for overlooking side effects of technologies (Akinseye et al., 2023; Boardman and Weimer, 2014), this study combines CBR with net income and gross profit margin to provide more comprehensive insights into profitability. Accordingly, the following empirical model used by Katungi et al. (2011) is applied in this analysis. The following equation 1 is applied:

$$AGM = ATR - ATC \tag{1}$$

Where AGM stands for average gross margin, ATR is the average total revenue, and ATC is the average total cost. In our analysis, the AGM represents the farm average net income which is equal to the average total revenue derived from grain sold at farm gate price minus the average total variable cost for 1 hectare level valued at their respective market prices.

2.2.2 Sensitivity analysis

The consistency of the net income (profitability) is checked through sensitivity analysis using the best and worst-case analysis following the study of Beshir and Nishikawa (2012) with five cases scenarios. For each ICRSVs ("Soubatimi and Tiandougou-coura") and Local variety, we applied the scenarios to three key variables (i.e., the average farm total variable costs, average farm yield, and the farm gate price) selected based on their higher sensitivity to the revenue stream. This is the best-fitting sensitivity method because improved sorghum varieties are subject to seasonal variations of inputs and farm gate prices and yields which may randomly affect the net income over the years. However, other methods such as Monte Carlo are more suitable for cost-effectiveness analysis (Boardman and Weimer, 2014) but it is not used in this study framework. In addition, in partial sensitivity analysis, one particular variable is selected to vary whilst the others remain constant. A potential limitation of this method is that in a complex farming environment such as improved sorghum production system, sensitivity based on a particular single assumption is not as strong as a sound sensitivity test.

2.2.3 Risk analysis

Risk analysis is carried out through stochastic dominance analysis and is used for ranking the ICRSVs ("Soubatimi and Tiandougou-coura") in comparison with farmers' best "Local" varieties in terms of average yields and average net incomes. As suggested by Lowenberg-DeBoer et al. (1992), Steele and Torrie (2002), the present analysis performed the Kolmogorov–Smirnov (K-S) non-parametric test to determine the statistical difference of the probability distributions based on a pairwise comparison between "Soubatimi," Tiandougou-coura, and the "Local" varieties using their respective average yields and average net incomes per hectare. As a non-parametric test, the K-S test is performed using a null hypothesis (H0) that there is no statistical difference between the probability distribution curves of the ICRSVs and the "Local" varieties. This is against the alternative that there is statistical difference between the probability distribution curves. Then, the test result is considered as only indicative when the K-S test is not significant at a 5 percent level rejecting the null hypothesis of no statistical differences between the graphs (Hien et al., 1997). In this study, we reject the H0 indicating that there is a statistical difference between the probability distribution curves, hence validating our empirical cumulative distribution function curves (see the K-S test result in Supplementary materials).

2.2.4 Study area

The study covered the Sikasso region, one of the most important agroecological zones (based on the quantity of rainfall received *per annum*) in the southern Sudan Savanna of Mali. On the one hand, Sikasso was chosen for the study based on the fact that the Africa RISING's large-scale Diffusion of Technologies for Sorghum and Millet Systems (ARDT-SMS, 2015–2019) project was implemented in the region. In this project framework, the on-farm trials of dual-purpose, ICRSVs ("Soubatimi" and "Tiandougou-coura") compared to the "Local" varieties were grown under the fertiliser package of "100 kg complex cereal and 50 kg urea" per hectare in 2017 and 2018. On the other hand, the same trials were conducted in the region under the Enhancing Crops Productivity and Climate Resilience for Food and Nutrition Security ("APSAN Mali") project in 2020. Moreover, the population is estimated at 3,736,267 inhabitants representing 18.6 percent of the country's total population (INSTAT, 2020) with an average annual temperature of 27.0°C. The rainy season lasts approximately 3–6 months from May to October. The rainfall is abundant compared to the other agroecological zones with an annual average of 1,121 mm and between 600 and 1,400 mm (Falconnier et al., 2015). This offers the region an excellent opportunity to practise cereal cultivation with a large diversity of crops. The local economy is predominated by farm and farming activities. Most importantly, smallholder farmers depend on livestock raising, cotton and maize cultivation for income-generation. Then, they cultivate sorghum and millet as staple foods. The map of the study area is presented in Figure 2.

2.2.5 Data collection

Data were collected from the Sikasso region, southern Mali, particularly in the districts of Bougouni, Koutiala, and Yorosso. These districts have been the testing nest of on-farm trials of "Soubatimi and Tiandougou-coura" over 3 years (2017, 2018, and 2020). A total of 50 sorghum farmers were targeted in 14 villages over the three districts for collecting complementary information regarding cost items (inputs, farm equipment rental, labour, storage, and transportation costs) at 1 ha level. A multi-stage sampling technique was applied to collect appropriate data with 3 years of recall back information on sorghum production cost items in August 2021. First, at stage 1, a purposive selection was made at the village and farmer levels based on the use of the recommended fertiliser package, i.e., 100 kg of complex cereal and 50 kg of urea per hectare during the on-farm trials. Second, at stage 2, we retained the villages where the two ICRSVs ("Soubatimi" and "Tiandougou-coura") were grown under the above fertiliser package. Finally, at stage 3, the plots were randomly selected from farmers who participated in the on-farm trials within the 3-year applying the recommended fertiliser package.

- First, 9 on-farm trial plots (including one female plot) were randomly selected from 4 villages (Dieba, Sibirila, Flola, and Madina) in Bougouni district in 2017.
- Second, 10 plots (including two female plots) were maintained in 7 villages from 2 districts: Bougouni (Dieba, Sibirila, Flola, and Madina) and Koutiala (M'Pessoba, Zansoni, and Namposela) in 2018.
- Third, 12 plots (including one female plot) were considered in 8 villages from 3 districts: Bougouni (Bassa, Zambougou, and N'kemene), Koutiala (M'Pessoba and Nianabougou), and Yorosso (Kiffosso, Makoungo, and Karangana) in 2020.

So, in each village, the ICRSVs were cultivated in comparison with farmers' best "Local" sorghum varieties, i.e., "Sokorka," "Kalosabani," "Niodionani," "Lata," "Gugneblé," "Seguetana," and "Sogrekun" on 400 m^2 area. Then, the plot yields were extrapolated to 1 ha level and adjusted at 10 percent given that farmers may receive technical assistance from research technicians in the farming processes. So, a final sample of 31 on-farm trial plots was retained from farmers who provided complete information during the 3-year survey period. A structured and pre-tested focus group discussions

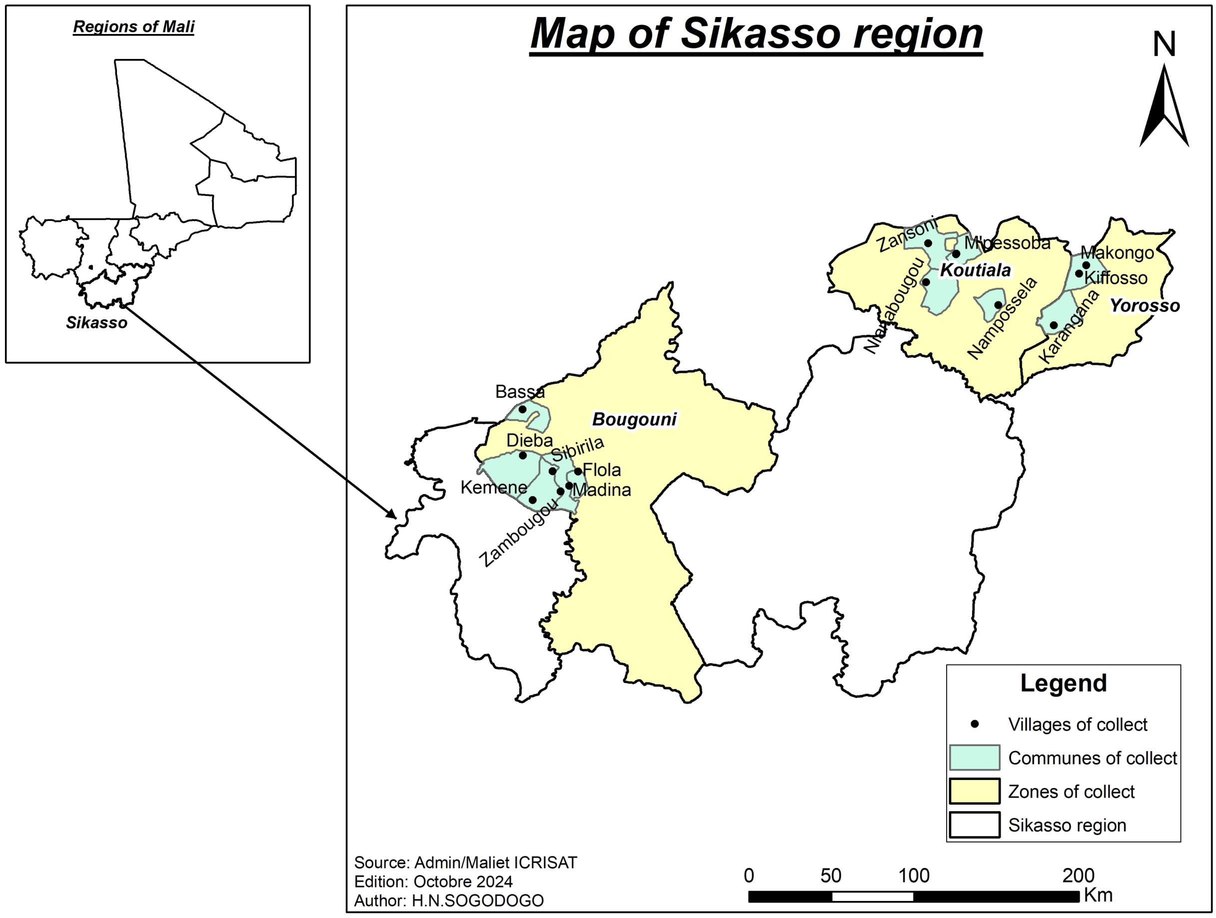

FIGURE 2
Map of the study area, Sikasso region, southern Mali. Source: authors' conception.

(FGDs) guide and individual questionnaires were used in interacting with farmers. Then, during the interaction, written consent was obtained from the farmers' leader, and a verbal agreement was obtained from each farmer before both FGDs and individuals field surveys. We used data triangulation to compare the values of our key sensitive variables, i.e., average sorghum yield and gate price with their values in the existing available breeding data base and the literature, respectively. Table 1 presents the cost items and their respective unit of measures.

Table 1 shows that the farm partial budget components unit of measure are likely the same for all three years except for 2020, when farmers tend to move to contract arrangements for renting farm equipment. Farmers explain this shift by saying that the contract arrangement is cheaper than the daily fee, and they have experienced an increase in moral hazard with daily fee rental arrangements over years.

3 Results and discussion

In this section, the summary statistics of the variables of interest from the farm partial budgets are presented and discussed. Then, sensitivity analysis and stochastic dominance analysis are used to assess the consistency of the results.

3.1 Summary statistics farm partial budgets

Table 2 shows the descriptive statistics of ICRSVs and "Local" varieties with respect to farm gate price, adjusted yield, farm net income, cost–benefit ratio, and input cost share in the farm total cost over the 3 years average data. The selection of these variables is based on the study's interests highlighting the profitability information. Then, we provide discussion on the average figures related to the farm gate price, adjusted yield, farm net income, and cost–benefit ratio as mentioned in Table 2.

Table 2 shows that the average farm gate price is 123 CFA which is consistent with both ICRSVs and the "Local" varieties over the 3-year period. This price consistency might be explained by the fact that gate prices for sorghum grains does not vary regardless of whether it is improved or "Local" varieties. Most recently, the same average gate price (123 CFA) was recorded by Miklyaev et al. (2017a,b) studying the cost–benefit analysis of sorghum and millet value chains in Mali.

The average adjusted (at 10 percent) yields were 1,820 Kg/ha, 1,517 Kg/ha, and 980 Kg/ha for "Soubatimi," "Tiandougou-coura," and "Local" varieties presented in Table 2, respectively. An important remark is that these averages are free from high seasonal inconsistency. The figures show a much higher average adjusted yield of "Soubatimi" in 2020 over "Tiandougou-coura" and the "Local." This might be explained by high drought tolerant trait of "Soubatimi" at maturity

TABLE 1 Cost item variable descriptions over the 3 years (2017, 2018, and 2020).

Year	2017	2018	2020
Variables	Unit of measure		
Yields			
Sorghum yields	kg/ha	kg/ha	kg/ha
Adjusted yields	kg/ha	kg/ha	kg/ha
Basic inputs			
Seeds (improved sorghum)	kg/ha	kg/ha	kg/ha
Fertilisers (cereal complex)	kg/ha	kg/ha	kg/ha
Fertilisers (urea)	kg/ha	kg/ha	kg/ha
Herbicides (“Béret Rouge”)	litre	litre	litre
Fungicides (“Clathio C”)	sachet	sachet	sachet
Farm equipment rental			
Draught power (ploughing)	daily fee	daily fee	contract
Draught power (hoeing)	daily fee	daily fee	contract
Draught power (mounding)	daily fee	daily fee	contract
Labour			
Weeding	man/day	man/day	man/day
Harvesting	man/day	man/day	man/day
Threshing and winnowing	contract	man/day	man/day
Storage			
Sacks	Number	Number	Number
Transportation			
Transports	Number	Number	Number

Source: authors from field survey data 2021.

stage compared to the other varieties used in this study. In comparison with other studies in sorghum literature, “Soubatimi” outperformed the average potential sorghum yield (1.500 kg/ha) reported by Traore et al. (2017) and the average sorghum yield reported (1,600 Kg/ha) by Miklyaev et al. (2017a,b) which are all one-season data and might suffer from seasonal inconsistency (Akinseye et al., 2023; Gierend et al., 2014). The higher yield performance of “Soubatimi” over its competitor varieties in this analysis might be partially explained by the higher drought tolerance trait of the variety at maturity stage. On the other hand, “Tiandougou-coura” also performs better than the “Local” varieties. This result was expected as the ICRSVs yield higher and more climate-resilient than farmers’ best “Local” varieties. In comparison with existing literature, the variety yield is quite lower than the average 1,600 Kg/ha (Miklyaev et al., 2017a,b). This shows the relevance of the data type used in our study leading to more consistent results than 1-year data. These findings indicate that given the current fertiliser package used in our analysis, both ICRSVs performed better than the farmers’ best “Local” varieties.

Regarding the average net incomes, the amounts of 79,661 CFA/ha, 45,073 CFA/ha, and (-12,113) CFA/ha were recorded for both ICRSVs and the “Local” varieties, respectively. These gross margins represent 93 percent and 53 percent of the annual average income *per capita* for the ICRSVs in rural Mali, respectively. Given these figures, adopting the ICRSVs might be better way to alleviate rural poverty. An important notice is that our margins from both ICRSVs are higher than that of Basavaraja et al. (2005) with an average of 13,672.65 CFA[5] in India, analysing kharif sorghum profitability and Kraybill and Kidoido (2009) with the average of 2,337.10 CFA[6] analysing sorghum profitability under relative low input use in Uganda. However, the margins obtained from both ICRSV cultivation are lower than that (average of 102,070 CFA/ha) of Amponsah et al. (2013) analysing improved sorghum profitability in Mali. Concerning the “Local” varieties, our result which led to a loss of an average of 12,113 CFA/ha indicates the low yield potential of “Local” sorghum variety cultivation in Mali. This finding corroborated that of Kraybill and Kidoido (2009) analysing the profitability of local sorghum with an average loss of 4116.34 CFA/ha under low input use in Uganda and obtaining an average gross margin of 25,193 CFA/ha under high input use.

The average CBR of 1.54, 1.32, and 0.91 were recorded, respectively, for both ICRSVs and the “Local” varieties. This indicates that each cost unit invested will bring a 0.54 and 0.32 unit of benefit to farmers, for both ICRSVs presented in Table 2, respectively. Similar findings are obtained by Akinseye et al. (2023). On the contrary, USAID (2010) reported CBR less than 1 in Mali. Finally, Table 2 shows that the average basic input costs of the ICRSVs and the “Local” varieties have the highest share of 39.99 percent, 40.87 percent, and 41.11 percent in the farms’ total cost, respectively. This implies that sorghum farmers should manage with care the costs of basic inputs such as improved seeds, fertilisers, herbicides, and fungicides to improve their profit margins. This finding is consistent with Gierend et al. (2014) stating the difficulties in CBA where some cost structures might be overestimated if the investigator did not use rigorous methods and data triangulation.

In addition, we performed a paired *t*-test of mean difference (see Supplementary materials for the test results) using the adjusted average yields and net incomes which are highly dependent and critical variables in profitability analysis. The result indicates no statistically significant mean difference between the two ICRSVs (“Soubatimi” and “Tiandougou-coura”). In contrast, the *t*-test indicates the significant statistical mean difference between “Tiandougou-coura” and the “Local” varieties (1 percent significant). Based on this, the study suggests that the ICRSVs cultivation is highly recommendable to smallholder farmers in Mali.

3.2 Analysis of variance and linear model

This sub-section first present the analysis of variance (ANOVA) for checking the presence of any year effect and variety effect in the data with our selected key variables. Second, the linear model is presented to test the consistency of the ANOVA results in Tables 3, 4, respectively. In the linear model, the data are shaped into years and variety sequences to estimate two effects. So, the first estimation was intended to capture the presence of any significant year effect and the second estimation was to capture any variety effect for the selected variables of interest in the model. For the year effect estimation, 2017

5 1792.22 Indian Rupee exchanged in West African CFA at today exchange rate of 574.64 CFA for 1 USD on Internet.

6 13,892 Ugandan shilling exchanged in West African CFA at today exchange rate of 5.94 shilling for 1 CFA on Internet.

TABLE 2 Summary statistics of the variables of interests from farm partial budgets.

Varieties/Years	2017	2018	2020	Mean	Min	Max	SD
"Soubatimi"							
Farm gate price (CFA)	120	125	125	123	120	125	2.89
Adjusted yield (kg/ha)	1,665	1,614	2,181	1,820	1,614	2,181	313.50
Net income (CFA/ha)	54,375	62,310	122,299	79,661	54,375	122,299	37,137.55
CBR	1.37	1.45	1.81	1.54	1.37	1.81	0.24
Input cost share (%)	41.29	40.83	37.84	39.99	37.84	41.29	1.87
"Tiandougou-coura"							
Farm gate price (CFA)	120	125	125	123	120	125	2.89
Adjusted yield (kg/ha)	1,635	1,440	1,475	1,517	1,440	1,635	104.11
Net income (CFA/ha)	50,811	41,060	43,349	45,073	41,060	50,811	5,099.15
CBR	1.35	1.30	1.31	1.32	1.30	1.35	0.03
Input cost share (percent)	41.29	40.98	40.33	40.87	40.33	41.29	0.49
"Local"							
Farm gate price (CFA)	120	125	125	123	120	125	2.89
Adjusted yield (kg/ha)	1,080	945	916	980	916	1,080	87.45
Net income (CFA/ha)	−7,700	−14,475	−14,164	−12,113	−14,475	−7,700	3,824.93
CBR	0.94	0.89	0.89	0.91	0.89	0.94	0.03
Input cost share (percent)	41.01	40.05	42.29	41.11	40.05	42.29	1.13

Source: authors from field survey data 2021, CBR: cost–benefit ratio, and SD: standard deviation.

is the reference year compared to 2018 and 2020. Then, for variety effect estimation, "Soubatimi" is the reference variety compared to "Tiandougou-coura" and the "Local" varieties.

Table 3 shows the ANOVA under the null hypothesis that there is no year and variety mean effect estimate variances over years against the alternative hypothesis of year and variety mean effect estimate variances given the confidence interval level $\alpha = 5$ percent. The results indicate the presence of mean year effect estimate variance for the average gate price (statistically significant). On the other hand, there is also the presence of variety mean effect estimate variances for the adjusted sorghum yield, sorghum farm net income, and CBR (statistically significant).

Table 4 shows first, a significant positive mean price effect estimates in 2018 and 2020 in reference to 2017. The estimates confirmed the results of the previous ANOVA which indicated a significant farm gate price effect over years. This finding might indicate that sorghum production system in Mali is highly sensitive to any farm gate price variation from 1 year to another relative to the other variables used in this analysis. Given that situation, sorghum gate price monitoring and the gate price stabilisation mechanism can be a better adaptive public policy in Malian's sorghum production system. On the other hand, regarding the variety effect, the results indicate a significant negative mean variety effect estimates for "Tiandougou-coura" and the "Local" varieties in reference to "Soubatimi" the dominant variety in term of average adjusted yields.

This finding also confirmed the results of the ANOVA which showed the presence of significant variety effect for the adjusted yield. The negative variety effect estimates also explain the dominance of "Soubatimi" in terms of higher yield performance over its competitor varieties. In addition, a negative mean variety effect estimates were found for only the "Local" varieties in reference to "Soubatimi" in term of net income and CBR with 1 percent significance. So, this also explains the dominance of "Soubatimi" over farmers' best "Local" varieties in terms of profitability. In brief, the results from the linear models confirmed that of the ANOVA model indicating a consistent mean year and mean variety effects estimate variances in the sorghum production system in Mali. These findings corroborated that of Akinseye et al. (2023) who reported significant seasonal and variety effects in the improved sorghums production system in Mali.

TABLE 3 Analysis of variance.

ANOVA		
Mean Variables	Year effect *p*-value	Variety effect *p*-value
Gate price	2.2e-16***	1.000
Adjusted yield	0.8764	0.0056***
Net income	0.8606	0.0059***
CBR	0.8873	0.0036***
Input cost share	0.6472	0.5633

Source: authors from farm partial budget tables, ***$p < 0.01$, CBR stands for cost–benefit ratio.

3.3 Graphical evidence of sorghum average adjusted yields and average net incomes

This sub-section presents two graphs for testing the adjusted yield and net income differences of the ICRSVs and "Local" varieties

TABLE 4 Linear model estimates for testing the consistency of the ANOVA.

Linear models				
Mean Variables	Years	Coef. (p-value)	Varieties	Coef. (p-value)
Gate price	2018	5.000 (2e-16***)	Tiandougou-coura	−2.890e-14 (1)
	2020	5.000 (2e-16***)	Local	−2.828e-14 (1)
Adjusted yield	2018	−127.0 (0.7460)	Tiandougou-coura	−303.3 (0.1088*)
	2020	64.0 (0.8699)	Local	−839.7 (0.0019***)
Net income	2018	−2864 (0.946)	Tiandougou-coura	−34588 (0.0994)
	2020	17999 (0.674)	Local	−91774 (0.0021***)
CBR	2018	−0.0067 (0.9818)	Tiandougou-coura	−0.2233 (0.0932)
	2020	0.1167 (0.6923)	Local	−0.6367 (0.0012***)
Input cost share	2018	−0.5767 (0.613)	Tiandougou-coura	0.8800 (0.436)
	2020	−1.0433 (0.371)	Local	1.1300 (0.325)

Source: authors from farm partial budget tables, $***p < 0.01$, $*p < 0.1$.

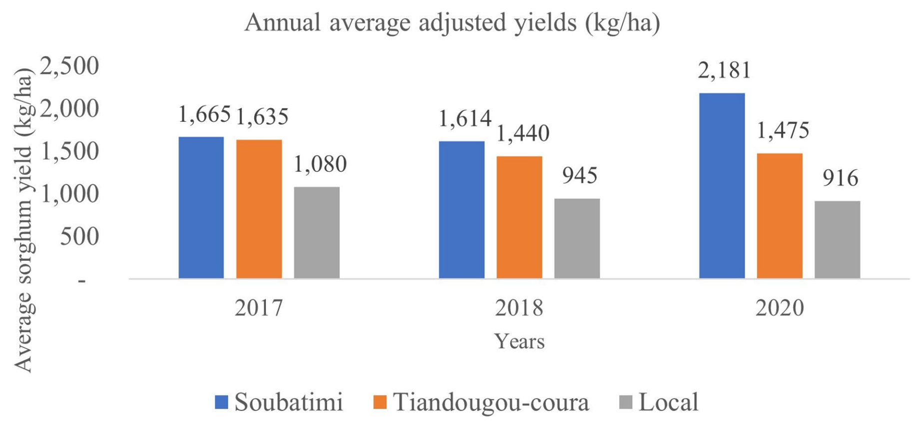

FIGURE 3
Annual average yields (kg/ha) of ICRSVs and "Local" sorghum varieties. Source: authors from field survey data 2021.

over the 3 years (2017, 2018, and 2020). The adjusted average yield differences are presented in Figure 3.

Figure 3 shows a slight fall in the average yields from 2017 to 2018 for the ICRSVs. However, both ICRSVs indicate a pick in average yield in 2020. This pick from "Soubatimi" is higher than that of "Tiandougou-coura" within the same year (2020). These differences might be explained by the seasonal effect between zones and farmers' practises over the years. Nonetheless, yields from "Local" varieties have decreased over the three-year study period. Overall, in terms of adjusted yield, the improved varieties performed better over time while the "Local" varieties' performance decreased over the years. This result could be explained by farmers getting more experience and understanding of the ICRSVs production system and the use of technology packages in southern Mali. Then, the annual net income differences is presented in Figure 4.

Figure 4, on the one hand, highlights positive earnings from both ICRSVs with little difference in average net incomes. On the other hand, a negative cash return is recorded for the "Local" varieties throughout the 3-year study period.

3.4 Sensitivity analysis

In this sub-section, the sensitivity analysis results and discussion of the ICRSVs and "Local" varieties are presented, respectively, in Tables 5–7. For each variety, five scenarios are compared to the baseline situation. Using three years of data, the percentage value changes were chosen for each scenario based on its key variable fluctuation range over the 3-year study period. So, based on our calculations (see Supplementary materials), the percentage changes are specific for each variety. The scenario was increased and decreased by this percentage value for checking the consistency except for the first scenario (farm total costs) where the increase case is only considered due to the fact that input costs got higher over time and the decrease case was seldom recorded in Mali considering the literature.

The baseline scenario in Table 5 indicates an average 34 percent gross profit margin with 79,661 CFA/ha average net income over the 3-year time span. Moreover, under five (5) sensitivity scenarios, "Soubatimi" is still profitable under scenarios 1, 2, 4, and 5 with gross profit margins of 30, 48, 38, and 32 percents, respectively. The highest gross profit margin (48 percent which is greater than 34 percent in the

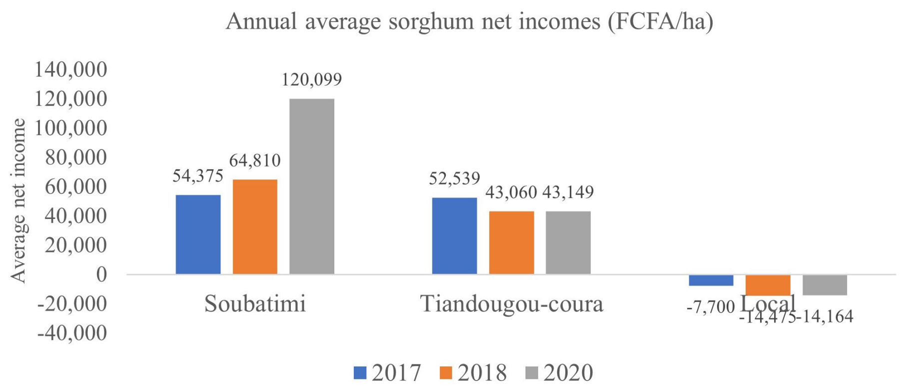

FIGURE 4
Annual average net incomes (CFA/ha) of ICRSVs and "Local" sorghum varieties. Source: authors from field survey data 2021.

TABLE 5 Sensitivity analysis "Soubatimi" (2017, 2018, and 2020).

Scenarios	Total revenue (CFA)	Total variable cost (CFA)	Net income (CFA)	Gross profit margin (percent)
0. Baseline (average values over 3 years)	224,713	145,051	79,661	34
1. Average farm total variable costs increased by 8 percent no change in yield	224,713	156,655	68,057	30
2. Average farm yield increased by 35 percent and total variable costs increased by 8 percent	303,013	156,655	146,358	48
3. Average farm yield decreased by 35 percent and total variable costs increased by 8 percent	145,895	156,655	−10,760	−7
4. Gate price increased by 5 percent keeping others constant	235,677	145,051	90,626	38
5. Gate price decreased by 5 percent keeping others constant	213,232	145,051	68,180	32

Source: authors' calculation based on field survey data 2021.

TABLE 6 Sensitivity analysis "Tiandougou-coura" (2017, 2018, and 2020).

Scenarios	Total revenue (CFA)	Total variable cost (CFA)	Net income (CFA)	Gross profit margin (percent)
0. Baseline (average values over 3 years)	186,875	141,801	45,073	24
1. Average farm total variable costs increased by 5 percent no change in yield	186,875	148,891	37,983	20
2. Average farm yield increased by 14 percent and total variable costs increased by 5 percent	213,262	148,891	64,371	30
3. Average farm yield decreased by 14 percent and total variable costs increased by 5 percent	160,882	148,891	11,991	7
4. Gate price increased by 5 percent keeping others constant	196,426	141,801	54,624	28
5. Gate price decreased by 5 percent keeping others constant	177,718	141,801	35,917	20

Source: authors' calculation based on field survey data 2021.

baseline) is recorded in scenario 2 (average farm adjusted yield increased by 35 percent, and total variable costs increased by 8 percent) with an average net income of 146,358 CFA/ha. On the contrary, a negative gross profit margin is recorded under scenario 3 with (−7 percent) largely explained by the high variation of the variety yield over the years (35 percent). In short, this sensitivity analysis should be a profitability guidance under the used fertiliser package, i.e., "100 kg complex cereal and 50 kg urea" in sorghum production system in Mali.

The baseline scenario in Table 6 indicated an average 24 percent gross profit margin with 45,073 CFA/ha average net income over the 3-year period. Moreover, under five sensitivity scenarios, "Tiandougou-coura" is still profitable under all the applied scenarios gross profit margins of 20 (for scenarios 1 and 5), 30, 7, and 28 percents for scenarios 2, 3, and 4, respectively. In addition, the highest gross profit margin of 30 percent is recorded in scenario 2 (average farm adjusted yield increased by 14 percent, and total variable costs increased by 5 percent). Hence, it can be concluded that the gross profit margin of "Tiandougou-coura" is smother than that of "Soubatimi" although the dominant ICRSVs. This might be explained by its low yield variation over years (14 percent). Shortly saying, this sensitivity analysis should be a profitability guidance under the above-used fertiliser package in sorghum production system in Mali.

The baseline scenario in Table 7 indicates the average net income loss of 10 percent with 12,113 CFA/ha over the 3-year study period. Moreover, under all the applied five sensitivity scenarios, the "Local" varieties led to a loss with negative gross profit margins of (−18, −12, −24, −5, and − 16 percents). In addition, the highest loss is recorded in scenario 3 (average farm adjusted yield decreased by 18 percent, and

TABLE 7 Sensitivity analysis "Local" (2017, 2018, and 2020).

Scenarios	Total revenue (CFA)	Total variable cost (CFA)	Net income (CFA)	Gross profit margin (percent)
0. Baseline (average values over 3 years)	120,750	132,863	−12,113	−10
1. Average farm total variable costs increased by 7 percent no change in yield	120,750	142,163	−21,413	−18
2. Average farm yield increased by 18 percent and total variable costs increased by 7 percent	126,619	142,163	−15,545	−12
3. Average farm yield decreased by 18 percent and total variable costs increased by 7 percent	114,560	142,163	−27,604	−24
4. Gate price increased by 5 percent keeping others constant	126,962	132,863	−5,901	−5
5. Gate price decreased by 5 percent keeping others constant	11,4870	132,863	−17,993	−16

Source: authors' calculation based on field survey data 2021.

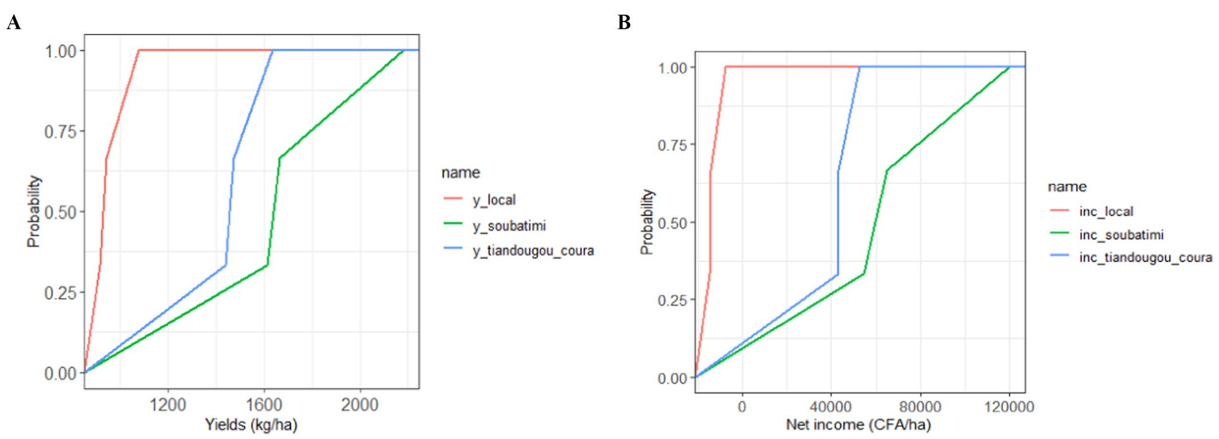

FIGURE 5
ECDF of sorghum average adjusted yields and average net incomes. **(A)** ECDF of average adjusted yields. **(B)** ECDF of average net incomes Source: authors from field survey data 2021.

total variable costs increased by 7 percent). This sensitivity analysis should be a guide in the sorghum production system given the above-used fertiliser package as well.

3.5 Stochastic dominance analysis

In this sub-section, the concept of Empirical Cumulative Distribution Function (ECDF) is used to assess the stochastic dominance between the ICRSVs and "Local" varieties. For the ECDF interpretation, the dominant variety is the one located on the right side of the others. The variety located on the left side is dominated by the right side ones (Hien et al., 1997). We present below the ECDF graphs of sorghum average adjusted yields and average net incomes, respectively, as key profitability indicators for variety ranking and risk analysis in Figures 5A,B respectively.

Figures 5A,B show the ECDF of the average adjusted grain yields and net incomes from ICRSVs compared to the "Local" varieties, respectively. The first-degree stochastic dominance was used for ranking the varieties. It implies that there is no cross-cutting point in the probability distribution. Otherwise, in the presence of cross-cutting point, the second-degree stochastic dominance is used for ranking the technologies (Hien et al., 1997). The present ECDF graphs indicate that "Soubatimi" is dominant over "Tiandougou-coura" and the "Local" varieties given the current probability distributions of the average adjusted grain yields and net incomes levels of "Soubatimi" lying on the right side of the others.

Admittedly, between the two ICRSVs, "Tiandougou-coura" is also dominated by "Soubatimi" given the current probability distributions of the average adjusted grain yields and net incomes of "Soubatimi" lying on the right side. Overall, "Soubatimi" is the dominant variety over "Tiandougou-coura" and the "Local" varieties. As a result, both ICRSVs are dominant over the "Local" varieties given the probability distributions considered in this analysis. In other words, this implies that the ICRSVs would be acceptable by risk-neutral and risk-averse individual sorghum farmers. This result is similar to that obtained by Hien et al. (1997) comparing the yield of four fertiliser treatments in Burkina Faso. To conclude, the first concern of sorghum farmers might be the higher yields to secure home consumption and generate marketable surplus for sale. The finding gives more insight in terms of grain yields and cash earnings when farmers are invited to choose amongst a set of proposed ICRSVs.

4 Conclusion and policy implications

In SSA, including Mali, research outcomes demonstrated the low adoption rate of improved agricultural technologies due to farmers' reluctance towards the released technologies. Financial profitability information can be useful to farmers at the early stage of dissemination process of the ICRSVs. This study performed a CBA using 3-year average yield data. Farm partial budget, sensitivity analysis, and stochastic dominance analysis methods were used to assess the financial profitability of two ICRSVs ("Soubatimi" and "Tiandougou-coura") compared to the "Local" varieties. The study unit was farmers' on-farm trial plots. A final sample of 31 plots cultivated under the fertiliser package of "100 kg complex cereal and 50 kg Urea" per hectare was held.

The farm partial budget analysis revealed that growing the ICRSVs was profitable with 34 percent and 24 percent gross profit margins, respectively. On the contrary, farmers' best "Local" varieties were not profitable with a 10 percent loss. The sensitivity analysis for testing the consistency showed that "Soubatimi" was still profitable (4/5) under a total of five applied scenarios. On the other hand, "Tiandougou-coura" was also profitable (5/5) under all applied scenarios. The stochastic dominance analysis for ranking the varieties and risk analysis revealed that "Soubatimi" is dominant over "Tiandougou-coura" and the "Local" varieties in terms of average adjusted yields and net incomes. This suggests that both ICRSVs would be accepted by risk-neutral farmers with relative preference for "Soubatimi" for those who prefer more to less, but a risk-averse farmer would probably choose "Tiandougou-coura" in which yield is relatively consistent, hence more robust in the sensitivity analysis results shown above.

First, the study suggests the scale up of the ICRSVs given their gross profit margins which might imply that farmers would be better off with their adoption in Mali. Second, the study suggests facilitating the implementation outreach programmes to inform smallholder sorghum farmers on the ICRSVs' traits and profitability information as decision support tool for a larger adoption. Finally, policymakers should reinforce the budding fodder market opportunity with value chain approach which in turn can undoubtedly improve the ICRSVs profitability for farmers. Beyond the country frontiers, these recommendations can be relevant policy to the widened SSA countries where sorghum represents the major staple cereal for food, nutrition, and income security for rural smallholder farmers.

As a limit, the study did not consider the fodder yields in the profitability due to the lack of appropriate fodder market, although the ICRSVs have high potential fodder yield for livestock feeding which has a high economic importance. Undoubtedly, accounting for this fodder monetisation would further increase the gross profit margins. So, any future research integrating the value of fodder in ICRSVs profitability would be more insightful.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written consent was obtained from the farmers leader and a verbal agreement was obtained from each farmer before the survey (FGDs and individuals) was taken up on the field.

Author contributions

AC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. FB: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. JY: Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing. BK: Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. BN: Funding acquisition, Project administration, Resources, Validation, Writing – review & editing. NW: Funding acquisition, Project administration, Resources, Writing – review & editing. MJ: Funding acquisition, Project administration, Resources, Writing – review & editing. KS: Supervision, Validation, Writing – review & editing.

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Conflict of interest

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

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2024.1477039/full#supplementary-material

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