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To cite this article: Philomena Chioma-Akalugo Ogwuike, Aminou Arouna & Clinton Obinna Ogwuike (2021): Assessment of rice threshing technology characteristics for enhanced rice sector development in Senegal, African Journal of Science, Technology, Innovation and Development, DOI: [10.1080/20421338.2021.1924424](https://doi.org/10.1080/20421338.2021.1924424)

To link to this article: <https://doi.org/10.1080/20421338.2021.1924424>



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Published online: 23 Jun 2021.



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Assessment of rice threshing technology characteristics for enhanced rice sector development in Senegal

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Understanding the technology characteristics desirable to farmers to increase the adoption of improved technologies remains a high-priority research issue in sub-Saharan Africa (SSA). The study aimed to quantify farmers' demand and assessment of the characteristics of rice threshing technologies to enhance the adoption of innovations in Senegal. A multistage sampling technique was used to collect primary data from 318 rice farmers in the Senegal River Valley. Three indexes (demand, supply and attainment) of technology characteristics were estimated to assess farmers' perceptions of the characteristics of three threshing techniques (traditional, ASI thresher and combine harvester-thresher). The results showed that of the eleven selected characteristics, time savings (0.95), labour savings (0.94) and grain quality (0.93) were farmers' key demand. The ASI thresher and combine harvester-thresher met farmers' needs well in terms of the attributes of grain quality and production capacity. However, users of the traditional technique reported low levels of perceived usefulness, and users of the combine harvester-thresher reported low levels of ease of use. Women labour usefulness is a trade-off for advancement in threshing technologies in pursuance of rice sector improvement, implying that efforts towards developing gender-friendly threshers are required. The variables estimated in this study offer policy considerations for development of the rice production system in Senegal. The originality of this paper is its use of a combination of take-the-best theory, the technology acceptance model and an indexing approach to reveal specific characteristics for the development of best-fit mechanization equipment, mainly improved threshers for rice sector development in SSA.

Keywords: adoption, indexing approach, mechanization, perception, rice threshers, specific characteristics

Introduction

High dependency on rice importation is a very contentious issue in sub-Saharan Africa (SSA). Despite progress in rice production in SSA, with a 108% increase between 2008 and 2018 (Arouna et al. 2021), domestic rice production satisfies only approximately 60% of consumption due to the triple effect of population growth, urbanization and changing consumer behaviour in the region. Among SSA countries, Senegal remains heavily dependent on rice importation. Domestic production represented only 32% of the consumption in 2018, and the country was ranked as the third largest importing country in West Africa, with an importation of 1.25 million tons of milled rice (USDA 2020). Senegal's self-sufficiency in rice requires local production to meet domestic needs in both quality and quantity, but this is fraught with various challenges. Among these challenges are finding solutions to the production of poor-quality local rice, post-harvest losses and increased production capacity for domestic rice commercial viability. High threshing losses have been recorded in many SSA countries, with 30–35% in Senegal (AfricaRice 2006; Azouma, Porosi, and Yamaguchi 2009; Rickman et al. 2013). Improving production, the use of proper postharvest technologies and improving market competitiveness are important considerations in dealing with the issues of national rice production in Senegal (Yemane 2014). The magnitude of postharvest losses in food value chains is increasingly being debated among food system analysts and policymakers, along

with the design of policies to try to reduce these losses (Minten, Tamru, and Reardon 2021). However, a significant number of rice farmers in the Senegal River Valley (SRV) thresh rice with manual techniques and have high postharvest losses despite the efforts of research and development agencies in rice system development that have introduced improved threshing technologies into the region. The two improved threshers available in the SRV are the ASI thresher (or ASI for short)¹ and combine harvester-thresher (or combine).

The major concern of the research and development agencies of the rice sector in Senegal and Africa more generally is how to enhance the adoption of improved technologies among smallholder farmers. This raises the need for research and development agents and policymakers to be able to identify the technology characteristics that drive the preferences of end users, who occupy a prominent node in the adoption decision process. Efforts to spur agricultural development have been met with continued low levels of adoption of improved technologies in SSA (Arouna et al. 2020). Therefore, understanding the technology-specific characteristics that would motivate farmers to embrace improved technologies remains a high-priority research issue. It is important to examine the actual desires of the farmers that drive their preferences for one thresher technology over another because, should the farmers fail to use the technology, the expected benefits would not be realized, and the efforts of mechanization would be

defeated. Moreover, technology adoption efforts may not succeed if the desires and expectations of the end-user farmers of the innovation are not known and accounted for in the development of the technologies. The factors required in the development of ideal mechanization equipment for smallholder farmers, especially threshing technology, have not yet been fully investigated in the literature. Against this backdrop, this study was conceptualized to quantify farmers' demand and assessment of the characteristics of the rice threshing technologies in use in the SRV. Specifically, this study quantified the levels of importance farmers placed on the specific technology characteristics, level of satisfaction, and expectations met. The study asked the following research questions: What technology-specific characteristics are of primary importance to rice farmers when selecting rice threshing technology? Which of the available technologies best meet the expectations of the farmers? The two null hypotheses tested in the study were as follows:

- (i) H_{01} : The rice farmers have no preference for the technology characteristics patterning to performance compared to those patterning to service delivery.
- (ii) H_{02} : None of the available threshing technologies meets the needs of rice farmers.

The contribution of this study to the literature is twofold. First, we use a combination of take-the-best (TTB) theory, the technology acceptance model (TAM) and an indexing approach to assess specific characteristics for the development of best-fit mechanization equipment, especially threshing technology. Many studies seeking to assess the adoption of mechanization equipment by smallholder farmers have focused on exogenous factors, such as economic and financial constraints (Berhane et al. 2017) or environmental factors (Daum et al. 2020). However, studies that assess the technology-specific characteristics demanded by end users are few. Second, studies on mechanization for smallholder farmers have focused on production equipment (Houssou and Chapoto 2015; Adu-Baffour, Daum, and Birner 2019; Kirui 2019; Mano, Takahashi, and Otsuka 2020). A recent review of mechanization in Africa focused only on mechanized crop production (Daum and Birner 2020). In contrast, this study is, to our knowledge, the first to analyze smallholder farmers' demand and assessment of postharvest equipment characteristics, especially regarding the ASI thresher. Overall, this paper reveals specific characteristics for the development of best-fit mechanization equipment (mainly improved threshers) for efficient postharvest handling, rice sector development and achievement of rice self-sufficiency in SSA. The next section of this paper presents a review of the relevant literature. The section thereafter presents the theoretical framework followed by the study methodology and the results and discussion sections, respectively. The final section focuses on the conclusions and recommendations.

Review of relevant literature

Rice threshing techniques in the Senegal River Valley

Recently, actors in rice sector development in the SRV have determinedly targeted developing appropriate

grain-threshing devices, threshing components and threshers. Ogwuike (2019) and Ogwuike, Ogwuike, and Arouna (2020) documented the detailed techniques of threshing rice in the SRV. There are three main techniques used for rice threshing in the SRV: traditional, ASI and combine.

Traditional manual threshing

Harvesting is done manually by cutting mature rice crops, which are tied in bundles and heaped together to dry before threshing. The threshing materials used may include a trunk of wood or metallic drum, a spread sheet of tapolene or cloths, tray pans and basins. During threshing, the trunk is laid on the spread sheet, and the dry straws tied in bundles (having been previously heaped to dry) are lifted and hit repeatedly (approximately 3 or 4 times) against the trunk to let loose the grain, which drops and gathers on the sheet for subsequent winnowing (Ogwuike, Ogwuike, and Arouna 2020). The trash comes out as a mixture of chaff, pebbles, stones and other debris. These factors result in great grain losses and much time spent cleaning, which increases the labour demand. AfricaRice (2006) estimated threshing losses of up to 35%. In addition, extra labour may be required for winnowing and sifting to recover lost grains. Farmers in Senegal consider manual rice threshing to be time-consuming and arduous (Donovan et al. 1998; AfricaRice 2006). In contrast, manual threshing is popular because of its low cost and is often used by women in rural areas to gain income. It is ideal for subsistence production and encourages the use of family labour, mostly appreciated by poor households. Manual beating produces hourly outputs of approximately 10–30 kg of grain (AfricaRice 2006). Khir et al. (2017) described manual threshing as being labour intensive and backbreaking, with poor threshing performance that causes grain losses and damage. The ease of use is limited due to the high labour demand, which may be difficult to meet during the peak harvest period. These undesirable attributes influence farmers' perception of manual techniques. Labour charges are approximately 10% of paddy output or its equivalent.

Improved threshers

The use of improved postharvest technology remains one of the proactive measures to graduate agricultural production from subsistence to commercial production (Azouma, Porosi, and Yamaguchi 2009; Lowder, Skoet, and Raney 2016). There are two improved threshers in use in the SRV: combine harvester-thresher and ASI thresher.

The combine harvester-thresher machine was introduced in Senegal from Asia. It integrates complete harvesting processes of cutting and gathering panicles or straws, threshes, and winnows, produces clean paddy and transports it to warehouses. Two types of combine harvesters in use in the SRV are small and large combines. The large combine has a high processing capacity (6.0–7.5 tons/hour) and threshing efficiency. It is highly sophisticated and requires a high initial cost of investment but

needs only three trained operators. The low labour demand implies that the preparation of paddy for sale can be done quickly, which may reduce postharvest losses. However, the large combine has the disadvantage that the grain sieve plate component does not suit the grain characteristics of the local rice, leading to significant grain loss and the need for second winnowing or sifting, and no solution to this has been developed yet. The large combine works efficiently on level, nonwaterlogged (not muddy) fields and may not be favourable for most rice fields in the SRV. Moreover, it breaks down often, and spare parts are not readily available. As a result, there are few operative large combines in the SRV, which hardly meet the demand of farmers. The harvesting and threshing services of this combine costs approximately 18–20% of paddy output or its monetary equivalent. A small combine can harvest and thresh approximately 3.0–4.0 tons/hour (Rickman et al. 2013). It works like a large combine, but it is less bulky, cheaper and easier to manage. Local manufacturers attempt to build small combines. However, the machine needs a skilled operator, and essential parts are still imported.

The ASI thresher (see Appendix Plate 1) is a project of national interest in Senegal. This technology was introduced into Senegal from the Philippines to purposely substitute for manual rice threshing, curb the burden of threshing drudgery, and improve yield, production capacity and grain quality to enhance the commercialization of rice. The name ASI is an acronym for AfricaRice, SAED (the Senegal Extension Authority for the Development of the Senegalese River Valley) and ISRA (the Senegalese National Agricultural Research Institute). Ogwuike, Ogwuike, and Arouna (2020) has provided a detailed literature on ASI thresher. The ASI thresher has spread across all rice-producing regions of Senegal and remarkably transformed Senegal's rice sector. The ASI has also diffused to various African countries (Mauritania, Nigeria, Burkina Faso, Benin, Uganda, and Mali) and has been modified in Cameroon, Chad and Nigeria to process other crops (e.g., corn, soybeans, guinea corn, and millet). Certain parts and the engine of ASI are imported, but they can be manufactured locally from available recyclable materials. The plate sieve of the ASI is modified to control grain loss (Mohapatra 2012). The technology is portable, and it can be coupled and trailed or carried in vans to farms in remote and muddy fields. There were over 320 functional ASIs in the SRV during the period of this survey (June 2016), and they covered approximately 30,000–35,000 ha of rice area. The ASI possesses high technical performance and financial profitability. With an average of 6 persons, the ASI can thresh harvested panicles with a capacity of approximately 6–7 tons of paddy per day (Azouma, Porosi, and Yamaguchi 2009; Diagne, Diagne, and Demont 2011). Straw losses are minimal at 1–2% of total output. The ASI charges 5–10% of the paddy or its value for threshing. With an average purchase price of 2.8 million FCFA (US\$5000), ASIs are generally bought by farmers' associations and rich farmers (Mohapatra 2012). Unlike combines, the ASI is effective for threshing rice from waterlogged fields since rice crops are harvested manually.

Technology assessment and factors affecting technology adoption

Producing quality rice and improving paddy yield (productivity) are linked to technology performance and are complicated processes requiring technological innovation. Each technology possesses a set of characteristics that may (or may not) favour its adoption. The quality of produced grain (output factors), resource use efficiency and technology characteristics determine the preference of one technology over another (Sall, Norman, and Featherstream 2000). Studies have found that the adoption of mechanization equipment by smallholder farmers is determined by factors such as economic and financial constraints (Berhane et al. 2017; Daum et al. 2020). Rice farmers exposed to diverse threshing techniques actively seek technology that meet their preferred criteria. Abdul and Salin (2005) reported that farmers preferred the modified pedal thresher to the unmodified model because it does not break the straw, which farmers use to roof houses. Sall, Norman, and Featherstream (2000) described technology in terms of embedded characteristics. The authors' analysis included some social environmental factors not directly embedded in the technology but strictly based on farmers' perceptions.

Theoretical framework

Technology acceptance model (TAM)

This study adopted the technology acceptance model (TAM) (Venkatesh and Davis 2000) to explain and predict the behavioural intentions of individual rice farmers towards the usage of the rice thresher technologies. TAM theorizes that a farmer's behavioural intention to use a thresher is determined by two beliefs: perceived usefulness and perceived ease of use. Perceived usefulness refers to the extent to which a farmer believes that using a specific thresher will enhance his/her production performance. Rice farmers' production performance may be measured in terms of output, resource use, social and environmental factors, and machine-specific characteristics. On the other hand, the perceived ease of use of a thresher refers to the extent to which a farmer believes that using a specific thresher will be free of effort. This defines the service delivery terms of a thresher, which in this study include the variables of accessibility, affordability and availability and which intrinsically determine the effort a farmer must make to obtain the service of any thresher technology.

In practice, a farmer in the SRV hires a service provider, who brings the ASI or combine to thresh the rice. Normally, the service provider charges processing tolls. The ease of use of the technology therefore directly relates to how affordable the farmer considers the terms of the service agreement to be. However, the ease of usage may be implicated in a situation where threshers are in short supply or where there are large number of farmers queuing up for turns to have their rice threshed (availability). Specifically, in the case of a large combine, the ease of use is complicated, as a large combine operates with extreme difficulty in muddy, unleveled or waterlogged rice fields. The ASI, on the one hand, may have the problem of portability because it

cannot travel very long distances and thus requires transport in vans. The ease of use depends on the level of difficulty a farmer ascribes to these and other related factors.

The TAM theorizes that the effects of external influence on the intention to use a thresher are mediated by perceived usefulness and perceived ease of use (Figure 1). In the context of this study, this theory implies that the introduction of the ASI into Senegal by development agencies would be meaningless if the farmers did not perceive the ASI to be useful and/or the services it renders easy to acquire – implying that farmers, as end users, have the major role to play in the process of ASI technology acceptance or adoption. This theory therefore supports assessing technology characteristics for adoption through the lens of the end users.

Take-the-best (TTB) theory

Linking technological characteristics and consumer behaviour in the adoption decision process is important for technology development, adoption and diffusion. The rice farmers’ preference behaviour for one technology over the others is captured, in this study, by the characteristics demand theory developed by Kelvin Lancaster (Lancaster 1966), which argues that the utility consumers derive is not from the available alternative technologies but from the characteristics of the component goods. The theory seeks to address the classic consumer’s problem of how consumers derive satisfaction from a technology. This theory shows that under certain assumptions, goods can be reduced to bundles of attributes or characteristics. The consumer’s problem can be transformed into an equivalent problem, in which he/she maximizes his/her utility over attributes, subject to a budget constraint for effective prices of those attributes. This therefore solves the substitute’s problem, making it possible to reasonably measure how similar the characteristics of two different technologies are.

TTB theory, derived from characteristics demand theory, was found to be useful in modelling consumers’ dealing with trade-offs in the evaluation of industries and varietal technologies (Caliari, Marco, and Ricardo 2017). More often, the development of machine innovation is viewed through the lenses of technology-producing firms that deal with supply terms and hardly through the viewpoint of the consumer of the service of the

technology (demand factors). In a few cases, innovation determinants have been viewed through the demand side or lenses of consumers (Pick et al. 1994; Sall, Norman, and Featherstream 2000). Accordingly, we maintain that end users of the services of the thresher technologies have the relevant information required in the assessment of the threshers. Farmers who demand the service of technologies seek information about the technology characteristics. Therefore, in this study model, demand variables include the factors that rice farmers consider important in choosing technologies and that essentially drive their demand for the service of the specific technology.

TTB theory suggests the use of technology characteristics that farmers consider important and desirable and information on technology performance in determining factors that drive supply because they influence the preference of one technology over another (Caliari, Marco, and Ricardo 2017). Here, performance refers to the level of satisfaction farmers derive from the characteristics embedded in the technology. The linkages between demand and supply factors are central in the innovative technology process and substantiated in the visible interaction between rice farmers and service providers. The indexing model in Sall, Norman, and Featherstream (2000) and the TTB model were used in this study to analyze the linkages between demand and supply factors to explain the adoption of thresher techniques in the SRV.

Methodology

Study area

This study was conducted in the departments of Dagana and Podor in Senegal. These departments belong to the SRV, which represents approximately 60% of Senegalese rice production (USDA 2018). The Senegal rice belt extends principally across the SRV, where producers are smallholder farmers. The Senegal River is the second longest river (1800 km) in West Africa. Rainfall occurs from April to October, with river flooding between July and October. In total, 30% of Senegalese national rice production are from rained production system, and 70% are irrigated production system. Rice farmers in the departments of Dagana and Podor practice irrigated production systems (Tanaka, Diagne, and Saito 2015). Many irrigation infrastructures were developed in the SRV, including

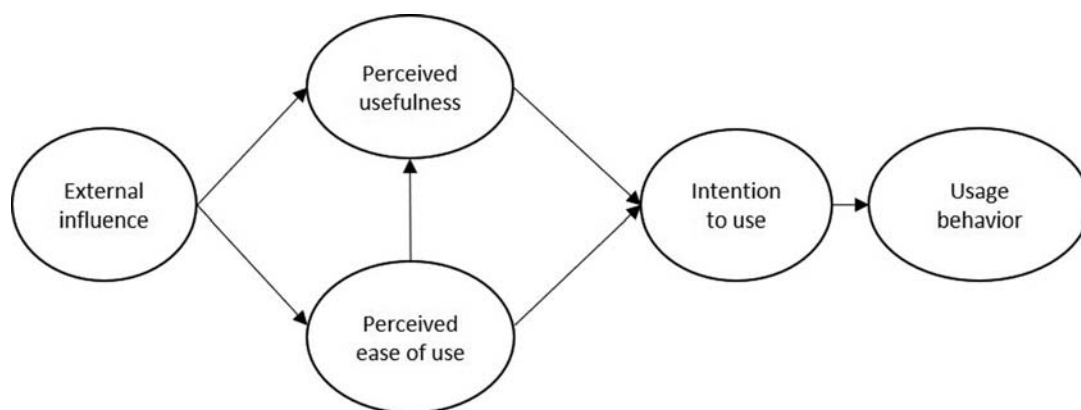


Figure 1: Technology acceptance model. Source: Venkatesh and Davis (2000)

large-scale irrigation schemes developed by the central government and village irrigation schemes (*Périmètre Irrigué Villageois*) developed by the SAED. The irrigated area for rice production is 63,900 ha (43,200 ha for Dagana and 20,700 ha for Podor). This points out the readiness of the Senegalese government to intensify rice production. Senegal has two rice production seasons: the dry season (February/March-May/June) and the rainy season (June/July–November/December). There are more attacks by pests and wildlife (such as red-billed quele, a granivorous bird) during the dry season.

Data collection

The data used in this analysis were primary data collected through a field survey conducted in July/August 2016 in the SRV. In total, 318 irrigated rice farmers were surveyed from the departments of Dagana and Podor in the SRV, where different threshing technologies are used for intensive rice production activities. The respondents were selected using multistage sampling techniques and interviewed with the aid of structured questionnaires. Data were collected on the farmers’ perceptions of the specific attributes of the technology they used over the years 2012–2015. To do so, some technology attributes were applied for the three technology alternatives (traditional, ASI thresher and combine harvester-thresher). Each respondent was asked to provide information on two levels: (i) the general level – the level of importance the farmer attributed to the characteristics of the three technologies and the satisfaction derived irrespective of the type or combination of technology used. The intention was to capture the perception of a typical farmer randomly drawn from the population of farmers. (ii) Specific Level – each farmer was required to provide similar information on the technology he/she was currently using. For the survey, we interviewed members of farming households who understood the threshing business.

Data analysis

Technology attributes or characteristics play an important role in the adoption process. The indexing model developed by Reed, Binks, and Ennew (1991) and applied by Sall, Norman, and Featherstream (2000) was used to

assess the degree to which specific technology attributes meet farmers’ preferences. In the process, the farmers judged each attribute along two scales: (1) the importance of the attribute, ranked in three levels (very important=3, important=2 or not so important=1); and (2) satisfaction with the technology according to the attribute, ranked in three levels (high=3, moderate=2 or low=1). Let N represent the number of respondents in the survey with the response matrix, as shown in Table 1. The matrix, n_{ij} , represents the number of farmers who rated a characteristic based on its importance, i , and their satisfaction with attribute j . For example, n_{31} stands for the number of respondents who ranked an attribute as ‘very important’ and the quality of the characteristic as ‘low satisfaction’.

To estimate the index and meet inequality conditions, Sall, Norman, and Featherstream (2000) propose a weighting matrix (Table 2). The last column presents the supply weights (s_i), which are the weights of the rating of the farmers on the degree to which a specific attribute is exhibited in a technology. d_j in the bottom row represents the weight of the degree of importance of an attribute. With the weights, the value in each cell is derived as follows:

$$w_{ij} = s_i d_j \tag{1}$$

A number of conditions must hold for s_j , d_i and w_{ij} (see details in Sall, Norman, and Featherstream 2000). Three indexes (demand D, supply S and attainment W) for each technology characteristic are constructed using the response matrices and the weights in Tables 1 and 2, respectively. The demand index D measures the level of importance that farmers attach to a particular characteristic. The demand index D is expressed as follows:

$$D = \frac{1}{d_1 N} \sum_{j=1}^3 d_j c_j \tag{2}$$

The demand index D ranges from >0 to 1. In the case where all farmers rated a particular attribute as being very important, the value of D is 1. The minimum value of D,

Table 1: Table of two scales judging the attributes of technology.

	Very important	Important	Not so important	Row total*
High satisfaction	n_{11}	n_{12}	n_{13}	r_1
Moderate satisfaction	n_{21}	n_{22}	n_{23}	r_2
Low satisfaction	n_{31}	n_{32}	n_{33}	r_3
Column total (c_i)**	c_1	c_2	c_3	N

Note: * $r_1 = n_{11} + n_{12} + n_{13}$; ** $c_1 = n_{11} + n_{21} + n_{31}$

Table 2: Weighting matrix.

	Very important	Important	Not very important	Supply weights
High	w_{11}	w_{12}	w_{13}	s_1
Moderate	w_{21}	w_{22}	w_{23}	s_2
Low	w_{31}	w_{32}	w_{33}	s_3
Demand weights	d_1	d_2	d_3	

$s_1 = w_{11} + w_{12} + w_{13}$; $d_1 = w_{11} + w_{21} + w_{31}$

which arises when all respondents indicate that the attribute is not so important, is positive and expressed as $d_3/d_1 > 0$. This can be easily demonstrated from equation 2.

Supply index S captures the level of satisfaction farmers derive from a specific characteristic of a threshing technology. It is given by:

$$S = \frac{1}{s_1N} \sum_{i=1}^3 s_i r_i \tag{3}$$

The maximum value of S is 1 and implies that all farmers rated the derived satisfaction on a particular attribute at a high level. The minimum value is negative and expressed as $s_3/s_1 < 0$, indicating that all the farmers indicate low satisfaction.

The attainment index W matches the farmers' rating of the importance of a particular characteristic with their level of satisfaction with a particular technology's performance regarding that characteristic. The attainment index W is expressed as follows:

$$W = \frac{1}{w_{11}N} \sum_{j=1}^3 \sum_{i=1}^3 w_{ij} n_{ij} \tag{4}$$

The maximum value of W is 1, which is reached when all the farmers indicate that a particular characteristic is very important and that they are very satisfied with the technology's related performance. The minimum value of W is negative and expressed as $s_3/s_1 < 0$.

The technologies evaluated included the traditional technology, ASI and combine, the three threshing techniques commonly in use in the SRV at the time of data collection. The two sets of weights chosen following the conditions defined in Sall, Norman, and Featherstream (2000) were $s_j = (5, 10, -4)$ and $d_i = (10, 7, 4)$. Based on key informants and a group discussion, eleven characteristics were selected to assess the rice farmers' perception of the threshing techniques in the SRV (Table 3). Following the TAM described in the theoretical framework, the characteristics were grouped into four categories: (i) output quality (grain recovery rate, grain purity and grain quality), resource use (female labour use rate and cost effectiveness), technical characteristics (time savings, labour savings and processing capacity) and

service delivery (accessibility, availability and affordability). In the output quality, the grain recovery rate measures the proportion of rice grain loss that is likely to occur when a specific technology is used; the grain purity refers to the absence of chaff, animal droppings, pebbles, sand or other objects; and the grain quality assesses the proportion of broken grain produced and the absence of colour or odour. Table 3 also presents the hypothesized satisfaction with the threshing technologies available in the SRV.

Results and discussion

Descriptive statistics of rice farming households in the SRV

The data used in the analysis were provided by 318 respondent farmers, of whom 53.6% (171 farmers) threshed rice with the ASI, 31.7% (101) used the combine and 43.9% (140) adopted manual threshing techniques in 2016. The mean age of the farmers was 46 years. On average, farmers had used threshing techniques for 23 years and had 3 years of formal education. This implies that the perceptions of the farmers provided in this study were informed not by a mere comprehension of theories, concepts or principles but by their actual impressions and personal experiences from long engagement in threshing activities. The distribution according to the sex of household heads showed that only 15% of household heads were female, indicating that the decisions of male farmers are central in explaining technology adoption behaviour. The farmers had an average farm size of 2.5 ha, which can increase with the use of improved and productivity-enhancing threshers. The results showed that manual thresher users allocated 48.01 h/ha, while the adopters of improved threshers spent 5.51 h/ha; the two groups produced paddy amounting to 4.56 and 5.82 tons/ha and leading to average annual rice incomes of 219,060 FCFA and 1,961,505 FCFA, respectively.

Aggregated demand, supply and attainment indexes of attributes

Table 4 showed the results of the assessment of the aggregated demand, supply and attainment indexes of the characteristics of the threshing technique by rice farmers irrespective of the technology use category. The robustness of index values was verified and confirmed as in

Table 3: Technology attributes or characteristics evaluated.

Group of characteristics	Selected attributes	Hypothesized satisfaction with technologies
1. Output quality	Grain recovery rate	Preference for the ASI because the sieve plate is modified to address this problem
	Grain purity	Preference for the combine harvester because rice crop is harvested and threshed directly without exposure to human or animal (e.g., rodents) encroachments
2. Resource use	Grain quality	Similarly favourable for the improved technologies
	Female labour use rate	Preference for the manual thresher
	Cost effectiveness	Preference for the manual thresher, similar for the improved technologies
3. Technical characteristics	Time saving, labour saving, processing capacity	Preference for the improved technologies
4. Service delivery	Accessibility, availability, affordability	Preference for manual and ASI

Table 4: Farmers' demand indexes for the rice threshing technologies' characteristics.

Characteristics (1)	Demand index (2)	Supply index (3)	Attainment index (4)
Time saving	0.95	0.57	0.54
Labour saving	0.94	0.61	0.56
Grain quality	0.93	0.90	0.85
Grain purity	0.93	0.73	0.67
Grain recovery rate	0.91	0.73	0.67
Availability	0.91	0.69	0.63
Affordability	0.89	0.71	0.64
Cost effectiveness	0.88	0.71	0.64
Processing capacity	0.87	0.79	0.70
Accessibility	0.88	0.69	0.62
Female labour use rate	0.80	0.54	0.52

Sall, Norman, and Featherstream (2000). The rankings are in line with the hypotheses in Table 3. The demand indexes (Column 2) showed that the farmers perceived all the characteristics evaluated in this study as important. However, the perceived usefulness of characteristics such as time savings (0.95), labour savings (0.94), grain quality (0.93), grain purity (0.93) and grain recovery rate (0.91) had higher demand indexes than perceived ease of use characteristics, including availability (0.91), affordability (0.89), accessibility (0.88) and female labour use rate (0.80). Based on this finding, the rice farmers' demands were higher for the technology characteristics regarding performance than for the characteristics regarding ease of use. In other words, the high demand index values implied that farmers attached greater importance to characteristics of technology performance than to those of service delivery, confirming that the farmers desire technologies that enhance the commercialization of rice. Column 3 presents the supply indexes representing the overall levels of satisfaction that the farmers derived on each characteristic, disregarding the technology used. These characteristics were in the following (descending) order: grain quality, processing capacity, grain purity, grain recovery rate, affordability, cost effectiveness, availability, accessibility, labour savings, time savings, and female labour use rate. The maximum supply index value was 0.90 for grain quality, implying that up to 90% of the farmers perceived that the supply of the grain quality attribute was high. This high estimated supply index implied that with the prevalent thresher technologies in use, rice grain quality is no longer among the predominant delimiting factors in rice commercialization in the SRV. Over 70% of the farmers reported high satisfaction with the attributes of processing capacity (0.79), grain purity (0.73), grain recovery rate (0.73), affordability (0.71) and cost effectiveness (0.71). Farmers reported moderate levels of satisfaction with availability and accessibility (0.69 each) and labour savings (0.61). The lowest satisfaction was expressed regarding the attributes of time saving (0.57) and female labour use rate (0.54). The low rate of female labour use is in line with the results of Eerdewijk and Danielsen (2015), who found that women are constrained by the introduction of workload-reducing mechanization solutions. In contrast, Baudron et al. (2019) found that mechanized land preparation benefited both men and women and that it also reduced the need for weeding, a laborious task often

carried out by women. Indeed, new technologies target different crops and tasks, thereby influencing men and women differently (Doss 2001). Therefore, women's labour usefulness should be a trade-off for advancement in threshing technology development.

The distribution of the attainment index values (column 4) showed a consistent pattern with that of the supply index but not the demand index. Grain quality consistently had the maximum attainment index value (0.85), implying that up to 85% of the farmers perceived that grain quality was highly important and that the technology supplied this aspect. Other attributes with their index values were processing capacity (0.70), grain purity and grain recovery rate (0.67 each), affordability and cost effectiveness (0.64 each), availability (0.63), accessibility (0.63), labour savings (0.56), time savings (0.54) and female labour use rate (0.52). The high attainment index value for processing capacity implies that the available rice thresher techniques in the SRV met all farmers' processing needs for both subsistence and commercialization purposes. Overall, the farmers' expectations were poorly met in the attributes of time savings, labour savings and female labour use rate. However, the aggregated supply and attainment indexes should be interpreted with caution. The disaggregated indexes in the next section clearly indicated the level of farmers' satisfaction *vis-a-vis* the characteristics of each threshing technology.

Disaggregated supply index according to threshing technologies

The supply index was disaggregated according to technologies to show the levels of satisfaction farmers derived from the characteristics of each threshing technology (Table 5). The attributes conformed with the *a priori* expectations (Table 3). Users of the traditional technology (Column 2) favoured it from the service perspective and considered it to partly meet the needs of resource use factors but found it to be deficient in terms of output and technical characteristics. In terms of service delivery, the traditional technology supplied the best accessibility (0.81), affordability (0.72) and availability (0.70). The users specifically perceived the need to improve the supply of the attributes of grain quality (0.61), processing capacity (0.59) and cost effectiveness (0.55), which were in moderate supply. The supply of grain purity attributes (0.48) was low, and the supply of the grain recovery rate (0.36), labour supply (0.12) and time savings

Table 5: Disaggregated supply index according to threshing technologies.

Characteristics	Manual threshing	ASI thresher	Combine harvester-thresher
Accessibility	0.87	0.86	0.27
Female labour use rate	0.81	0.57	0.08
Affordability	0.72	0.77	0.40
Availability	0.70	0.86	0.04
Grain quality	0.61	0.84	0.91
Processing capacity	0.59	0.80	0.89
Cost effectiveness	0.55	0.77	0.79
Grain purity	0.48	0.86	0.79
Grain recovery rate	0.36	0.87	0.82
Labour saving	0.12	0.88	0.94
Time saving	-0.02	0.87	0.97

(-0.02) remained critically low, indicating that these aspects represented a burden to the rice farmers. The low rates of grain purity attributes and grain recovery rates confirm the results of Rickman et al. (2013) that traditional threshing is associated with high quantitative and qualitative losses estimated at 30–35%. The negative index in the attribute of time saving implied that all the users of traditional technology indicated that the supply of the attribute was low. These findings vividly confirmed that the traditional technique was not appropriate for commercial rice production if farmers hoped to expand production and engage in off-season production. Comparing between improved technologies (Columns 3 and 4), ASI technology users were better served than combine harvester-thresher users in terms of service delivery, with the results showing high accessibility (0.86 > 0.27), availability (0.86 > 0.04) and affordability (0.77 > 0.40). On the other hand, combine users were better supplied in terms of grain quality (0.91 > 0.84), time savings (0.97 > 0.87), labour savings (0.94 > 0.88) and processing capacity (0.89 > 0.80). The grain quality result confirms the findings of Berhane et al. (2017) that the combine was associated with higher yields, likely due to lower postharvest losses. In these aspects, the combine was found to be more sophisticated and to have higher commercial capability than the ASI.

Attainment index of threshing technologies

An attainment index, measuring the extent to which users' needs are met, was estimated for each threshing technology (Table 6). The needs of the users of traditional technology were well met only in terms of female labour use rate and accessibility but were only moderately met

regarding the characteristics of grain quality, affordability and availability. The needs regarding the attributes of grain recovery rate, grain purity, and time- and labour-savings were poorly met. The respondents unanimously indicated that the characteristic of time saving was completely lacking. The disaggregated index values showed a discrepancy between the ASI and the combine in the levels of importance the farmers attached to the characteristics of the female labour use rate and service delivery factors (accessibility, availability and affordability). For instance, the needs regarding the characteristics of the female labour use rate were moderately met by the ASI (0.40) but poorly met by the combine (0.15). However, the needs were well met for the two improved technologies in terms of labour savings, time savings, cost effectiveness, processing capacity and grain quality. The users of the combine showed high satisfaction with its technical characteristics, but the level of service delivery was critically poor, as shown in the very low values of the service indexes (0.27 for accessibility; 0.35 for affordability and only 0.04 for availability). This is in line with Rickman et al. (2013), who showed that combines often break down and can only enter fields when the soil is dry. Such situations cause delays in harvesting, increase the risk of shattering and bird damage and reduce the adoption of combine harvesters. Therefore, an adaptation of the ASI thresher to meet the demands found in this study may help increase the mechanization of rice production by smallholder farmers.

Conclusion and recommendations

This study used an indexed model to measure the level of satisfaction of users with the characteristics of rice

Table 6: Disaggregated attainment index according to threshing technologies.

Characteristics	Manual threshing	ASI thresher	Combine harvester-thresher
Female labour use rate	0.80	0.40	0.15
Accessibility	0.80	0.70	0.27
Grain quality	0.63	0.83	0.89
Affordability	0.62	0.70	0.35
Availability	0.60	0.73	0.04
Processing capacity	0.54	0.77	0.83
Cost effectiveness	0.50	0.76	0.76
Grain recovery rate	0.35	0.79	0.77
Grain purity	0.35	0.79	0.76
Labour saving	0.11	0.80	0.93
Time saving	-0.03	0.82	0.94

thresher technologies to enhance the adoption of innovations to support the self-sufficiency of domestic rice production in Senegal. The results show that the innovative factors required for an ideal rice thresher technology have not yet been conclusively developed. The specific technology characteristics that were of primary importance to the rice farmers when selecting rice threshers were output quality factors, which define the perceived usefulness of the technology. The time factor was a heavy burden for users of traditional technology. The ASI thresher is the technology that best meets the needs of the farmers. Users of the combine harvester-thresher desired improved service delivery. Women's labour usefulness is a trade-off for advancement in threshing technologies towards rice commercialization in Senegal. This study therefore recommends efforts towards developing gender-friendly threshers. The attributes analyzed in this study can support technical and policy considerations for all actors seeking the development of the rice sector in Senegal.

Acknowledgments

This paper is based on the PhD thesis of the lead author at the Department of Agricultural Economics and Farm Management, Federal University of Agriculture Abeokuta in Nigeria (Ogwuike 2019). The authors would like to thank the CGIAR Research Program on Rice Agri-Food Systems (RICE) and the African Development Bank (AfDB) project 'Support to Agricultural Research for Development of Strategic Crops in Africa' (#2100155022217) for providing financial support for data collection. The authors are also grateful to the Africa Rice Center (AfricaRice) and the Department of Agricultural Economics and Farm Management at the Federal University of Agriculture Abeokuta. Finally, the authors thank Dr. Jean Moreira, Aristide Akpa, Wilfried Yergo, Maimouna Ndour and Rico Amoussouhoui for their various contributions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Note

1. ASI is an acronym for AfricaRice, SAED (the Senegal Extension Authority for the Development of Senegalese River Valley) and ISRA (the Senegalese National Agricultural Research Institute).

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Appendix: Improved thresher technologies



Plate 1: ASI Thresher