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Identification of socio-economic characteristics and farmers' practices affecting rice (*Oryza* spp.) yields in Benin (West Africa)

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Abstract

Rice (*Oryza* spp.) is one of the major staple foods in Benin. Benin has increased rice production through the expansion of cultivation area rather than increasing rice yields. To better understand the factors affecting rice yields, a thorough understanding of the current rice production system characteristics and constraints is required. The present study identifies socio-economic characteristics and farmers' practices affecting rice yields and suggests improved cultivation practices in the sector. Data were collected through semi-structured interviews, including socio-economic characteristics and rice cultivation practices from 230 randomly selected rice producers in North and Central Benin. Descriptive statistics and cluster analysis were used to group rice producers into different groups. Findings revealed that the proportion of rice producers having access to credit was low (33.5 %). Out of seventeen variables, only three (lowland rice cultivation, irrigated rice cultivation and total land cultivated area) discriminated best the rice producers in three (03) clusters with distinct characteristics in terms of socio-economics factors and cropping practices affecting rice yields. Most respondents (more than 70 %) did not practice crop rotation or fallow. This, together with low levels of chemical fertiliser applications and type of rice cultivation, explains poor rice production in particular in clusters 1 and 2. Yield enhancement is possible through the combination of lowland and irrigated cultivation performed by farmers in cluster 3 with the highest mean rice yield (3.8 t ha^{-1}). We suggest tackling the specific characteristics and needs of rice producers would more adequately help to improve rice yields. Interventions to enhance rice yields include training on best rice production practices, provision of input subsidies and access to irrigation tailored to the specific constraints and needs of each rice grower type. Finally, enabling access to credit will improve productivity of rice farmers in Benin.

Keywords: crop rotation, irrigation, mineral fertilisers, rice cultivation, smallholders

1 Introduction

Rice (*Oryza* spp.) is one of the most common staple foods in Benin. Its consumption is estimated at 55 kg per capita per year (Soullier *et al.*, 2020). However, in 2015, national rice production only reached 25 % of the country's demand (Demont *et al.*, 2017; MAEP, 2017; FAO, 2019). Loko *et al.* (2022) found that smallholder rice yields in Benin are low and highly variable (1.6–2.1 t ha^{-1}). Benin has increased rice production by expanding cultivated areas rather than increasing rice yields (MAEP, 2017; Nonvide, 2020; Arouna *et al.*, 2021; Loko *et al.*, 2022). From 2012 to 2018, the rice growth rate declined by 1.64 per cent mainly due to poor access to improved seeds, inadequate knowledge of water resources management, poor access to production inputs (herbicides, fertilisers, etc.), flooding fields, poor access to agricultural information, and inability of the policy and government subsidies to sustain rice production (Nonvide *et al.*, 2018; Arouna *et al.*, 2021). The country thus remains a net

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rice importer, and the rice deficit has continuously increased since 2013 (FAO, 2019).

Akpoti *et al.* (2020) estimated that the use of 60 % of the suitable inland valley areas (351,000–406,000 ha) available in Benin is needed to attain self-sufficiency in rice. The best strategy to reduce the gap between rice supply and demand is to increase rice yields (MAEP, 2017; Arouna *et al.*, 2021). A number of technologies have been identified with the potential to increase rice yields. They include high-yielding rice varieties, enhancing nutrient and water availability and efficient agronomic management techniques (Adekambi *et al.*, 2009; Nguezet *et al.*, 2011; Anang *et al.*, 2016; Nonvide *et al.*, 2018; Codjo *et al.*, 2019; Akpoti *et al.*, 2020; Nonvide, 2020; Nonvide, 2021; Rahman & Connor, 2022). Earlier studies indicated that rice yield growth, in Benin (Adekambi *et al.*, 2009; Nonvide *et al.*, 2018), Nigeria (Nguezet *et al.*, 2011), Indonesia (Sparta *et al.*, 2020) and Bangladesh (Rahman & Connor, 2022), contributed to reducing hunger and poverty and improving food security. Several studies have revealed some biophysical constraints to rice production. These constraints include irregular and reduced rainfall, heat, drought, flood, soil erosion, low soil fertility, pests and diseases and weed infestation (Totin *et al.*, 2013; Adégbola *et al.*, 2016; Atidegla *et al.*, 2017; MCVDD, 2019; Wabi *et al.*, 2021). Climate change is expected to worsen these constraints and affect rice yields. Benin faces other constraints to rice production, including high labour, limited access to land, high input costs (e.g., fertilisers, pesticides, herbicides), limited access to credit and poor mechanisation (MAEP, 2017; Olounlade *et al.*, 2018; Nonvide *et al.*, 2018; Dossou *et al.*, 2020; Arouna *et al.*, 2021).

The rice development goal in Benin was to reach 600,000 t of paddy by 2015 (Nonvide *et al.*, 2018) to be self-sufficient in production by 2021 (MAEP, 2017). By 2021, rice yield should attain 5 t ha^{-1} (MAEP, 2017). To boost rice production, a second phase of the National Rice Development Strategies (NRDS) plan was developed in 2019 (CARD, 2021). The NRDS is a policy document for achieving the rice development goal in Benin. The main goal of the NRDS was to respond to different constraints and challenges in the rice sector, including the lack of irrigation schemes, difficulties in water management practices, the lack of production inputs (e.g., herbicides and fertilisers, etc.) and the lack of access and availability of quality seeds. As a result, NRDS predominantly focused on improving technical factors and significant increases in farm inputs to increase rice productivity at the national level. However, despite these efforts, Beninese rice production is still characterised by low production volumes that were estimated at only 274,523 t of paddy rice with a yield of 3.9 t ha^{-1} in 2020 (MAEP, 2017; Loko *et al.*, 2022; FAO, 2022), far below the target of 5 t ha^{-1} and reflecting the limited uptake of practices promoted by the NRDS. Farmers' socio-economic characteristics (access to credit, education, frequency of extension visits, etc.) and cropping practices (rice varieties, fertilisers use, etc.) were identified as some of the major factors that influence rice productivity in Benin (Atidegla *et al.*, 2017; Zannou *et al.*, 2018; Dossou *et al.*, 2020; Loko *et al.*, 2022). Hence, to increase rice productivity in the country, a thorough understanding of the current rice production system characteristics and constraints is required. Farmers are vital sources of information and key stakeholders in agricultural research (January *et al.*, 2018; Nonvide, 2020). Therefore, they should be involved from the beginning, in agricultural research and development policies (January *et al.*, 2018).

Lewis *et al.* (2018) highlight that smallholder farmers in Africa share certain characteristics such as limited access to land and financial capital, high levels of vulnerability and low market participation. However, not all smallholders are equally resource-poor and market-restricted or have limited access to land (Lopez-Ridaura *et al.*, 2018). In Benin, for instance, smallholder farmers grow rice in diverse farming systems that are characterised by a wide variation in social, ecological and economic conditions (SNDR, 2011; Totin *et al.*, 2013; MAEP, 2017; Dossou *et al.*, 2020; Loko *et al.*, 2022). Therefore, any initiative for smallholder rice sector development has to account for this heterogeneity. Farm typology can help group smallholder farmers into homogenous groups based on specific criteria (e.g., resources endowment, livelihood activities, agricultural management practices and constraints) (Lopez-Ridaura *et al.*, 2018) to identify the diversity of farming systems and to tailor rice productivity interventions to the specific needs and opportunities of the rice farmer.

Several studies have focused on various biophysical and technological aspects of the Beninese rice sector in Benin (Totin *et al.*, 2013; Adégbola *et al.*, 2016; Atidegla *et al.*, 2017; Nonvide *et al.*, 2018; Dossou *et al.*, 2020; Wabi *et al.*, 2021). They include the adoption of improved rice varieties, determination of appropriate rice sowing dates, water management, soil fertility management, access to credit and adaptation to climate change. However, few studies analyzed farmers' practices and farm-related characteristics affecting rice production in Benin. Nonvide (2020) identified socio-economic variables such as education, access to credit, frequency of extension visits, fertilisers use, market participation, off-farm activities, access to media and perception of soil fertility as the factors that influence the adoption of improved rice varieties in the municipality of Malanville (North of Benin). Adekambi *et al.* (2009) indicated that the adoption of high-yielding varieties such as New Rice varieties for Africa (NERICA) in Central Benin increased rice yields and improved household expenditure among female-headed households (161.75 FCFA/day) and male-headed households (128.34 FCFA/day). In Central Benin, rice farmers were grouped in three clusters based on their socio-demographic charateristics and expectations towards credit (Dossou *et al.*, 2020). Olounlade *et al.* (2018) showed that education level, monthly income and household size were the main factors limiting access to credit in Glazoué (Central Benin). The innovation platforms that establishing contractual relationships between rice producers and processors could be promoted to facilitate spot market for paddy transaction in the central part of Benin (Codjo *et al.*, 2019). Nonvide *et al.* (2018) found that 75 % of the irrigated rice farmers and 60 % of dry-land farmers in Malanville perceived that irrigation played key roles in rice yields improvement leading to high net income, employment opportunity, poverty reduction and contribution to food security. Zannou *et al.* (2018) found that, due to declining soil fertility, the majority (71 %) of irrigated rice seed farmers in Koussin-Lélé (South Benin) applied a mineral fertiliser rate of more than 300 kg.ha-1, which is above the recommended rate of 275 kg.ha-1. To cope with climate change and to increase rice yields, rice producers in Dokomey (South of Benin) use the IR841 improved rice variety (*Oryza sativa* L.), adjust cropping date and use varieties with short maturing dates (Atidegla *et al.*, 2017). Arouna & Aboudou (2020) found that e-registration and geo-referencing of rice value chain actors in Southern part of Benin were instrumental in the diffusion of improved technologies and effective monitoring of technologie dissemination. Nonvide (2021) identified education, membership of a farmer-based organisation, access to extension services, access to credit, media and use of a mobile phone as key factors affecting adoption of agricultural technologies among rice farmers in Benin. However, these approaches were only applied in one municipality and on one rice production system (rainfed rice, irrigated rice or lowland rice), and may therefore not be suitable for the whole country, because of variability in climatic conditions, agricultural practices, socio-economic and demographic factors (Nonvide, 2020; Wabi *et al.*, 2021; Loko *et al.*, 2022). Information on socio-economic characteristics and cropping practices among rice producers in Benin, is required for informed decision-making and future rice productivity enhancement programmes tailored to the specific rice farmer needs (Atidegla *et al.*, 2017; Dossou *et al.*, 2020). Information on agricultural practices and farmers' resource mobilisation, which affect the production orientation, input use and cropping intensity, are determinants for improving yields (Niang *et al.*, 2017; Rahman & Connor, 2022). Unfortunately, this information is not always available.

Therefore, the present study aims to identify socio-economic characteristics and farmers' practices affecting rice yields in Benin and to suggest improved production management in the rice sector. The study, consequently, seeks to answer the following research questions: (1) how is the current rice production system structured? and (2) what type of specific research interventions and strategic actions are to be planned to improve rice production capacity? In the frame of the study, it is hypothesised that: (i) rice production in Benin is supported by a significant increase in farm inputs provided by the government; (ii) improving agricultural practices will increase rice yields by minimizing yield-reducing factors. This study will provide new perspectives that can inform policymakers, farmers and other stakeholders on ways to improve rice yields in Benin.

2 Materials and methods

2.1 Study area

The study was conducted in the three major rice production agro-ecological zones (AEZ) of Benin: (i) the Sudano-Sahelian zone of North Benin (AEZ 1), (ii) the West-Atacora zone (AEZ 4) and (iii) the cotton zone of Central Benin (AEZ 5) (Wabi *et al.*, 2021; MAEP, 2022). The contributions of the AEZ1, AEZ 4 and AEZ 5 to national rice production over 2017-2021 were 36 %, 24 % and 15 %, respectively (MAEP, 2022). For the study, Malanville, Tanguiéta and Glazoué were selected based on criteria of the highest contributor municipality to the volume of rice production per AEZ (Wabi *et al.*, 2021). From 2017 to 2021, the contribution of the municipality's rice production to their respective AEZ's total rice production was 70 %, 35 % and 10 % for Malanville, Glazoué and Tanguiéta (Table 1, Fig. 1), respectively (MAEP, 2022). In another study, these three municipalities were also considered as the largest contributor to rice production to their respective AEZ's total rice production (Wabi *et al.*, 2021).

Crop cultivation and livestock rearing were the main activities of the local population in the three agro-ecological zones (MAEP, 2017; MCVDD, 2019; Wabi *et al.*, 2021). In Benin, rice production largely depends on weather conditions (Wabi *et al.*, 2021). In Benin, only 2 % of the rice area is irrigated (Nonvide, 2020). Malanville is known as the most extensive rice area in Benin (Nonvide *et al.*, 2018; Wabi *et al.*, 2021) and produces more rice (116, 652 t in 2021) than any other municipality in Benin (MAEP, 2022). In Malanville, Glazoué and Tanguiéta, most rice farmers practice rice

Table 1: *Description of the three municipalities studied.*

	Malanville	*Glazoué*	*Tanguiéta*
AEZ*	AEZ 1	AEZ 5	AEZ 4
Latitude†	11°20’–12°00’ N	7°90’–8°30’ N	10°37’–11°46’ N
Longitude†	3°00’–3°40’ E	2°05’–2°22’E	01°07’–02°00’ E
Climate†	Dry tropical	Sub-humid tropical	Dry tropical
Rainy season†	May to October	April to July and Oct. to Nov.	May to Nov.
Dry season†	November to April	August to Sept. and Dec. to March	November to May
Annual rainfall†	700–1000 mm	1100–1300 mm	800–1100 mm

*AEZ: agro-ecological zone; †MAEP, 2017; MCVDD, 2019.

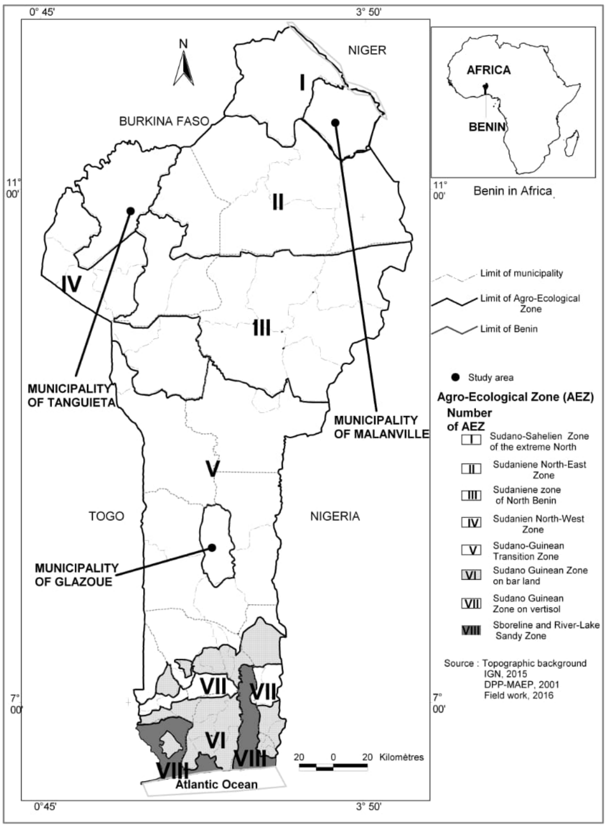

Fig. 1: *Geographical location of the three municipalities studied.*

mono-cropping (MAEP, 2017). In Malanville, rice cropping systems consist of rainfed lowlands and irrigated rice, whereas in Glazoué and Tanguiéta, mostly rainfed upland and rainfed lowland rice are cultivated (Wabi *et al.*, 2021; Loko *et al.*, 2022). In the three municipalities, most farmers manually perform land preparation using hand hoes, while some in Malanville and Tanguiéta use an ox-plough (MAEP, 2017; Loko *et al.*, 2022). Sowing in pockets is the most commonly used planting method in the three municipalities, with some farmers practising nursery transplantation in Malanville (Niang *et al.*, 2017; Loko *et al.*, 2022). In Malanville, Tanguiéta and Glazoué, IR841 (*Oryza sativa* L.) and Nerica-L20 (*O. sativa* x *O. glaberrima*) varieties are mainly used, and most farmers use chemical fertilisers (NPK and urea) in rice production (MAEP, 2017; Loko *et al.*, 2022). In the three municipalities, weeding is done manually with some herbicide applications in the municipality of Malanville (Niang *et al.*, 2017; Nonvide *et al.*, 2018). About 90.9 % of rice farmers do not use any phytosanitary method for pest management in the rice fields (Loko *et al.*, 2022). Rice yields were estimated at 2.1 t ha^{-1} in North Benin (Malanville and Tanguiéta) and 1.6 t ha^{-1} in Central Benin (Glazoué) (Loko *et al.*, 2022).

2.2 Sampling method

Respondents were selected using multi-stage and cluster-sampling methods to ensure a good representation of rice-producing households. For this, we obtained the dataset of rice producers from each municipality with the help of the extension services of the Ministry of Agriculture. In the first stage, we identified two (02) villages per municipality that are representative in terms of socio-economic features, rice farming systems, and farm and livelihood characteristics. This forms a total of six (06) villages. In a second stage, the minimum sample size required for the study was determined using a sample size formula suggested by Dagnelie (1998), as shown in Equation 1:

$$\mathrm{N} = \frac{\mathrm{Z}^2 p(1-p)}{d^2} \tag{1}$$

where N represents the minimum sample size, Z indicates the confidence level at 95 % (standard value of 1.96), p denotes the estimated proportion of an attribute, and d represents the desired precision ($1 \leq d \leq 15$) fixed at 6 %. In this study, p is the proportion of rice farmers, and it was estimated by dividing the total number of households producing rice (5796) by the entire agricultural population (18869) in the study area ($p = 31$ %). The agricultural population was obtained from the demographic data of the “General Census of Population and Habitation” by the “Institut National des Statistiques Appliquées et de l’Economie” of Benin in 2013 (INSAE, 2016). In a third stage, the final sample was selected from each municipality by determining its size in proportion to the entire study population.

A total of 230 household heads were thus randomly selected and interviewed from the list of rice producers provided by the extension services. One day before going to a respondent, the farmer’s leader informed the selected household heads to ascertain the interviewee's willingness and availability. A list of alternative interviewees (also randomly selected from the list of rice producers provided by the extension services) was compiled in case the selected household heads were absent or refused to participate in the survey. Data were collected during the dry season (November 2015 to January 2016). This period was chosen for the interview because, in the dry season, agricultural activity intensity is low. Therefore, farmers were more available to participate in the survey. The data collected (Annex 1) included mainly socio-economic and demographic characteristics of surveyed households and their rice cropping practices. Socio-demographic characteristics included gender, age, marital status, education, ethnicity, religion, origin, and household size, while socio-economic characteristics included access to land, total cultivated land area, workforce involved in rice production, experience in rice cultivation, land allocated to rice, access to extension services, membership of farmers association, access to credit, other crop practised, off-farm activities, and motivation (consumption, market or both). Rice cropping practices include mainly the type of rice cultivation, varieties produced, use of draught power, crop rotation, fallow practices and fertilisers use.

2.3 Data analysis

2.3.1 Socio-economic and demographic characteristics of rice producers

The socio-economic and demographic characteristics were described and analysed using descriptive statistics (frequencies, means and standard deviation) of qualitative and quantitative rice producer data.

2.3.2 Rice producer typology

Farm typology has been used for nearly two decades to identify the heterogeneity of farming systems and to perform their clustering (Lopez-Ridaura *et al.*, 2018). The typology can be constructed based on functional (livelihoods) or structural (farm resources and assets) variables, or both

Table 2: *List of the 17 variables used for grouping rice producers.*

No.	*Variable*	*Unit*	*Code used*
	Qualitative variables		
1	Lowland rice cultivation	Yes = 1; No = 0	Plow
2	Irrigated rice cultivation	Yes = 1; No = 0	PIr
3	Upland rice cultivation	Yes = 1; No = 0	pUp
4	Both lowland and irrigated rice cultivation	Yes = 1; No = 0	PlowIrr
5	Use of draught power	Yes = 1; No = 0	uATr
6	Crop rotation (growing of other crops such as legumes or root in the same plot after harvesting rice)	Yes = 1; No = 0	pRot
7	Fallow (uncropping or unworking the rice fields for a period of time)	Yes = 1; No = 0	PFal
8	Motivation	Consumption = 1; Market = 2; Both = 3	Motiv
	Quantitative variables		
9	Total cultivated land area	ha	LCA
10	Household size	Number	HousSi
11	Workforce involved in rice production	Number	FAW
12	Farm size (both cultivated and non-cultivated lands)	ha	LAv
13	Experience in rice cultivation	Number	Yexp
14	Land allocated to rice	ha	RCA
15	NPK fertiliser applied per ha of rice	kg ha^{-1}	NPK ha
16	Urea fertilizer applied per ha of rice	kg ha^{-1}	Urea ha
17	Rice yield	kg ha^{-1}	RYield

(Lopez-Ridaura *et al.*, 2018). In total, nine (09) quantitative and eight (08) qualitative variables linked to rice production systems were used to group rice producers in this study (Table 2). Clusters of rice producers were then described using the 17 variables. In this study, Factor Analysis of Mixed Data (FAMD) and Hierarchical Clustering on Principal Components (HCPC) were combined to describe better and to highlight better the resemblances between individuals (Quinn, 2004; Bergmann *et al.*, 2020; Loko *et al.*, 2022).

In the first step, a Factor Analysis of Mixed Data (FAMD) was used to cluster rice producers in homogeneous groups. In practice, the FAMD acts globally as a Principal Component Analysis (PCA) that consists of analyzing mixed data (quantitative and qualitative variables) (Pagès, 2004). In the second step, a Hierarchical Clustering on Principal Components (HCPC) was performed to classify the 230 rice producers into small groups based on the FAMD. The HCPC method was employed to develop a typology that more accurately describes technical differences among rice producers. In the third step, two stepwise discriminant analyses (one on quantitative and another on qualitative variables) were conducted to identify which variables best discriminated the identified groups of rice producers. Variables selections were based on the likelihood test using the Akaike Information Criterion (AIC) (Venables & Ripley, 2002) for qualitative variables and on classification rate (Weihs *et al.*, 2005) for quantitative variables. AIC and classification rate were used to distinguish among a set of possible models describing the relationship between qualitative and quantitative variables, respectively. The models that best fit to the data were those showing the lowest AIC for active qualitative variables and the highest classification rate with a low rate of error for active quantitative variables. As a result, the active qualitative and quantitative variables selected as the best discriminatory in our study came from the model which best fits the data. Statistical analyses were performed in R software (R Core Team, 2016). FAMD and HCPC were run using the "*factoextra*" package (Kassambara & Mundt, 2017), whereas stepwise discriminant analysis was conducted using the *MASS* (Venables & Ripley, 2002) and *klaR* (Weihs *et al.*, 2005) packages. Prior to the analysis of variance (ANOVA), a normality test was applied to quantitative variables. The non-parametric Levene's test was used to check the homogeneity of variances (Niang *et al.*, 2017). Analysis of variance (ANOVA) was used for the comparison of means among rice producer groups. Student-Newman-Keuls (SNK) test was used to rank rice producer groups that are significantly different from each other. P-values below 0.05 were considered to indicate statistical significance.

Table 3: *Socio-economic and demographic characteristics of rice producers.*

	Parameters	*Proportion (%)*
Gender	Male	72.6
	Female	27.4
Age	<30	7.4
	30-59	78.7
	≥ 60	13.9
Years of rice farming experience	<10	3.9
	10-20	31.3
	≥ 20	64.8
Marital status	Married	96.5
	Widow (er)	2.6
	Divorced	0.9
Education	No education	68.3
	Primary education	22.6
	Secondary education	8.3
	University	0.8
Ethnicity	Mahi	7.0
	Idatcha	13.0
	Fon	0.4
	Dendi	52.6
	Waama	9.6
	Koteni	3.0
	Nateni	10.9
	Tantari	2.2
	Others	1.3
Religion	Christian	23.5
	Muslim	53.9
	Animist	22.6
Origin	Native	93.9
	Foreign	6.1
Access to extension services	Yes	80.9
	No	19.1
Membership of farmer association	Yes	49.1
	No	50.9
Access to credit	Yes	33.5
	No	66.5

3 Results

3.1 Socio-economic and demographic characteristics of producers

Rice was predominantly produced by men (72.6 %). Most respondents (78.7 %) were between 30 and 59 years old with a mean age of 46 (Table 3). About 68.3 % of respondents did not receive any formal education, whereas 22.6 % attended primary school (Table 3). The most represented ethnic group among respondents was Dendi (52.6 %). The share of rice producers belonging to farmer associations was 49.1 %. Among farmers surveyed, 33.5 % had access to credit.

3.2 *Access of respondents to land and their economic activities*

Most respondents had access to land through inheritance (85.2 %). Other modes of access to land were also found in the study area, such as donation (13.9 %), purchase (4 %) and land rent (4 %).

Most respondents (92.6 %) produced crops other than rice, including maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), millet (*Pennisetum glaucum* (L.) R. Br), cowpea (*Vigna unguiculata* L.), groundnut (*Arachis hypogea* L.), soybean (*Glycine max* (L.) Merr.), cassava (*Manihot esculenta* Crantz), yams (*Dioscorea* spp. L.), cotton (*Gossypium hirsutum* L.), tomatoes (*Lycopersicon esculentum* L.), onion (*Allium cepa* L.) and pepper (*Capsicum* spp. L.). Eighty per cent (80 %) of respondents practised animal husbandry that involved chickens (*Gallus gallus domesticus* Brisson), donkeys (*Equus* spp. L.), guinea fowl (*Numida meleagris* L.), domesticated pigeons (*Columba livia* Gmelin), pigs (*Sus scrofa domesticus* Erxleben), sheep (*Ovis aries* L.), goats (*Capra aegagrus hircus* Erxleben) and cows (*Bos taurus* L.). Off-farm activities reported by respondents in the study area included commerce (25.2 %), and others (7.4 %): crafts, traditional healing, salaried jobs, photography, taxi-driving, preaching and teaching and caretaking jobs.

3.3 *Rice producers and cropping practices*

Rice mono-cropping was used by all farmers in the study area. Most farmers used the IR841 variety (*Oryza sativa* L.). The first three (3) FAMD axes (Dim 1, Dim 2 and Dim 3) were used to describe rice producer profiles. They were all significant and represented 19.9 % ($P < 0.0001$), 17.8 % ($P < 0.001$), and 12.2 % ($P < 0.001$) of the total variance, respectively. Based on the three axes accounting for 49.9 % of the total variance, three (03) clusters were identified (Fig. 2). Stepwise discriminant analysis revealed that variables such as "lowland rice cultivation" and "irrigated rice cultivation" were the best qualitative discriminating variables of the identified rice producer clusters (Fig. 3a). The total cultivated land area (hectare) was identified as the best quantitative variable to distinguish the identified groups of rice producers (Fig. 3b). This quantitative variable discriminated the clusters in 70 % of cases with a relatively low error rate (30 %). The three (03) rice producer clusters were characterised as follows (Table 4):

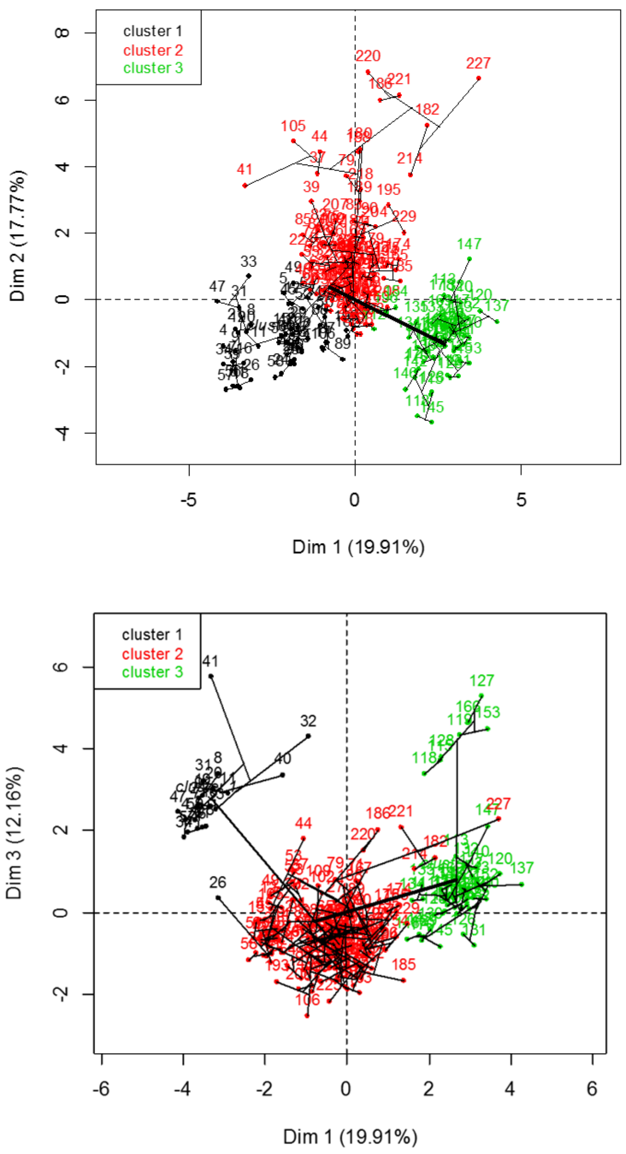

Fig. 2: *Classification of individual rice producers based on factor analysis of mixed data and hierarchical clustering on principal components: (a) grouping of rice producers according to axes 1 and 2 and (b) grouping of rice producers according to axes 1 and 3.*

Cluster 1

This cluster included 9.6 % of respondents (n = 22) and consisted of upland rice growers. Farmers from this cluster were the least experienced in rice cultivation (9 years). The lowest mean rice yields (2.8 t ha^{-1}) were found in this group. This cluster showed the lowest mean land area allocated to rice (1.5 ha) and had the highest farm size (8.7 ha). Most farmers did not practice crop rotation (75 % of the group members) or fallow (80 % of the group members). The mean land area cultivated was 5.3 ha; while the mean fertilisers rates applied in rice fields were 173.7 kg ha^{-1} and 66.1 kg ha^{-1} for

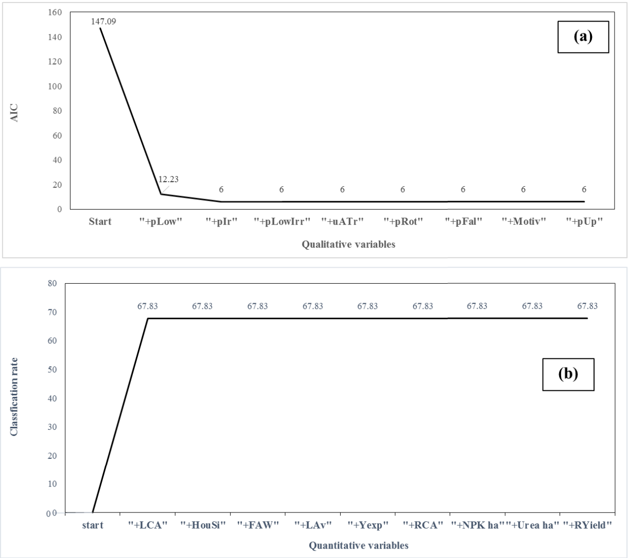

Fig. 3: *Graphical outputs of stepwise discriminant analyses (a) for qualitative and (b) quantitative variables.*
***Legend**: Plow: lowland rice cultivation ; PIr: irrigated rice cultivation; PlowIrr: both lowland and irrigated rice cultivation; uATr: use of draught animal power; pRot: crop rotation; PFal: use fallow; Motiv: motivation for producing rice; pUp: upland rice cultivation; LCA: total cultivated land; HousSi: household size; FAW: household workforce involved in rice production; LAv: farm size; Yexp: years of experience; RCA: land allocated to rice; NPK ha:amount of NPK applied to rice in the previous year (2014); Urea ha: amount of urea applied to rice in the previous year (2014) : RYield: rice yield in the previous year (2014).*

NPK and urea, respectively. These farmers did not own any irrigation material.

Cluster 2

Farmers from this cluster were the largest group, with 67.8 % of respondents (n = 156) and consisted of lowland rice growers. This cluster showed the highest mean total cultivated land (5.6 ha). The mean land area allocated to rice was 1.6 ha. Mean fertilisers rates applied to rice were 124.7 kg ha^{-1} and 93.0 kg ha^{-1} of NPK and urea, respectively. Most respondents in cluster 2 did not practice crop rotation (73.2 % of the group members) or fallow (78.2 % of the group members). In this cluster, farmers obtained intermediate rice yields (3.0 t ha^{-1}) and a medium level of experience in rice cultivation (15 years). The majority of farmers in cluster 2 did not own irrigation materials.

Cluster 3

This cluster contained 22.6 % of respondents (n = 52) who cultivated rice in two ecosystems (lowland and irrigated systems) and possessed irrigation materials. Farmers in this cluster had the strongest experience in rice cultivation (20 years), the highest mean rice yield (3.8 t ha^{-1}) and the highest land surface allocated to rice (2 ha). On average, farmers in cluster 3 applied 135.1 kg ha^{-1} of urea and 136.2 kg ha^{-1} of NPK-fertilisers. Most of the respondents in the cluster 3 did not practice crop rotation (79.0 % of the group members) or fallow (84.0 % of the group members).

4 Discussion

4.1 Socio-economic and demographic characteristics of producers

The majority of the rice farmers in the study area are male. This stressed that women often do not inherit land in the study area, but are mainly involved in post-harvest activities. This corroborated previous findings in Benin (Adégbola *et al.*, 2016; Loko *et al.*, 2022), Tanzania (January *et al.*, 2018), Nigeria (Kolawole *et al.*, 2012) and Burkina-Faso (Yaméogo *et al.*, 2018) that rice was mostly produced by men. Ninety-seven percent (97 %) of the rice farmers are married (Table 3). This indicated that some of them may have support from their family members in implementing rice production. This result supports the findings of Matanmi *et al.* (2011), who found that 82 % of rice farmers were married in the Patigi local government area of Kwara State, Nigeria. The majority (79 %) of respondents were between 30 and 59 years old, implying that rice producers are still productive and energetic, which was already shown by Saliu *et al.* (2016), who indicated that the average age of rice farmers in Kogi State, Nigeria was 42 years. Rice farmers' educational level is generally low (Table 3). This may not facilitate the diffusion of agricultural innovations and improvement of rice farming systems, as better-educated farmers were willing to adopt new technologies (Saliu *et al.*, 2016; Zama *et al.*, 2021). Only 33.5 % of rice producers have access to credit (Table 3), which can limit farm investment and, subsequently, rice productivity. Lack of credit was the main constraint limiting farmers' use of farm inputs, hired labour, transport and market opportunities in Nigeria (Odoh *et al.*, 2009), Ghana (Anang *et al.*, 2016), Tanzania (January *et al.*, 2018) and India (Shigwan *et al.*, 2019). Zama *et al.* (2021) reported that rice farmers with access to credit were more likely to undertake climate change adaptation strategies in Ndop-Cameroon. Efforts are needed to improve access to credit as well as the effectiveness of financial services to rice producers. In Benin, Dossou *et al.* (2020) suggested building a contract farming framework that combines credit supply, financial education and technical support for rice producers and enhances their awareness-raising of the benefits of solidarity credit groups. Most respondents (92.6 %) produce crops other than rice. This can improve their household food security and balance periods of poor harvest as well as offset climate change risks. This corroborated previous findings by

Table 4: *Main characteristics of the three clusters of rice producers in North and Central Benin (mean ± standard deviation).*

Quantitative variables (unit)	*Cluster*			*P value*
	1 (9.6 %)	*2 (67.8 %)*	*3 (22.6 %)*	
Household size (number of people)	8.3 ± 0.99^c	11.2 ± 0.61^b	13.9 ± 0.75^a	< 0.001
Number of family workers (number of people)	5.4 ± 0.90^b	5.6 ± 0.25^b	7.4 ± 0.36^a	< 0.001
Farm size (ha)	8.7 ± 1.10^a	7.3 ± 0.46^b	3.3 ± 0.13^c	< 0.001
Total cultivated land area (ha)	5.3 ± 0.83^a	5.6 ± 0.33^a	3.1 ± 0.11^b	< 0.001
Rice-cultivated area (ha)	1.5 ± 0.31^b	1.6 ± 0.11^b	2.0 ± 0.09^a	< 0.001
NPK applied (kg ha^{-1})	173.7 ± 9.75^a	124.7 ± 4.81^b	136.2 ± 6.04^b	< 0.001
Urea applied (kg ha^{-1})	66.1 ± 2.94^c	93.0 ± 3.78^b	135.1 ± 6.16^a	< 0.001
Rice yields (t ha^{-1})	2.8 ± 0.12^c	3.5 ± 0.10^b	3.8 ± 0.15^a	< 0.001
Years of experience in rice cultivation (year)	9.2 ± 1.36^c	14.9 ± 0.63^b	20.4 ± 1.07^a	< 0.001

Means followed by the same letters in the same line are not significantly different ($P > 0.05$; Student Newman-Keuls test).

Loko *et al.* (2022) that agriculture was the main source of income for Beninese rice producers. Between 7 and 25 % of respondents practice off-farm activities, which can enhance their financial capacity to invest in agriculture. However, the proportion of rice producers practising off-farm activities is low and highlight the urgent need to facilitate credit access to rice producers.

4.2 Cropping practices and rice producers' socio-economic characteristics affecting rice yields

In the study area, rice is grown in mono-cropping systems. Rice monoculture led to ecological degradation and high risks such as reduced soil fertility and loss of biodiversity (Djagba *et al.*, 2018; Arouna *et al.*, 2021). Moreover, continuous mono-cropping was reported to negatively affect rice yields because of the high occurrence of pests and diseases and weed infestation in rice fields (Kinyau *et al.*, 2013; Loko *et al.*, 2022), which affects the sustainability of rice cultivation. Kega *et al.* (2017) reported that pest reproduction rates were high under continuous rice cultivation. In terms of rice varieties, most respondents used the IR841 variety (*Oryza sativa* L.). This variety allowed farmers to better utilise available water, making it suitable for growing in lowland, upland or irrigated systems (Totin *et al.*, 2013). Kinkpe *et al.* (2018) reported that this variety was the most preferred local rice for consumption as compared to imported rice in Benin due to its whiteness, swelling capacity, flavour, and long-grain form.

Findings reveal three (03) rice producer clusters that significantly differ in terms of socio-economic characteristics and cropping practices, such as the use of chemical fertilisers, rice area cultivated, and rice production systems that affect rice yields. The largest and lowest average household sizes occur in clusters 3 (14 members) and 1 (8 members), respectively (Table 4). The highest and lowest mean number of family agricultural workers are in clusters 3 (7) and 1 (5), respectively (Table 4). The largest household size in cluster 3 may be seen as an asset for rice cultivation, as it can reduce hired labour costs and increase rice productivity, while the producers of clusters 1 and 2 may suffer from labour shortages. In the Philippines, Koirala *et al.* (2016) reported that labour costs were a key factor limiting rice productivity. However, as the farm size of rice growers in cluster 3 is smaller than those in clusters 1 and 2 (Table 4), and these farming families, therefore, produce less rice, the family members of producers in cluster 3 are more likely to be food-insecure and undernourished than those in clusters 1 and 2 (Table 4). In Ghana (Aidoo *et al.*, 2013) and Thailand (Tiwasing *et al.*, 2018), it was found that high household size means more family members being undernourished due to resource scarcity and limited land availability. Farmers in clusters 1 and 2 may use part of their farmland to cultivate other (subsistence) food crops, thereby reducing the risk of food insecurity and improving their income. Djagba *et al.* (2018) reported the key role of crop diversification in achieving food security and income generation for the households in inland valleys of Benin.

NPK and urea are the most commonly used chemical fertilisers in rice production in the study area (Table 4). The average quantity of NPK-fertilisers used by farmers in all clusters is lower than the rates of 200 kg.ha-1 (SNDR, 2011) recommended by Beninese extension services for rice cultivation. Urea rates applied by rice growers in clusters 1 and 2 are lower than the 100 kg.ha-1 recommended by the

Beninese extension services. These findings were consistent with those of Saito *et al.* (2019), who reported that farmers used less than the recommended quantities of chemical fertilisers, mostly because of their high cost and inaccessibility (Nonvide *et al.*, 2018; Nonvide, 2020; Arouna *et al.*, 2021; Loko *et al.*, 2022). Only in cluster 3 the average amount of applied urea was higher than the recommended rate of 100 kg.ha-1. This corroborated previous findings in Benin that irrigated rice farmers applied a mineral fertiliser rate which is higher than the recommended rate of 275 kg.ha-1 (Zannou *et al.*, 2018). The current chemical fertiliser application rates do not allow rice growers to achieve the yield that could be attained at its full genetic potential, especially for farmers in clusters 1 and 2. In all clusters, most rice growers do not practice crop rotation or fallow, indicating unsustainable land use management that may affect soil fertility and, consequently, the sustainability of rice cultivation. Farmers may have little incentive to apply a fallow period on their land because of the limited land available for agriculture resulting from an increasing population which exerts pressure on resource use. Fallow land was, by definition, temporarily unproductive land, which did not match to obtain short-term profits (Gaiser *et al.*, 2011). Djagba *et al.* (2018) highlighted the importance of a cereal-legume crop rotation as a central pillar of crop yield stability and sustainability of farmland in the inland valleys of Benin.

Most respondents (67.8 % of the respondents: cluster 2) practise lowland rice production, whereas farmers in cluster 1 (9.6 % of the respondents) and cluster 3 (22.6 % of the respondents) use upland and both lowland and irrigated production systems, respectively (Table 4). The highest mean rice yield (3.8 t.ha-1) is achieved by farmers in cluster 3 (Table 4). These farmers combine two cultivation systems (lowland and irrigated). Anang *et al.* (2016) reported that improving access to irrigation could increase rice yields in the North of Ghana. Farmers in cluster 3 allocate the most land to rice cultivation (2 ha). They own irrigation materials and can supply water to rice paddies. They are also the most experienced (20 years of experience on average) and have the highest number of family workers involved in rice production. The lowest mean rice yield of 2.8 t.ha-1 is found in cluster 1, where farmers cultivate upland rice (Table 4). This low rice yield might be attributed to poor water availability, low numbers of family farm workers and limited experience in rice farming (Totin *et al.*, 2013). Other yield-limiting factors were drought, flood, diseases, weed insfestation, higher incidence of pests and climate change (January *et al.*, 2018; Arouna *et al.*, 2021; Wabi *et al.*, 2021). In the upland system, rice yields were significantly affected by frequency of weeding, bird control and varietal choice (Niang *et al.*, 2017). Arouna *et al.* (2021) also found that upland rice yield was low compared to lowland or irrigated rice yields in Benin, because of its dependence on rainfall and variability in climatic conditions (Wabi *et al.*, 2021) but also because of the high pressure of biotic factors such as weeds and birds (Niang *et al.*, 2017).

4.3 *Outlook for sustainable rice production in Benin*

Our results suggest ways to improve the Beninese rice sector sustainability. This may include improving the ecological, technical and economic aspects of rice productivity.

Ecological factors

Rice production can potentially be increased, particularly when farmers spread production risks by combining different production systems (e.g., lowland and irrigated rice, lowland and upland rice, upland and irrigated rice or a combination of these three systems). This practice can help producers offset both climate variability and socio-economic risks, which may have different impacts on the two rice production systems in the same year. With no adaptation actions, climate change was expected to reduce rice yields in African countries (Van Oort & Zwart, 2018). Most authors also highlighted an urgent need for research on adaptation options, such as tolerance against abiotic stress factors in rice production systems in West Africa. In our study, 77 % (clusters 1 and 2) of respondents apply predominantly rainfall-dependent rice production systems. Variable and unpredictable rainfall were a determinant of rice yield variation in rainfed and upland systems (Wabi *et al.*, 2021), while solar radiation, temperature and air humidity were the key climatic factors for improving rice yields in upland, irrigated, and lowland systems in West Africa (Niang *et al.*, 2017). Wabi *et al.* (2021) found that future climate change and climate variability were likely to affect rice yields in Benin, due to the high probabilities (0.7 to 1) of a dry period at the flowering stage. Understanding the potential impact of climate change and variability on rice production systems in Benin should be a priority to increase its productivity. Nonvide (2020) and Arouna *et al.* (2021) demonstrated that improved high-yielding varieties were key factors for adapting of cropping systems to abiotic stress factors. Overall, the changing climate is expected to worsen these constraints and affect rice productivity. Changes in climatic factors such as changing rainfall patterns and the rising temperature significantly affected agricultural insect pests (Skendži *et al.*, 2021). Climatic factors can increase the number of pest generations and the incidence of insect-transmitted plant diseases. The use of modeling prediction tools, monitoring climate and pest population and modified integrated pest management practices should be a priority for future research on the impact of climate change on agricultural insect pests (Heong *et al.*, 2021).

Technical and economic factors
It is clearly shown that rice producers in the study area (clusters 1, 2 and 3), poorly manage soil fertility, and this highlights the urgent need for capacity building and training on best rice production practices and awareness-raising for crop rotation, fallow practices promoting, organic matter conservation and management (Meyer *et al.*, 2019) or water harversting technologies (Zama *et al.*, 2021). Doing so, will surely increase the positive long-term impact for sustainable rice yields. Zama *et al.* (2021) found that construction and maintenance of rain water haversting helped rice farmers in Ndop-Cameroon to improve rice yields. Training on improved agronomic practices combined with farm inputs (chemical fertilisers use, pesticides, improved germplasm, etc.) have been effective in increasing the rice yields of trainees in Tanzania (Nakano *et al.* 2018). During such trainings, topics related to water management, chemical fertilisation and leguminous crop use as well as animal waste used in rice production systems could also be envisaged. Niang *et al.* (2017) found that farmers' yields in rice production systems were more likely high with a combination of higher fertiliser application rates (equal to, or higher than the average of 100 N ha^{-1}, 16 P ha^{-1} and 29 K ha^{-1}) and appropriate water management. In the study area, low application rates (of NPK-fertilisers in the three clusters and of urea in clusters 1 and 2) are observed. This implies a need to improve access to agricultural inputs and their efficiency. We suggest introducing of a subsidy policy to reduce agricultural production costs and to fund rice production inputs (rice seeds and mineral fertilisers) to increase rice productivity. The overall proportion of rice producers having access to credit is low (33.5 %). Rice producers, therefore, also need access to credit. This may help (e.g., those in clusters 1 and 2), in some cases, to have access to hired labour, improve their transport schemes and market opportunities. In fact, access to credit was seen as a great asset for farmers particularly rice producers, because it allowed them to improve their production methods and significantly increase their farm outputs (Odoh *et al.*, 2009; Shigwan *et al.*, 2019; Zama *et al.*, 2021).

5 Conclusions

The purpose of the present study was to identify socio-economic characteristics and farmers' practices affecting rice yields in Central and North Benin and to suggest improved cultivation practices in the sector. Results show that the proportion of rice producers having access to credit is low (33.5 %), which hampers the adoption of rice yield-increasing practices. Findings reveal three (03) rice producer clusters that significantly differ in terms of socio-economic characteristics and cropping practices, such as fertilisers use, rice-cultivated area and rice production systems, all of which affected rice yields. Yield enhancement is possible through the combination of lowland and irrigated rice cultivation as is done by farmers in cluster 3, who obtained the highest mean rice yield (3.8 t ha^{-1}).

Our study suggests that there is a large scope for increasing rice yields in Benin. To achieve that objective, efforts are needed to improve farmers' access to credit. This may help rice growers (e.g., those in clusters 1 and 2) access hired labour, purchase fertilisers and improve their current cropping practices. We also recommend the Governmental and Non-Governmental Organisations (NGOs) support rice growers through training on rice production (crop rotation, fallow practices, organic matter conservation and management or water harvesting techniques, etc.) and access to irrigation and provision of input subsidies (for fertilisers, rice seeds and other inputs) that are tailored to the specific needs and constraints of each rice producer type. In the context of global warming, anticipatory research is needed to tackle the potential impact of climate change on rice farming which is largely dependent on weather conditions.

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Conflict of interest
The authors declare that they have no conflict of interest.

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