Rice pests in the Republic of Benin: farmers' perceptions, knowledge and management practices

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Running title: Rice pests management in Benin

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.ABSTRACT

BACKGROUND: Rice (*Oryza* spp) is one of the most consumed cereals in the Republic of Benin. However, rice production is threatened by various pests, which lead to important yield losses. For the development of integrated management strategies responding to the farmers' realities, it is important to document their perceptions, knowledge, and management of rice pests. Surveys involving 418 rice farmers to 21 ethnic groups through 39 villages were performed using rural appraisal tools.

RESULTS: Farmers perceived birds, specifically weavers as the most important rice pests. The surveyed farmers also identified the variegated grasshopper, *Zonocerus variegatus* L. and rice brown leaf spots (*Curvularia lunata* (Wakker) Boedijn) as the main pests in the northern region, while it is the pink stem borer, *Sesamia calamistis* Hampson and rice blast (*Magnaporthe grisea* (Hebert) Barr) in the southern region, and *Z. variegatus* and rice yellow mottle virus (genus Sobemovirus) in central Benin. The most important rice storage constraint was the rodent attacks and the surveyed farmers proposed thirteen key solutions to minimize constraints related to rice storage. Among various pest control methods recorded, farmers used mainly synthetic chemical pesticides. However, the Beninese National Pesticide Management Committee (CNGP) does not recommend for the rice protection (prohibited pesticides or intended for the protection of other crops) most of pesticides used by farmers.

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Farming experience, family size, region, and number of observed pests have significantly influenced farmers' decision to use pesticides.

CONCLUSION: The rice pests perceived by farmers as important vary significantly across regions. These results suggest that IPM programs that target rice pests accounting for these regional differences will be more effective. The identified variables that influence the use of pesticides must be taken in account in the development of strategies to encourage farmers to use eco-friendly pest management.

Keywords: Birds, Diseases, Insect pests, Pesticides, Rodents, Traditional control, Weeds.

1 Introduction

Rice (*Oryza* spp.) occupies a preponderant place in the diet of the African populations, representing more than 25% of the total cereals consumed[1]. Rice proves to be more and more a product with great consumption in the Republic of Benin[2], with an average annual rice consumption of 55 kg/capita/year[3]. In addition it is the third most-cultivated cereal after maize and sorghum, with an estimated production of 459 313 tons in 2018[3]. Rice is a great source of carbohydrates, fibers, vitamins and fatty acids[4]. In addition, it is a source of income for many Beninese farmers, which contribute to the livelihood system of many rural households[5]. However, domestic rice production falls short of demand, forcing the Republic of Benin to rely on large imports to make up the difference[6]. This low local rice production is due to several constraints, including pests, which considerably reduce the yield.

Rice production is confronted to diverse pests (weeds, insects, birds, rodents, and diseases), which lead to important losses[7,8]. For instance, the narrow brown leaf spot of rice caused by *Cercospora oryzae* Miyake can leads 60% of rice yield reductions[20], and post-harvesting losses due to insect and rodent attacks cause losses ranging from 10 to 40% of stored rice[24,25]. Several studies on weeds related to rice production in the Republic of Benin identified the rice vampireweed *Rhamphicarpa fistulosa* (Hochst.) as the most important one, which can cause up to 60% of yield losses[9, 10, 11, 12]. Although some studies have been carried out on rice field pests in Benin, they were mainly focused on stem borers[13, 14]; termites[15], and some diseases such as the narrow brown leaf spot of rice[18, 19, 20], rice blast[19], false smut disease[18], rice yellow mottle disease[21], and bacterial leaf blight[22]. None of these studies gives a global vision of pests' importance across the different Beninese rice-growing areas. Likewise, very little information exists on the constraints faced by farmers during rice storage and their importance across geographic areas. While, understanding farmers' perceptions and knowledge of rice pests would provide useful information for the development of sustainable management strategies[16,17]. Indeed, differences in perceptions and knowledge of crop pests by farmers and researchers constitutes a major obstacle to their cooperation for sustainable pest management[23].

The use of synthetic pesticides with its negative impacts on the environment and human health is a very common practice for the rice protection[9]. However, some studies have revealed the use of traditional control methods for rice pest control by Beninese farmers[9],[13]. For the development of an integrated pest management strategies adapted to smallholder rice farmers, it is important to identify effective traditional pest management methods adopted by farmers throughout the rice-growing areas of the Republic of Benin. Therefore, the objective of this study was to document farmers' perceptions, knowledge, and management of rice pests by farmers as well as storage constraints and practices throughout rice-growing areas in the Republic of Benin.

2 Material and methods

2.1 Study area

The study were carried out in the Republic of Benin, a country of West Africa located between meridians 0° 40' and 3° 45' East longitude and parallels 06° 15' and 12° 25' North latitude. The population of Benin is estimated at 10 008 749 inhabitants belonging around sixty ethnic groups unequally distributed throughout the country[26]. In the south, the climate is subequatorial with four uneven seasons, two rainy seasons and two dry seasons. While, unimodal rainfall regime is observed in the north and a transitional precipitation regime in the central region. In the south, the mean annual rainfall varies between 1000 and 1500 mm with annual mean ranging from 25.8 to 27.7 °C. In the northern region mean annual rainfall oscillates between 800 and 950 mm with an annual mean temperature of 27.5 °C. While, in the central region mean annual rainfall varies from 900 to 1200 mm, with a mean annual temperature ranging from 26 to 28 °C. Ferrallitic soils, tropical ferruginous soils, and vertisols are observed in the south of Benin, while in the north and in the centre, hydromorphic soils and tropical soils with concretions of crystalline basement are observed respectively. Plant formations are varied across Benin. There are forest galleries and forests in the south, while in the north and centre, savannah and dry semi deciduous forest predominate.

2.2 Sampling and site selection

The number of rice farmers to be surveyed was determine using the normal approximation of the binomial distribution proposed by Dagnelie[56]

$$n=\frac{U_{1-\propto/2}^{2}\times p(1-p)}{d^{2}}$$

Where n is the number of surveyed rice farmers; $U_{1-\propto/2}^{2}$= 1.96 is the quantile of a standard normal distribution for a probability value of 0.05; p = 0.11 is the proportion of rice producers population; d is the expected margin error of the estimation and a value of 8% was considered[57].

The value of p was determine according to Adebo et al.[58] by considering a single person interviewed per household, the number of agricultural households in the Republic of Benin

(651067 agricultural households)[26], and the number of households involved in rice production (72400 households)[59]. The value n suggesting that a minimum of 58 rice farmers to be surveyed.

The number of rice farmers surveyed was 418 of which 138 were in the south, 53 were in the centre, and 227 were in the north. Surveys were conducted in 39 villages spread across the north (21 villages), centre (6 villages), and south (12 villages) (Figure 1). These villages were selected in collaboration with the agents of the Territorial Agencies for Agricultural Development (ATDA) of each region based on rice production statistics and taking into account ethnic diversity, and accessibility.

2.3 Surveys

Data were collected from June to December 2019 using tools (questionnaires) and methods (household surveys, and field visits) of participatory research. Local translators were recruited in each surveyed village to facilitate discussions with farmers[27]. In each village, we presented the objectives of our study at the head of village and rice farmers to obtain their approval before starting the surveys. At least ten households were selected in each village using the transect method described by Dansi[28] for individual surveys. The sociodemographic data (age, sex, household size, years of experience in rice production, educational level, cultivated area, and workforce) of the surveyed farmers were firstly documented.

The proportion of male-headed (74.6%) households was higher than female-headed (25.4%). A great majority of surveyed farmers had no formal education (64.4%). Most of the surveyed farmers' attained primary (20.5%) and secondary (13.9%) level of education. Only 1.2% of the respondents had university level of education. The respondents were aged between 17 and 85 with middle age, average of 43.9 years. The experience of the surveyed farmers in rice production ranged from 01 to 66 years with an average farming experience of 13.9 years. The land size of rice averaged 0.9 ha with a minimum of 0.05 ha and a maximum of 16 ha. Surveyed farmers in southern region hired on average more labour intensive for rice production than those of the northern and central regions (Table 1).

Data collected were focused on the farmers' perceptions, knowledge, and management of rice pests, estimated losses due to pest attacks (based on 5-level scale (0, 25, 50, 75, and 100%)), storage constraints and solutions proposed by farmers, storage practices, duration of conservation, period of the infestation, and farmers' perception of factors favouring infestation of stored rice by pests. Colour photographs of all possible rice pests and their damages were used to assess farmers' knowledge of insect pests[29, 30], diseases[31], and vertebrates pests[32,33] for their correctly identification by farmers. According to Alibu[30], if pesticides were mentioned, farmers were asked to provide the commercial name of the pesticides or show the containers, source of the pesticides, timing of pesticide application, and how they were used.

2.4 Statistical analysis

Data were analysed through descriptive (means, percentages) and multivariate statistics. The binary probit regression was used to determine the factors influencing pesticide use by the surveyed farmers in the study area. The probit model calculated using STATA 13.0 software was summarised as follow:

$$Y_i = \beta_i + \sum_{i=1}^{n} \beta_i X_i + v$$

where Y_i = dummy variable on pesticide use (scored 1 if the farmer used any pesticide and 0 otherwise), X_1 = dummy variable on sex of farmer (male = 0, female = 1), X_2 = age of farmer, X_3 = education level (no formal education = 3, primary level = 6, secondary school = 9, university = 12), X_4 = years of experience in rice production, X_5 = farm size, X_6 = number of workforce, X_7 = number of family members, X_8-X_{10}= regional dummy (scored 1 if it is the region and 0 otherwise), X_{11}: number of diseases observed by farmers, X_{12}: number of other pests observed by farmers, and v is the random error.

3 Results

3.1 Farmers' perception, knowledge and management of field rice pests

Most of the surveyed farmers (89.7%) were able to identify at least one pest associated to rice fields. Birds (46.5% of responses), followed by insect pests (24.8%) and weeds (20.5%) were considered by the surveyed farmers as the most important biotic constraints of rice production in the study area. Rodent (7.1%) attacks were perceived as a lesser constraint. Fish were mentioned as rice pests only in the northern region (Table 2). For the great majority of the surveyed farmers (87%), losses caused by rice pests can be estimated at 25% of production.

3.1.1 Birds

All the surveyed farmers identified weavers as the main important rice-eating birds. For instance, in Dévé-Homey village, the surveyed farmers identified 5 different weavers causing important damage during rice production (Figure 2). The red-headed quelea (*Quelea* *erythrops* Hartlaub) locally called Aoui taji was perceived as the most important bird pest in this village, while the black-headed weaver (*Ploceus melanocephalus* L.) called Houdji-houdji was perceived as the first bird to consume rice in the fields. According to the surveyed farmers, birds cause significant damage because they feed on the sown milky seeds. As for the fish, the surveyed farmers did not mention any species in particular but noted that they are also important rice pests.

In order to avoid the bird consumption of sown rice seeds, all the surveyed farmers used at least one method of management. They fought birds by chasing them away with screams or stones using slingshots (93.1%), using scarecrows in the fields (5%), and spreading paddy rice poisoned by chemical pesticides in the rice (1.9%) (Figure 3a) or a combination of these methods; this trend was observed in all the surveyed regions. The avian control after panicle formation was done by the use of slingshots (52.4%) (Figure 3b), arrangement of the scarecrows in the field (11.2%), shouts (25.8%), use of protective nets (7.7%) to cover rice plants (Figure 3c), or use of cassette tapes (2.9%). The majority (83.7%) of these bird hunters remain in the shade under baits built for the occasion (Figure 3d). Almost half of the interviewed farmers (45.9%) used external labour they pay for this purpose. Some surveyed farmers revealed that some local rice varieties resisted to bird attacks; it is the case of the local variety Djimbo gazéré (Madekalli village) from which the curved position of the panicles prevents the birds from pecking them.

3.1.2 Insect pests

The surveyed farmers (67.9%) identified 16 rice insect pests (Table 3). The variegated grasshopper *Zonocerus variegatus* L. was reported as the most important one, and specifically in northern and central regions. In the southern region, it is rather the pink stalk borer (*Sesamia calamitis* Hampson) that was perceived as the most important insect pest. Termites and the borer *Chilo zacconius* Blesz were also mentioned as important pests in central region, but of less importance in the other two regions. Surveyed farmers in southern region highlighted *Diopsis thoracica* Westwood and *Scirpophaga* sp. as other pests, while the northern farmers incriminated some ants (Table 3).

Across the study area, very few surveyed farmers (8.9%) used insecticides to fight insect pests attack in rice fields, with only 5 insecticides recorded (Table 4). The commercial insecticide Pacha Super 35 EC intended for the protection of vegetable crops was the only insecticide used in southern Benin (20 surveyed farmers). The commercial insecticide locally called Piapia (Dichlorvos or DDVP), which is a prohibited insecticide in Republic of Benin, was used by all the surveyed farmers in madécali village in the northern Benin: the surveyed farmers revealed that they source Piapia from the neighbouring Nigeria. Two surveyed farmers in northern region also used the cotton insecticide called Thalis 112 EC for rice protection, while others cotton insecticides (Cobra 120 EC and Calfos 500 EC) were used by some surveyed farmers in the central region of Benin (Table 4). Application of all these insecticides is performed at the beginning of rice flowering.

3.1.3 Rodents

Four type of rodents were listed in the study area as important pests of rice fields: rats (*Rattus rattus* L.), mice (*Mus musculus* L.), greater cane rat (*Thryonomys swinderianus* Temminck), and rabbits (*Oryctolagus cuniculus* L.). Rats (76.3%) were the most cited rodents as pest in rice fields throughout the study area, followed by mouse (13.4%), greater cane rat (6.7%), and rabbits (3.6%). According to the surveyed farmers, their consumption of the seeds sown and the cutting of the rice stalks characterize their damage.

Some surveyed farmers (12.2%) use rodenticides, trapping, hunting, or biological control to manage rodents. After sowing or during storage, the majority of them (50.9%) mix paddy rice with rodenticides (Push out or Rat killer), which they place at strategic locations in their fields or stores and other farmers (21.6%) hunt rodents. Only 15.7% of farmers used traps to manage rodents both in the fields and during storage, or, in northern region performed biological control by the use of cats (11.8%).

3.1.4 Rice diseases

Almost half of the surveyed farmers (49.8%) did not identify any diseases affecting rice production, and those who listed at least one rice disease did so only after recognition of the disease symptoms represented in the pictures shown during the interviews. These remaining surveyed farmers reported six rice diseases (Table 5). Among them, the rice brown leaf spots is the most important in the study area but specifically in northern Benin. In central region, the rice yellow mottle virus was considered by the surveyed farmers as the most important, and in the southern region, it is the rice blast to be considered as the most important disease. The false smut disease and bacterial leaf blight were only reported by few surveyed farmers in the southern region (Table 5). Although some of the surveyed farmers mentioned rice diseases, none of them used a particular control method.

3.1.5 Weeds

All the surveyed farmers used at least one method for weed management, the great majority of them combining hoe weeding and selective herbicides (Table 6). In northern Benin, the majority of the surveyed farmers (89%) only used herbicides for weed management, while in the central region, the number of the surveyed farmers (21%) doing only hoe weeding was important, and only herbicide procedure much lower. The number of hoe weeding varied from 1 to 4 per rice season (Table 6) and per region two third of farmers in the North region only did one hoe weeding per rice season to remove the grasses close to rice, such as the *Poaceae* that the selective herbicides fail to eliminate. On the other hand, in central and southern Benin, the majority of the surveyed farmers carried out two and three hoe weeding respectively per rice season. Only two surveyed farmers, one in the north and one in the central regions carried out four hoe weeding per rice season. With regard to the management of weed residues after manual weeding, numerous farmers from north use weeded grass as organic amendment (36), the remaining ones disposed of weeded grass by abandon in the field or burn it (Table 6).

Twenty commercial herbicides were used by the surveyed farmers for weed control in rice fields throughout the study area (Table 7). The glyphosate (30% of herbicides) was the most commonly used ingredient, followed by the 2.4 D-amine salt (25%), propanil (20%), and Triclopyr (15%). The herbicides named Garyl 432 EC (28.5% of responses), Kalach Extra 70 SG (22.7%), Herbextra 720 SL (16.6%), and Calriz (10.5%) were the most used for weed control. However, a large discrepancy between regions was observed in terms of herbicides used. For example, Butaforce, Condor 50 SC, and Herbiax 60 AD-AG were among the most herbicides used in the southern region, and Pilaherb, and Stomp CS were used only by few surveyed farmers in central Benin. Nine herbicides listed by the surveyed farmers belong to a chemical family classified by the WHO as moderately hazardous (class II) (Table 7). Only 45% of these herbicides belongs to the list of products approved in Republic of Benin.

Most of the surveyed farmers (38.1%) combined different herbicides for weed control in rice fields. For example, the combination of Garyl 432 EC and Kalach Extra 70 SG (59 surveyed farmers) was most used by farmers in the northern region, while in the southern (16) and central (6) Benin it is the combination of Garyl 432 EC and Herbextra 720 SL (16).

3.2 Farmers' perception, knowledge and management of storage rice pests

3.2.1 Rice storage practices

Most of the surveyed farmers (73.8%) saved rice seeds in bedrooms, while 26.2% saved them in dedicated storerooms, the storage containers being mainly the polyethylene bags

(99.1%). However, some farmers to stored rice seeds also used basins (0.5%) and baskets (0.4%) as containers. For the seed conservation, the great majority of the surveyed farmers (99.7%) did not use any product and only one farmer (0.3%) in Gamia village in the Bembèrèkè district used a chemical insecticide locally called Piapia for seeds conservation. The duration of seed conservation varied largely between 3 to 72 months (Figure 4), with a peak in the 24 to 36 months interval (60.2% of responses).

3.2.2 Rice storage constraints

In the study area, farmers faced eight constraints to rice storage (Table 8). Attacks of stored rice by rodents such as mice and rats was the most important in the study area and specifically in northern and southern regions. In the central region, the lack of financial means was more prominent as a constraint. Interestingly, only a few surveyed farmers in southern and northern regions (6.6% of responses) mentioned insect attacks. For the great majority of the surveyed farmers (87.6%), losses caused by insect pests in stored rice are almost zero. However, 10.3% and 2.1% of the surveyed farmers estimated that insect pests could damage up to 25% and 75% respectively of stored rice.

3.2.3 Farmers knowledge of storage insect pests

The surveyed farmers throughout the study area listed seven insect pests of stored rice (Table 9). Only one rice insect pest, *Rhyzopertha dominica* Fabricius was mentioned by the surveyed farmers in the central region. Surveyed farmers in southern region perceived the weevils *Sitophilus oryzae* L. and *Sitophilus zeamais* Motschulsky, as well as the rice moth *Corcyra cephalonica* Stainton, as the most important rice storage insect pests. On the other hand, termites were perceived by farmers in northern Benin as the main insect pests of stored rice.

3.2.4 Farmers perception of factors favouring insect pest infestation

The surveyed farmers (31.6%) listed seven factors favouring the attack of stored rice by pests (Figure 5), upon whose the humidity level of the storage place (82.8% of responses) is as the most important one. The surveyed farmers also cited the smell (6% of responses), dirt (3.7%), and location (3%) of the storage structure as factor favouring the attack of pests on rice stocks. The surveyed farmers also mentioned the high seed moisture content (0.8%) and the long storage time (2.2%).

3.2.5 Storage insect pest management

Some surveyed farmers used commercial insecticides (17% of farmers) or insecticidal plants (4.3%) to protect stored rice against insect pests. Four commercial insecticides were used, including Lambda super 2.5 EC and Piapia that are not suitable for the protection of stored rice. Some farmers in southern region used the commercial insecticides Sofagrain and Percal 100 EC. Except for Lambda super 2.5 EC which was obtained from the extension agricultural services locally named ATDA (Regional Centre for Agricultural Promotion), the others insecticides were bought in the local markets. Outside of chemicals, some surveyed farmers in southern Benin used leaves and seeds powder of the neem *Azadirachta indica* A. Juss as insect repellent and insecticide.

3.2.6 Farmers' solutions for better conservation of stored rice

To minimize rice storage constraints, the surveyed farmers proposed thirteen key solutions (Table 8). Among them, dry the rice seeds well (31.9% of responses), place the bags of rice on a support to prevent rodent attacks (15.7%), keep the bags of rice out of termites' reach (10.9%), and use rodenticides (10.2%) were the main enumerated solutions by the surveyed farmers. Only few surveyed farmers in northern (8%) and southern (6.6%) regions mentioned also the use of insecticides as a storage constraint solution.

3.3 Determinants of the use of pesticides by rice farmers

The majority of surveyed farmers (73.2%) used at least one pesticide to protect rice both in the field and during storage (Table 10). Among them, 44.1% used more than one type of pesticides. Concerning the determinants of pesticides use by the surveyed farmers, the adjusted count R^2 equals of 0.061 shows that only 6.1% of the variance in the dependent variable is explained by the variance in the twelve independent variables. The log-likelihood and LR Chi-square values were significant ($P \leq 0.0001$). The probit regression results indicated four explanatory variables of farmers' pesticide use in the study area (Table 11). The estimated parameters of pesticide use and the marginal effect of each variable suggest that experience of rice farmers, and the number of family members significantly increased the use of pesticides. Among the region, the surveyed farmers in southern Benin significantly used more pesticides than farmers in other regions. Likewise, the number of pests observed by the surveyed farmers had increase their use of pesticides. The odds ratio results show that, there is a 5.8 % increase in the odds that the rice farmers be influenced to use pesticides when the number of family members increase with one unit (Table 11). In addition, there is a 100.5% increase in the odds that the rice farmers be influenced to use pesticides if they are from the south of Benin comparatively to rice farmers from centre of Benin.

4 Discussion

The majority of surveyed farmers mentioned birds as the main constraint of rice production in Republic of Benin. The importance of birds as rice pests was also revealed by Ivory Coast[7] and Nigerian[34] rice farmers, which mentioned that bird damage leads to important reduction in yield and harvest quality. In Senegal, annual bird damage was estimated at 13.2% of the potential rice production corresponding to economic losses of €7.1 million[35]. However, despite of the occurrence of the diversity of bird species in rice fields in the study area, very few farmers were able to identify granivorous bird species. While, Funmilayo and Akande[32] and Adekola *et al.*[34] identified respectively 11 and 27 bird pest species in rice fields in Nigeria with the red-headed quelea as the most important. It is known that rice fields is an important habitat of several non-granivorous birds[36], and bird species composition and distribution are influenced by the rice growing stages[37]. In addition, birds could be benefit to rice through the decomposition of rice straw, and pest control[60]. Therefore, it is urgent need to identify the most important avian pest species of rice production in Republic of Benin to propose efficient management methods and permit the conservation of non-pest species.

Similar to the rice farmers in the sub-region, weeds were considered as important rice pests[7,38]. The rice vampireweed *R.* fistulosa[9] and Striga species[39] are considered as the most important parasitic weed of rice production in Republic Benin. Knowing that, there is significant interaction between rodents and weeds in lowland rice agro-ecosystem[40], weeds providing a refuge area and alternative food source for rodents[41], the development of an integrated management strategy to fight these both pests is crucial for boost rice production.

Our results revealed that, in addition to birds and weeds management, it is important to develop control strategies taking in account the important insects and diseases revealed by the surveyed farmers in each region. In northern Benin, control strategies should target the grasshopper *Z. variegatus* and rice brown leaf spots. Indeed, *Z. variegatus* is considered as an important rice pest[42], and Afouda et al.[18] found a great incidence of rice brown leaf spots in north Benin. Moreover, in the Madékalli village, where fish were listed as important rice pests during flooding, it is important to train farmers on rice-fish coculture to improve their productivity, incomes, and utilization of water resources [43]. On the other hand, in central Benin, in addition to *Z. variegatus*, control strategies need to be focused on termite pests and the rice yellow mottle virus. According to Togola et al.[15], *Microcerotermes parvus*, *Microtermes* sp., *Pseudacanthotermes militaris* and *Amitermes evuncifer* are the termite pests to target in rice fields. Koudamiloro et al. [44] identified *Z. variegatus* as a vector of rice yellow mottle virus that could justified the high incidence of this disease in central Benin. In the southern Benin, control strategies should be developed against *S. calamitis* and rice blast, which have a great incidence in southern Benin[19]. The fact that *S. calamistis* only proliferates in region with bimodal rainfall distribution[45] could justified its importance in southern Benin.

Concerning rice storage, although the surveyed farmers do not perceived insects as a major constraint, Togola et al.[25] have shown that insects can cause significant losses particularly in the southern Benin. The rice storage insects perceived by the surveyed farmers through the regions are not in agreement with several studies, which showed that *Oryzaephilus surinamensis* and *Tribolium confusum* are the most dominant species in southern Benin[46], and *S. oryzae* and *S. cerealella* perceived as the most dominant in the centre region[25]. Therefore, it is important to evaluate the diversity and abundance of insects associated with stored rice in Republic of Benin. Surveyed farmers perceived rodents as the main constraint of rice storage and blamed bad storage practices as favouring their proliferation. Indeed, improved hygiene practices can successfully reduce rodent damages in stored rice[47]. The solutions proposed by the surveyed farmers such as place the bags on a support to avoid rodent attacks, owning cats, and disinfection of the storage place must be vulgarised throughout the study area.

Regarding rice pests' management, the surveyed farmers used some recommendable strategies such as the combination of hoe weeding and selective herbicides for weed control [48, 49] the used of human bird scares, and scarecrows for birds control[34], and traps for rodents control[50]. However, some surveyed farmers used glyphosate as herbicide. While, it is known that glyphosate are harmful to the environment, and human health, and pose health risks on native fish populations inhabiting rice fields[51]. It is therefore important to develop alternative weed control such as the use of rice varieties with high weed-suppressive potential[52]. Concerning insect pest management, no insecticides used by the surveyed farmers in the study area are recommended by the Beninese National Pesticide Management Committee (CNGP) for the rice field protection. While, insecticides such as CYPERCAL P 330 EC (Cypermethrin 30 g/L + Profenofos 300 g/L) and DECIS 25 EC (Deltamethrin 25 g/L) are recommended by this committee for insect management in rice fields. It is therefore important to educate rice farmers about the environmental and health risks on the use of inappropriate insecticides. The use of insecticidal plants such as *A. indica* by surveyed farmers for the protection of stored rice represents an efficient alternative to the use of insecticides[53]. As integrated pest management strategies, we recommend the use of pest-resistant rice varieties identified in the

Beninese traditional agriculture[60] combined with pest monitoring, and eco-friendly appropriate pesticides favouring the establishment of natural enemies.

Concerning the determinants of pesticides use, our results showed that surveyed farmers with long experience in rice production have a higher likelihood of using a pesticide compared to less experienced farmers. Indeed, for examples, farmers with more experience know that in the lowland rice fields the application of herbicide require very less time than hand weeding[39]. Similarly to Sri Lanka rice farmers[54] the household size positively increased the use of pesticides. The fact that the number of pests observed by the surveyed farmers had increase the use of pesticides is not surprising. Indeed, according to Obopile et al.[55], farmers' decision to protect crop depend, among other factors, on their knowledge and presence of pests. Among the region, the surveyed farmers in southern Benin significantly used more pesticides than farmers in other regions. This could be explained by the fact that in the southern Benin, climatic conditions are favourable for the proliferation of insects, and farmers store rice over a long period of time, which increases their infestation by insects and the use of insecticides[25]. The identified variables that influence the use of pesticides by rice farmers must be taken in account in the development of strategies to encourage farmers to use eco-friendly pest management.

5 Conclusion

Our study revealed that rice production in the study area is subject to significant biotic constraints, including birds, insects, and weeds attacks in the fields, while rodents were the most important constraint of stored rice. The different perception of important pests by the surveyed farmers throughout the regions must be taken in account in the development of integrated pest management strategies. It is important to strengthen farmers' knowledge on rice pests, and train them on the adequate measures to control them. The identified factors that influence the use of pesticides by rice farmers must be taken in account in the development of any integrated pest management strategies.

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CRediT authorship contribution statement

All authors: Funding acquisition. **Toffa Joelle**: Writing - original draft. **Loko Yêyinou Laura Estelle**: Project administration, Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Djedatin Gustave**: Writing - review & editing. **Gbemavo Chalemagne**: Writing - review & editing. **Orobiyi Azize**: Investigation. **Tchakpa Cyrille**: Investigation. **Ewedje Eben-Ezer**: Investigation. **François Sabot**: Supervision, Writing - review & editing.

Conflict of Interest Declaration

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1. Sociodemographic characteristics of surveyed households in the study area.

Characteristics	**North** (N= 227)	**Centre** (N=53)	**South** (N=138)	**All regions** (N = 418)
Gender (%)				
Male	74.9	69.8	76.1	74.6
Female	25.1	30.2	23.9	25.4
Education level (%)				
No formal education	69.2	62.3	57.2	64.4
Primary	20.1	24.5	19.6	20.5
Secondary	9.8	13.2	21	13.9
University	0.9	-	2.2	1.2
Age (years)				
Average	43.6 ± 0.8	43.1 ± 1.1	47.6 ± 1.8	43.9 ± 0.6
Range	18 - 85	25 - 78	17 - 76	17 - 85
Number of family members (%)				
Average	9.5 ± 0.4	7.7 ± 0.4	7.5 ± 0.3	8.6 ± 0.2
Range	1 - 34	2 - 15	1 - 24	1 - 34
Experience (years)				
Average	15.1 ±0.8	15.1 ± 1.9	11.5 ± 0.3	13.9 ± 0.8
Range	1 - 66	1 - 37	1 - 60	1 - 66
Farm size (hectare)				
Average	0.9 ± 0.0	1.2 ± 0.2	1.6 ± 0.3	0.9 ± 0.0
Range	0.05 - 16	0.25 - 5	0.25 - 8	0.05 - 16
Number of workforce				
Average	5.95 ± 0.45	6.40 ± 0.59	12.37 ± 1.37	8.12 ± 0.54
Range	0 - 60	0 - 20	1 - 120	0 - 120

N= Number of surveyed farmers.

Table 2. Farmers' perception (% of responses) of pests associated to rice production in the study area

Pests	**Local names (ethnic group)**	**North** (N = 190)	**Centre** (N = 49)	**South** (N = 136)	**All regions** (N = 375)
Birds	Koulouwo (Biali), Soumassé ou Soumra (Lokpa), Séguéssou (Wama), Karamoua or Dandani (Yom), Tchiro (Ditamari, Mokolé, Dendi), Touraize or Siko or Gounonsou (Bariba), Gounon or Chiro gouronbiron (Germa), Komorké (Mbermin), Eyê (Tchabé et Holli), Hwlenvi or Hèvi (Adja), Hê (Fon, Ouémè), Ohè (Sahouè)	42.6	52.1	48.6	46.5
Insects	Gagam (Dendi), Sasa or Yeléou (Mokolé), Kokonoun (bariba), Min-min (Lokpa), Bocléclé (Ouémè), Noulègbè (Sahouè)	27.7	20.9	23.2	24.8
Weeds	Bêté oguidon (Idaatcha), Igbè (Holli), Gnakassou (Bariba), Soubou (Dendi), Gnitou (Lokpa), Gbéhan (Fon), Gbé yanlan-yanlan (Ouémè), Ogbé (Sahouè)	22	14.2	21.1	20.5
Rodents	Tchon (Dendi), Kou or Kui or Mbiou (Lokpa), Kanti (Wama),Tchan (Mokolé), Ho (Mahi), Oya (Tchabé), Djaka (Adja), Gounannou (Bariba), Chom (Dendi), Adjaka (Fon), Gbédjaka (Ouémè), Djaka ou Zangbé (Sahouè)	5.3	12.8	7.1	7.1
Fish	Fotoforo (Dendi)	2.4	-	-	1.1

N= Number of surveyed farmers.

Table 3. Farmers' perception (% of responses) of insect pests associated to rice fields

Pests	**Local names (ethnic group)**	**North** (N = 133)	**Centre** (N = 47)	**South** (N = 104)	**All regions** (N = 284)
Zonocerus variegatus	Langban (Ifé), Kouni (Biali), Looni (Dendi), Tchroo or Ewée (Lokpa), Tchumon kpatan (Yom, Pilapila), Doezé (Germa), Ditchékédomouké (Mbermin), Figna (Bariba), Allakpa (Nago, Holli), Boclé (Fon), Klé (Mahi),Ougui (Tchabé)	42.4	40.2	16.5	30.5
Sesamia calamitis	Kyawa (Pila pila), Awa (Mahi)	2.1	1.3	33.9	16.2
Termites	Odidi (Ifé), Toapi (Biali), Tounou (Bariba), Doussou (Mokolé)	9.9	36.4	11.1	14.6
Chilo zacconius	Zounyon (Yom , Pilapila), Coconus (Bariba), Koko ilé (Holli),Sossombré (Lokpa), Atchi oloroun (Tchabé), Arinran (Idaatcha)	10.5	15.6	6.5	9.5
Heteronychus arater rugifrons	Colo (Germa), Séko séko (Holli)	3.7	-	9.6	5.8
Chnootriba similis	Founavou (Yom, Pilapila)	11	2.6	1.8	5.5
Sesselia pusilla	Aguira n'ta (Holli)	5.8	-	4.1	4.1
Cofana spectra	Igbé (Holli), Couture (Aizo)	2.6	-	5.5	3.5
Maliarpha separatella	Awa (Mahi)	-	1.3	4.1	2.1
Diopsis thoracica	-	5.2	-	-	2.1
Eysarcoris inconspicius	-	3.7	-	1.4	2.1
Orseolia oryzivora	Do (Germa)	2.1	-	0.9	1.2
Leptocorisa oratorius	-	-	2.6	1.4	1
Scirpophaga spp	-	-	-	2.3	1
Locris maculata	-	0.5	-	0.9	0.6
Ants	Tanan (Bariba)	0.5	-	-	0.2

N= Number of surveyed farmers.

Table 4. List of insecticides used by farmers to protect rice production

Location	Trade name	Active ingredient	Chemical family	Place of purchase	WHO class	Number of surveyed farmers			
						South (N = 20)	Centre (N = 2)	North (N = 15)	All regions (N = 37)
Field	Pacha Super 35 EC	Lambda-cyhalothrine (15 g/l) Acetamipride (20 g/l)	Pyrethroid	Market	II	20	-	-	20
	DD Force (Piapia)	Dichlorvos or DDPV1000 EC	Organophosphate	Nigeria	Ib	-	-	13	13
	Thalis 112 EC	Emamectin benzoate (48 g/l) + Acetamipride (64 g/)l	Avermectin + Neonicotinoid	Market	II	-	-	2	2
	Cobra 120 EC	Acetamiprid (64 g/l) + Spinetoram (56 g/l)	Pyrethroid + Spinosyns	Market	II	-	1	-	1
	Calfos 500 EC	Profenofos (500 g/l)	Organophosphate	Market	II	-	1	-	1
						(N = 58)	(N = 0)	(N = 13)	(N = 71)
Storage	Lambda Super 2.5	Lambda-cyhalothrine (25	Pyrethroid	ATDA	II	8	-	-	8

EC	g/l)							
Sofagrain	Pyrimiphos methyl (1.5%) + Deltamethrin (0.05%)	Pyrethroid	Market	II	40	-	-	40
DD Force (Piapia)	Dichlorvos or DDPV 1000 EC	Organophosphate	Nigeria	Ib	-	-	13	13
Percal 100 EC	Permethrin (100 g/l)	Pyrethroid	Market	II	10	-	-	10

Table 5. Farmers' perception (% of responses) of rice diseases according the production zones

Diseases	South (N = 64)	Centre (N = 38)	North (N = 108)	All regions (N = 210)
Narrow brown leaf spot of rice	13.1	12.5	41.5	27.1
Rice blast	29.8	27.5	21.1	25.1
Leaf scald	25.0	17.5	25.2	23.9
Rice yellow mottle virus	19.0	42.5	12.2	19.5
False smut disease	9.5	-	-	3.2
Bacterial leaf blight	3.6	-	-	1.2

N = number of interviewed farmers

Table 6. Weeding control methods, number of weeding in a rice season and management of weeded grass in the study area

	Number of surveyed farmers			
Weed control methods	North (N = 236)	Centre (N = 52)	South (N = 138)	All regions (N = 409)
Hoe weeding	69	21	24	114
Hoe weeding + herbicide	78	22	87	187
Herbicide	89	9	10	108
Number of hand weeding	(N = 147)	(N = 43)	(N = 111)	(N = 301)
1	91	6	5	102
2	51	20	51	122
3	4	16	55	75
4	1	1	-	2
Management of weeded grass	(N = 69)	(N = 21)	(N = 24)	(N = 114)
Used in organic amendment	36	-	-	36
Cleared out of the field	11	11	13	35
Abandoned in the field	13	10	11	34
Burned	8	-	-	8
Desiccated with herbicide	1	-	-	1

Table 7. List of herbicides used by farmers to protect rice production

Commercial name	Active ingredient	Chemical family	WHO class	CNGP	Percentage of responses			
					North (N= 167)	Centre (N= 31)	South (N=97)	All regions (N=295)
Garil 432 EC	Propanil (360 g/l) +Triclopyr (72 g/l)	Anilide + Pyridine	II	Rice	28.5	24.2	30.6	28.5
Kalach Extra70 SG	Glyphosate (700 g/kg)	Organophosphate	III	BS	24.5	22.6	19.4	22.7
Herbextra 720 SL	2,4 D- amine salt (720 g/l)	Alkylchlorophenoxy	II	Rice	19.2	29	6	16.6
Calriz	Propanil (360 g/l) + Triclopyr (72 g/l)	Anilide + Pyridine	II	Rice	13.1	6.5	7.5	10.5
ButaForce	Butachlore 50 %	Chloroacetamide	III	-	2.4	-	9	4.1
Force up SL	Glyphosate (480 g/l)	Organophosphate	III	-	4.1	-	1.5	2.7
Tripro EC	Propanil (360 g/l) +Triclopyr (72 g/l)	Anilide + Pyridine	II	Rice	2.9	-	3.8	2.7
Condor 500 SC	Fluometuron (250g/l) + Diuron (250 g/l)	Substituted urea + Phenylamide	II	-	-	-	9	2.7
Herbiax 60 AD-AG	Bensulfuron-methyl 60%	Pyrimidinyl sulfonylurea	III	-	-	4.8	6.7	2.7
ButaPlus	Butachlore 50 %	Chloroacetamide	III	-	2.9	-	3	2.5
Pilaherb	2,4 D- amine salt (720 g/l)	Alkylchlorophenoxy	II	-	-	8.1	-	1.1
Sharp Shooter	Glyphosate (480 g/l)	Organophosphate	III	BS	0.8	-	0.7	0.7
Adwuma Wura	Glyphosate (480 g/l)	Organophosphate	III	-	0.4	-	0.7	0.5
Stomp CS	Pendimethalin (450 g/l)	Dinitroaniline	III	Cotto	-	3.2	-	0.5

				n				
Finish 360 SL	Acid glyphosate (360 g/l)	Organophosphate	III	BS	-	1.6	0.7	0.5
Weed king	2,4 D- amine salt (480 g/l)	Alkylchlorophenoxy	II	-	0.4	-	-	0.2
Pilaherb	2,4 D- amine salt (720 g/l)	Alkylchlorophenoxy	II	-	0.4	-	-	0.2
Propacal Plus 560 EC	Propanil (300 g/l) + 2,4-D (200 g/l)	Phenoxyacetic	II	-	0.4	-	-	0.2
Flysate	Glyphosate isoproyalamine salts (41%)	Organophosphate	III	-	-	-	0.7	0.2
Weed fire 480 SL	Glyphosate (480 g/l)	Organophosphate	III	-	-	-	0.7	0.2

WHO classification class II: moderately hazardous, III: slightly hazardous. CNGP: Recommendation of the National Pesticide Management Committee of the Republic of Benin (2020), BS: Broad spectrum,

Table 8. Rice storage constraints and proposed solutions (% of responses) to overcome them throughout the study area

Constraints	**Regions**			**All regions** (N = 275)
	North (N = 152)	**Centre** (N = 20)	**South** (N = 103)	
Rodents	79.1	21.1	46	62.1
Insufficient storage warehouse	13.1	10.5	23.9	17.2
Lack of financial means	1.9	42.1	7.1	6.6
Insects	5.2	-	9.7	6.6
No drying and threshing air	-	26.3	11.5	6.3
Lack of pest control method	0.7	-	-	0.4
Need for tarpaulin covers	-	-	0.9	0.4
Lack of training	-	-	0.9	0.4
Proposed solutions	(N = 207)	(N = 49)	(N = 124)	(N = 380)
Dry the seeds well	3.2	58.7	77.6	31.9
Place the bags on a support to avoid rodent attacks	26.5	1.3	0.7	15.7
Keep bags out of termites' reach	18.8	-	-	10.9
Use of rodenticides	9.6	18.7	7.2	10.2
Owning cats	13.7	-	-	8
Use of insecticides	8	-	6.6	6.5
Avoid places where mice frequent	10.5	-	-	6.1
Put the rice bags at home	5.4	-	-	3.1
Good winnowing of seeds before storage	0.4	10.7	4.6	2.9
Disinfection of the storage place	2.9	2.6	2	2.6
Harvest the ripe rice	-	8	1.3	1.5
Store bags of rice in dry places	0.6	-	-	0.4
Store rice in a windowless store	0.4	-	-	0.2

Table 9. Farmers' perception (number of farmers) of storage insect pests associated to rice

Pests	North (N = 17)	Centre (N = 10)	South (N = 47)	All regions (N = 74)	
				Number	Percentage of responses
Sitophilus oryzae	-	-	24	24	22.9
Corcyra cephalonica	-	-	21	21	20
Sitophilus zeamais	2	-	17	19	18.1
Termites	16	-	-	16	15.2
Sitotroga cerealella	-	-	14	14	13.3
Rhyzopertha dominica	-	10	-	10	9.5
Trogoderma granarium	1	-	-	1	1

N= Number of surveyed farmers.

Table 10. Proportion of farmers using pesticides for rice protection in the study area

Pesticides	**North** (N = 172)	**Centre** (N = 32)	**South** (N = 102)	**All regions** (N = 306)	
				Number	**Percentage**
Herbicides	167	31	97	295	96.4
Insecticides	78	2	15	95	31.0
Rodenticides	23	3	25	51	16.7

Table 11. Factors influencing the use of pesticides by rice farmers in the study area

Variables	**Coefficient**	**Odds ratio**	**Standard error**	**P>|z|**	**Marginal effect**	**P>|z|**
Sex	-0.208	0.812	0.158	0.190	-0.069	0.187
Age	-0.008	0.992	0.006	0.173	-0.002	0.170
Educational level	-0.006	0.994	0.031	0.832	-0.002	0.832
Experience	0.014	1.014	0.007*	0.055	0.040*	0.052
Farm size	-0.074	0.928	0.050	0.141	-0.250	0.139
Number of workforce	-0.002	0.998	0.006	0.721	-0.000	0.721
Number of family members	0.057	1.058	0.016***	0.001	0.019***	0.000
North	0.318	1.374	0.211	0.115	0.106	0.112
South	0.696	2.005	0.219***	0.002	0.232***	0.001
Number of diseases observed by farmers	-0.132	0.876	0.090	0.142	-0.044	0.139
Number of others pests observed by farmers	0.074	1.076	0.044*	0.096	0.024*	0.093
Constant	0.488	1.629	0.306	0.111		

Log-likelihood	-246.38837
LR chi2 (11)	38.89
Prob > chi2	0.0001
Pseudo R2	0.0731

∗ Significant at 10% level ($p < 0.10$), ∗∗∗ Significant at 1% level ($p < 0.01$). Central region was used as reference.

Figure 1. Map of Benin showing the surveyed villages

Figure 2. Some important rice-eating weavers in Dévé-village

Figure 3. Some birds management methods in the study area. (a) birds poisoned by farmers using rice poisoned with commercial insecticide Sniper having the Bifenthrin as active ingredient ; (b) Keeping granivorous birds away from rice fields using slingshot; (c) Farmers fixing a net cover in his rice field; (d) straw hut built in rice field to hunt birds; (e) Scarecrow placed in rice fields to scare birds; (f) Plastic bag stakes, which emit noises during draughts that scare birds; (g) Hanging sheet metal with empty bottles and snail shells, which at the slightest air flow collide with each other and make noises that frighten birds.

Figure 4. Farmers' perception of the rice seeds' shelf life

Figure 5. Famers perception of factors favouring infestation of stored rice by pests

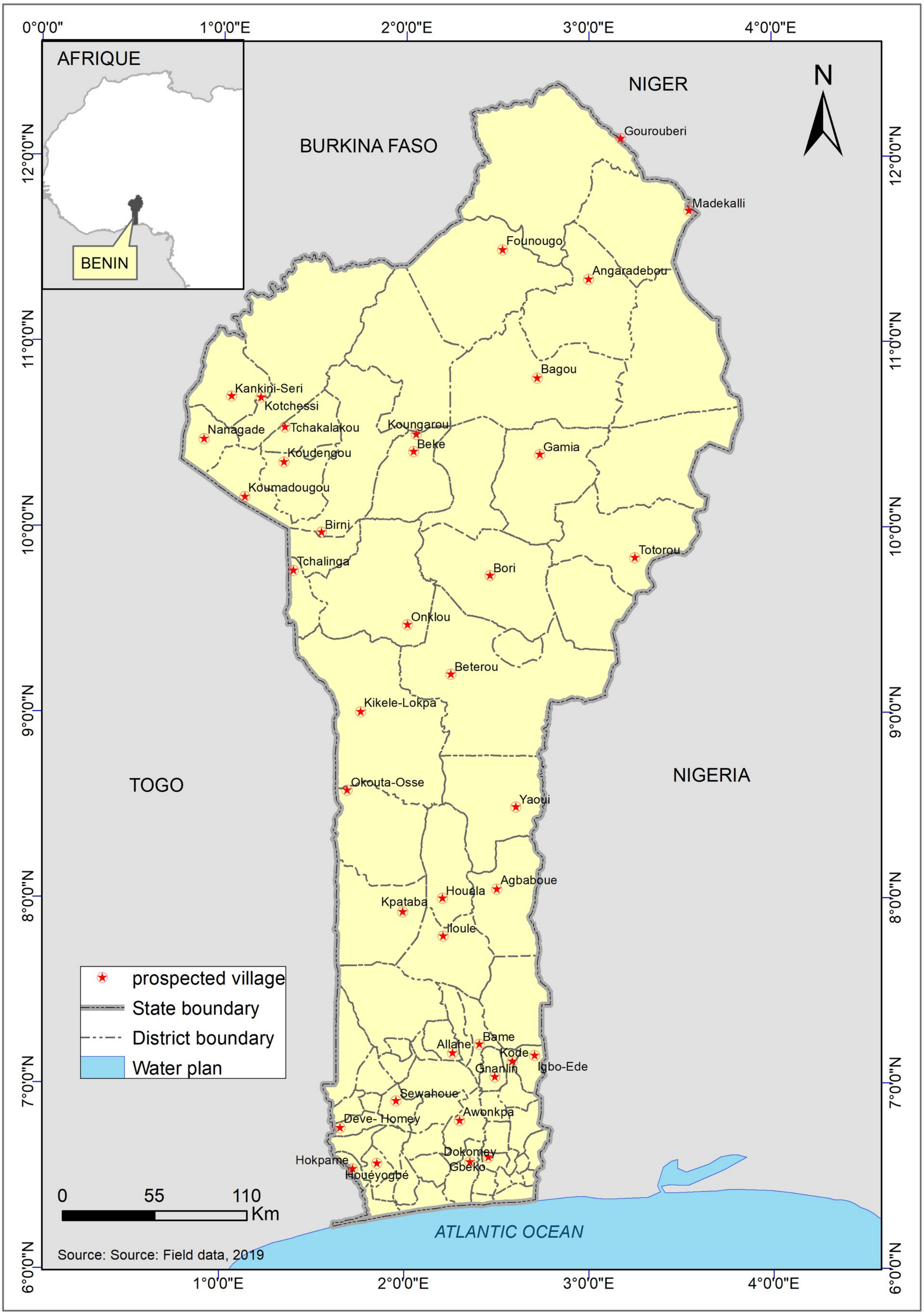
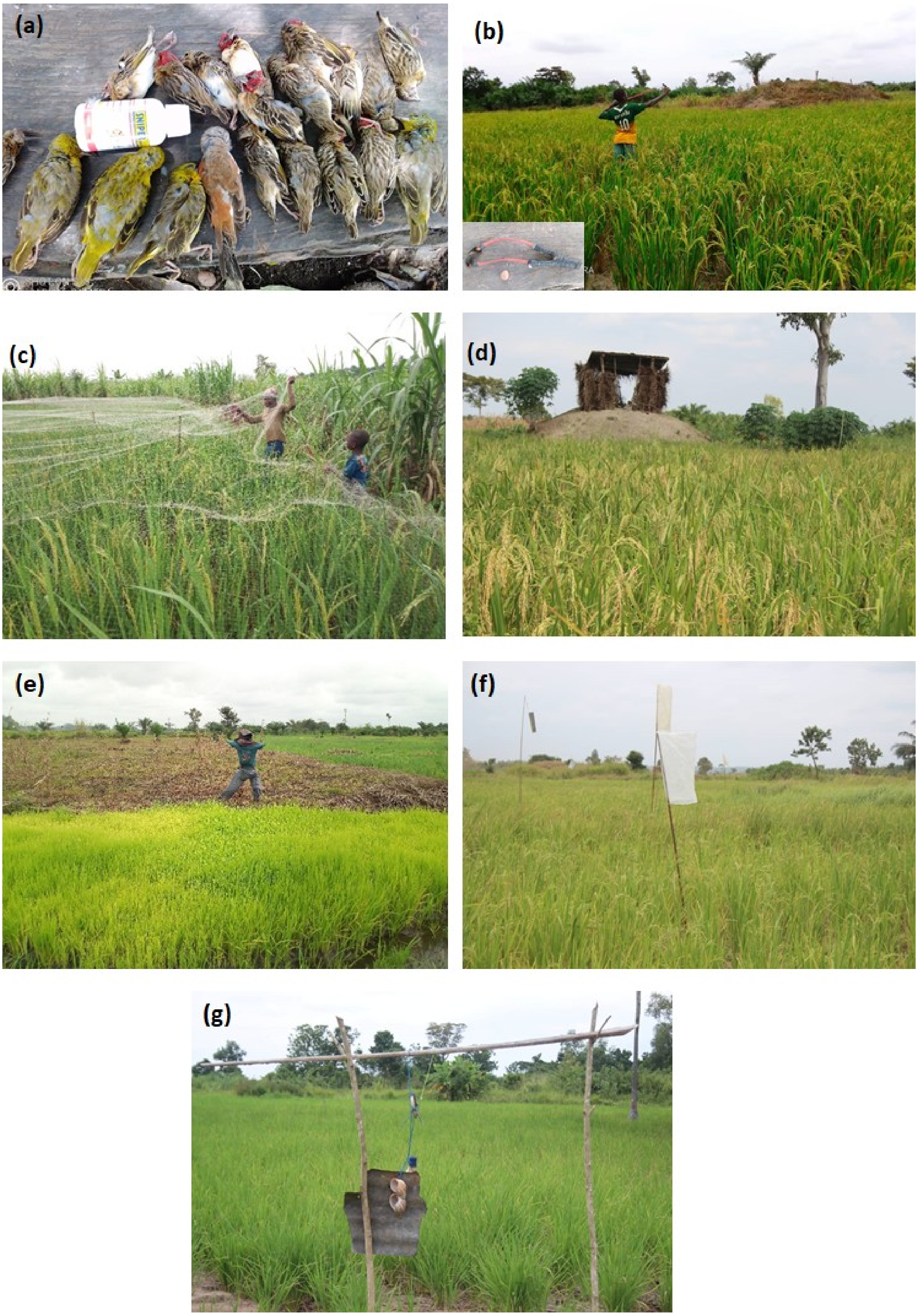


Figure 1: Map of Benin showing the surveyed villages

Figure 2: Some important rice-eating weavers in Dévé-village



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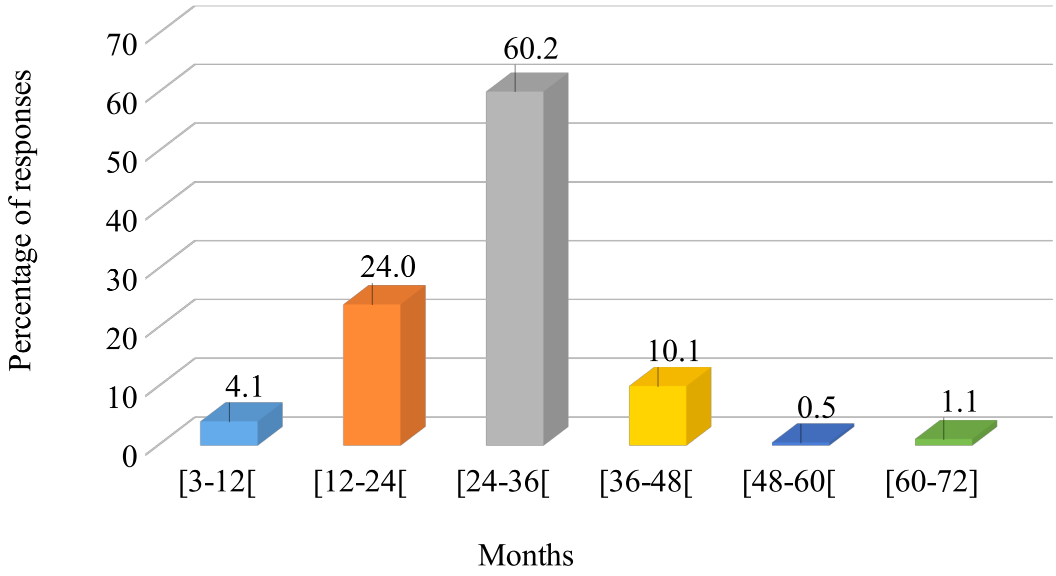

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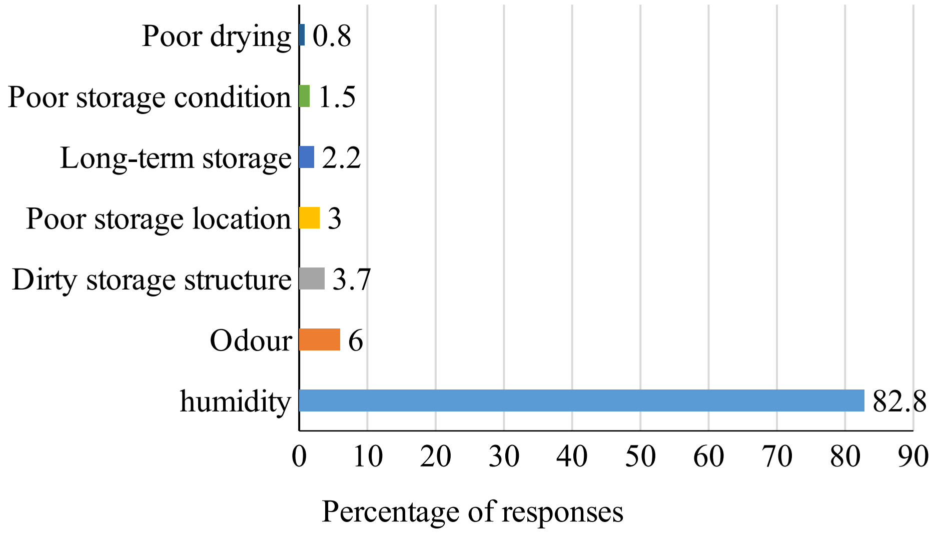

Figure 5: Famers perception of factors favouring infestation of stored rice by pests