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Inventory and impact of pests of different rice varieties stored in Senegal

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Abstract
Rice is the most widely consumed cereal in the world. In Senegal, it is the essential foodstuff of population. Its permanent availability in stocks is a factor of food security. However, rice stocks are attacked by several predators that could lead to losses. That is in prospect of ensuring better management of these stocks, that this study has been carried out. Its objective is to identify predators of different varieties of stored rice. In order to attain that, sampling on different varieties of stored rice from Senegal River valley has been completed. Varieties have been selected as paddy and white rice. It concerns Sahel 108, Sahel 134, Sahel 177, Sahel 202 and Sahel 317. An inventory of predators occurring in rice stocks, as well as an assessment of damage brought about by these pests, have been done, to determine abundance and diversity of predators, and losses they have caused too, respectively. Results reveal that four species of pests attack rice stocks namely, and in order of abundance in rice stocks, *Rhyzopertha dominica*, *Sitophilus oryzae*, *Corcyra cephalonica*, and *Tribolium castaneum.* Of all pests, *C. cephalonica* is lepidoptera, the others are beetles. Moreover, *Rhyzopertha dominica* is particularly abundant in paddy rice, whereas *Sitophilus oryzae* and *Corcyra cephalonica* are plentiful in white rice. Population of *T. castaneum* is low in both paddy and white rice. Diversity of the listed species is lower in paddy. In terms of varieties, it is less important in the Sahel 134. Appraisal of losses, which only concerns some varieties of white rice that are among the most widely cultivated in the Senegal River valley, reveals significant losses amounting to 11.11% in three months of storage.

Keywords: losses, pests, rice, storage, varieties

Introduction

Rice represents nutrition source for about 50% of the world population [25]. For human nutrition troughout the world, this cereal takes the lead [11]. Rice cultivation in Senegal has got a long tradition, especially in the "Basse Casamance" domain [18]. Rice consumption has increased rapidly, making it a major foostuff in both urban and rural areas [20]. According to FAO [14], rice use in Senegal varies between 80 kg and 100 kg per inhabitant and per annum, and national consumption is estimated at 1 million tonnes per year [6, 27]. However, both production and consumption reach 90% in Asia, with China, India and Indonesia which, on their own, represent more than half of the global production [12]. In West Africa, another center of rice use, Senegal has become one of the largest importers of broken rice behind Nigeria [27]. From which FAO expectations [14], which forecast that rice imports into West Africa will be in the order of 6.4-10.1 million tonnes in 2020 [14]. Senegalese rice production, accounts for only 20% of the whole demand, with the remaining 80% proceeding from importation [2]. Thus, each year Senegal imports around 800,000 tonnes of broken rice from Asian countries, compared with an average production of 450,000 tonnes of paddy rice, or 290,000 tonnes of white rice with 65% machine finishing rate [2]. In 2011 rice, on its own, represented 6.9% of Senegalese imports, that is to say almost 175.6 billion CFA francs [1]. These rice imports contribute to 16% of trade deficit [27]. To turn round this trend, Senegalese political authorities and partners in development have been implementing programmes over the past two decades, in order to reduce the country's dependence on imported rice [3, 13], and to achieve rice self-sufficiency by 2017 [22]. Among strategies, there is producing improved rice varieties out of agricultural research. In Senegal, there are 32 registered rice varieties in the official catalogue of crop species and varieties [19]. Despite all these efforts, Senegal have trouble to redress its balance trade, and reach rice self-sufficiency. This problem is partly due to post-harvest losses, which rise to 13.61% in 6 months of storage [26]. They occur at all levels, from harvest to consumption: first at the producer level, whether the product is for subsistence farming, for seed, or waiting to be marketed; then during carriage to stocking sites, at stocks, and finally in traders' stores [30]. This is confirmed by studies [24] which show that more than 30% of production is lost between harvest and use, a proportion that is higher in the Sahel region, due to long storage period. These losses are brought about, at 44%, by insects [31]. Furthermore, phenotypic damage, caused by these insects and losses they generate, both in field and stock, can expose producer to insecurity and precariousness [10]. According to Gueye *et al.* [17] much work refers to attack and loss about cereal and legume stocks by insects [17, 28, 4]. However, so far, little information are available on pests of rice stocks in Senegal. In fact, only studies in [26] have been carried out, and these did not take varieties into account. That is where lies the important of this work, for so far, specific studies have never been done on stored rice varieties. The general aim of the study is to inventory all predators found in different rice stored varieties, and evaluate their impact as for quantitative losses on these varieties.

Materials and Methods

Study site

Senegal is located at the extreme west of Africa, between 12° 20' and 16° 40' North latitude, and 11° 20' and 17° 30' West longitude. It covers an area of 196722 square kilometres. It is irrigated by three rivers (Senegal, Gambia and Casamance) and is located in a rainfall zone between isohyet 250 and isohyet 1250 mm. The country, therefore, has enormous agricultural potential, particularly in rice cultivation. The study has been carried out in the Senegal River Valley for it is the most important rice-growing area in the country. Irrigated rice cultivation is practised there and the greater part of Senegalese rice production is from this zone.

Sampling

It was carried out according to the method recommended by the World Food Programme (WFP). It consists of proceeding in the way illustrated in the table below.

Table 1: Sampling technique

Total number of bags	Actual number of bags sampled
1 à 10	All bags
11 à 25	5
26 à 50	7
51 à 100	10

In each locality, the number of warehouses and sampled varieties depended on the owner's agreement and availability. The formers varied between 4 and 5 warehouses. Total quantity of rice sampled in each warehouse varied between 1 and 2Kg. The whole number of varieties sampled was five (5): Sahel 108, Sahel 134, Sahel 177, Sahel 202, and Sahel 317. These varieties, in addition to their availability, were among the most cultivated in the zone because they had a short cycle and good yield. For Sahel 108, it is adapted to both seasons (rainy and dry). Taken samples are packaged in bags which have been labelled with the date of sampling, the name of the locality, and that of the variety.

Sample processing

Samples, packed in bags, were taken to laboratory to sort out occurring species. For that, samples were first distributed in plastic jars, then weighed, using an electronic balance (maximum weight: 620g, minimum weight: 1g, accuracy: 0.01g). At the end of the weighing, each jar contained 150g, and was labelled with the date of sorting, the name of the locality, and that of the variety. Thus, each jar was considered separately, and its content poured, and then spread out. This made it possible to identify and count individuals for each species. After which, each sample was put back into its jar, and closed with a riddled lid for individuals to breathe. Following all these activities, jars were then left at room temperature, under approximately the same conditions as those in stocks. Sorting and counting were done every 30 days. This corresponds to the duration for pests, found in stocks, to complete their life cycle. These two actions allowed to monitor the development of insect populations over time. This monitoring lasted for 7 months of storage.

Finally, assessment of losses caused by pests was only done on white rice and the following varieties: Sahel 108, Sahel 134 and Sahel 177. These varieties were chosen because they are among the most widely cultivated in the river valley, but also because of their short cycle of development, high productivity and good milling rate which is over 60% for all three varieties [33]. The sieving-weighing process was used to quantify losses. It consisted of putting varieties in jars that would each contain 100g of rice. After 30 days, content of each jar were weighed and sieved. After sieving, the latter was weighed again to assess losses due to insect activity, which were materialised by a difference in weight. This activity was continued for three months.

Data processing

Measured parameters

Abundance and diversity

In ecological aspect, peopling of these rice stock predators was expressed mathematically and graphically using several analytical methods.

Relative abundance (Pi)

It is defined as the ratio between the size of species i for example (ni) and the total number of individuals of the different species in the stand (N) [7]:

$$Pi = ni / Ni$$

Diversity

The study of settlement diversity was carried out with the help of numerous indices:

- **Shannon Diversity Index (H'α)**

It is an index, widely used in ecology [23]. It gives an account of the diversity of species that make up the stands in an environment [32]. The larger the Shannon index (H'α), the more diverse the stand [15]. It is between 0 and Log_2S, where S represents the species richness, which is the total number of species in a sample [32]. According to Shannon and Weaver, (1963) its expression is:

$$H'\alpha = -\Sigma Pilog_{2Pi}$$

- **Simpson's Index (Is)**

This is the probability that two individuals selected at random belong to the same species [16]. In [15], this index measures the degree of species diversity in the stands of an environment. According to this study, it has a value in the range [0, S]; 0: number of individuals concentrated in a single species; S: species richness). A high index indicates low diversity. Its formula is:

$$Is = 1 / \Sigma Pi_2$$

- **Piélou regularity or equitability index (EH)**

The Piélou index is used to measure the equitability (or equirepartition) of the species in the stand in relation to a theoretical equal distribution for all species [32]. This index varies between 0 and 1 [15]. It is maximum when the species have identical abundances in the stand and it is minimal when a single species dominates the whole stand [7]. It is formulated according to [15] as follows:

$$E_{H} = H'\alpha log_{2S}$$

H'α: observed value; Log2S: theoretical maximum value.

- **Dulmann's similarity index (K)**

This index is used to determine the specific similarities between different stands in an area [15].

$$K = \frac{2c}{a+b} \times 100$$

a: specific richness of stand 1; b: specific richness of stand 2; c: number of taxa common to both stands.

Evaluation of quantitative losses

Quantitative losses are related to weight reduction. They have been calculated according to [26] by the following formula:

$$\text{Losses (in \%)} = \frac{\text{Initial sample weight} - \text{Weight after sieving the sample}}{\text{Initial sample weight}} \times 100$$

Statistical analysis

The data resulting from the sample processing are discrete quantitative data. They are recorded in an Excel spreadsheet. The data concerning losses are put in CSV format and are then analysed with the R Software (version R 3. 6. 3). In order to quantitatively evaluate losses on white rice, different tests have been done with the R software. The Shapiro test completed on the weight variable, as it is the only quantitative variable in the database used to evaluate losses. This test showed that this variable does not follow the normal law. Thus, the Kruskall Wallis test was also carried out to determine the losses according to the varieties since these variables have modalities higher than 2.

Results and Discussion

Results

Insect pests identified in rice stored during the study are three (3) species of beetles divided into three (3) distinct families and one (1) species of lepidoptera. Beetles are *Tribolium castaneum*, *Sitophilus oryzae* and *Rhizopertha dominica,* belonging to the following families, respectively: Tenebrionidae, Curculionidae and Bostrychidae. The lepidoptera in question is *Corcyra cephalonica of the* family Pyralidae. Results obtained in Table 2 show that after seven (7) months of storage, 90.65% of the predators attacking rice stocks are beetles. Among them, *Rhizopertha dominica is* the most represented (61.25%) followed by *Sitophilus oryzae (*28.33%) and *Tribolium castaneum* (1.07%). Lepidoptera with only *Corcyra cephalonica* represent the remaining 9.35%.

Table 2: Different species recorded

Orders	Species	Families	Percentage (%)
Beetle	*Rhizopertha dominica*	Bostrychidae	61.25
	Sitophilus oryzae	Curculionidae	28.33
	Tribolium castaneum	Tenebrionidae	1.07
Lepidoptera	*Corcyra cephalonica*	Pyralidae	9.35

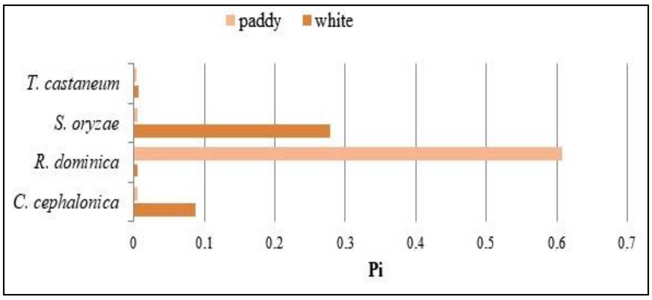
Abundance and diversity of pests

Abundance of pests

Following inventory of occurring species, the relative abundance was calculated for the different pests encountered. This made it possible to see the abundance of pests according to the parameters that are: Rice types, Varieties and Sortings (ST).

Abundance of pests according to the type of rice

Figure 1 shows the abundance of pests as a function of rice type. It shows an attack that is more pronounced in one type of rice. This is shown by the relative abundance of pests, which is relatively high in one of the rice types (paddy or white). Thus, it is noted in *R. dominica*, a higher *attack on paddy* rice than on white rice where it is found with a very low relative abundance. Conversely, *S. oryzae* and *C. cephalonica* attack white rice more strongly than paddy rice where they are less abundant. It should also be noted that *S. oryzae* is more abundant in white rice than *C. cephalonica.* However, in *T. castaneum* a very weak attack is observed on both types of rice.

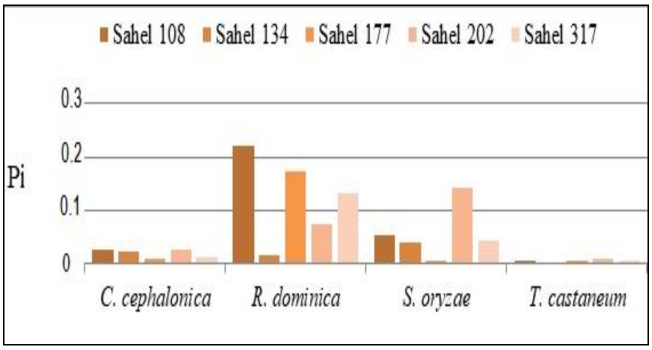


Pi: Relative abundance

Fig 1: Pest abundance as a function of rice type

Abundance of pests according to varieties

Figure 2 shows the abundance of pests as a function of variety. It reveals that *R. dominica* is the most attacking pest of the stored rice varieties. It is followed by *S. oryzea and* then *Corcyra cephalonica*. Finally, comes *T. castaneum which* is the pest that attacks the varieties the least, it is absent in the Sahel 134 variety and has almost zero relative abundance in the other varieties. However, it should be noted that *R. dominica* has a high abundance in the varieties Sahel 108, Sahel 177, and Sahel 317 but low in the varieties Sahel 134 and Sahel 202. *Sitophilus oryzea* has a population that is high in Sahel 202 and very low in Sahel 177. In the other varieties its population is quite high. *Corcyra cephalonica* has a low abundance in all varieties, but it is relatively low in Sahel 177 and Sahel 317.



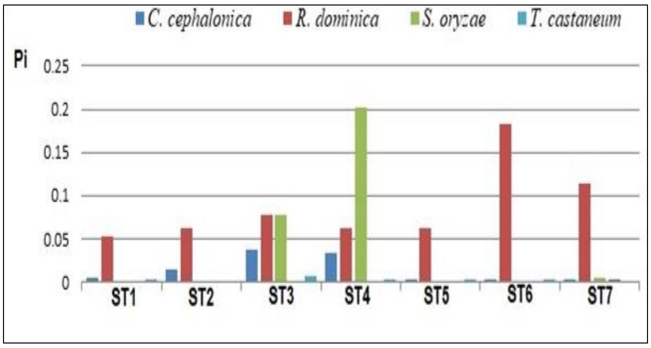
Pi: Relative abundance

Fig 1: Pest abundance as a function of variety

Abundance of pests according to sortings

Figure 3 shows the abundance of predators as a function of sorting. It can be seen that evolution of pest populations as they are sorted (ST = 30 days) is a sawtooth pattern. In the case of *R. dominica,* it is noted that population development is progressive until ST3, then there is a decrease which is constant between ST4 and ST5. It resumes and pe aks at

ST6 before declining again at ST7. On the other hand, C. *cephalonica* has an increase in population until TRI3, at which point it starts to decline. Beyond ST4 this decline is very strong with relative abundances almost nil. For *S. oryzea*, it appears from ST3 onwards and its population experiences a maximum growth at ST4. It is nil at ST5 and ST6 and remains very low at ST7 with a relative abundance that is also almost nil. However *T. castaneum is* observed from ST3 but is almost absent from the others with relative abundances very close to 0.



Pi: Relative abundance

Fig 2: Pest abundance as a function of sorting

Diversity of pests

The study of diversity required the use of different indices. These allow us to see the behaviour and diversity of pests attacking stored rice. They were calculated according to the following parameters: Types of rice, Varieties and Species.

Diversity of pests according to rice type

Table 3 shows the diversity of pests according to rice type. Thus, apart from their equal specific richness, this diversity translates into higher Shannon and equitability indices in white rice than in paddy rice. The Shannon diversity index value in white rice (0.91) reveals a more diverse stand than that found in paddy rice (0.54). However, these values are low compared to the theoretical maximum value of 2. In addition to this value, the equitability index shows that there is a disproportionate abundance between species in the two types of rice. However, this disproportion between species is more marked in paddy rice. The value of the Dulmann index reflects a 100% similarity between the two stands.

Table 3: Pest diversity by rice type

	Indices			
Type of rice	**S**	**Shannon (H'α)**	**Equitability (EH)**	**Dulmann (K)**
White	4	0.91	0.45	100%
Paddy	4	0.54	0.27	100%

Diversity of pests according to varieties

Table 4 shows diversity of pest stands by variety. Results show that Sahel 108, Sahel 177 and Sahel 202 varieties have a species richness of 4, while Sahel 134 and Sahel 317 have a species richness of 3. Sahel 108 and Sahel 202 have the most diverse pest stands. This can be seen in their respective Shannon indexes of 0.85 and 0.86. The variety Sahel 134 has the stand with the lowest species diversity, its Shannon index is 0.39. Sahel 317 and Sahel 177 have pest stands that can be considered moderately diverse compared to other varieties. The results also show a disproportionate abundance between species in all varieties. This disproportion is most pronounced in Sahel 134 and Sahel 177 with very low equitability indexes of 0.25 and 0.28 respectively. The other varieties have identical equitability indexes. The similarity of pest stands between Sahel 108, Sahel 177 and Sahel 202 varieties is 100%. However, stand similarity between Sahel 134 and the other varieties is 75%.

Table 4: Pest diversity by variety

	Indexes		
Varieties	**S**	**Shannon (H'α)**	**Equitability (EH)**
Sahel 108	4	0.85	0.43
Sahel 317	4	0.66	0.42
Sahel 177	4	0.55	0.28
Sahel 134	3	0.39	0.25
Sahel 202	4	0.86	0.43

Specific diversity of pests

Table 5 shows study of the specific diversity of pests attacking stored rice. Results show that globally 4 species of pests attack stored rice. They reveal a good degree of species diversity through the Simpson index, which is 2.15 compared to the theoretical maximum value (4). In addition, there is the Shannon index which confirms this diversity of species with a value of 1.33, which is quite close to the theoretical maximum value (2). The equitability index with a value of 0.66, which is high compared to the theoretical maximum (1), reflects a balanced abundance between species.

Table 5: Specific diversity of pests

Species	Staff	CA	S	Pi	$Pi^2 \times (10^{-4})$	Log_2Pi	$PiLog_2Pi$
C. cephalonica	312	IX	4	0.09336	87.1558	-3.4211	-0.3194
R. dominica	2047	XI	4	0.61251	3751.65	-0.7072	-0.4332
S. oryzae	947	X	4	0.28336	802.947	-1.8193	-0.5155
T. castaneum	36	VI	4	0.01077	1.16036	-6.5366	-0.0704
Total	3342						-1.3385
$Is=1/\sum Pi^2$ $H'\alpha = -\sum PiLog_2Pi$ $EH = H'\alpha / Log_2S$							2.15382 1.33848 0.66924

Evaluation of losses

Quantitative losses recorded on white rice after 3 months of storage in the laboratory amount to 11.11%. These losses were also studied according to varieties and sorting.

Losses according to rice varieties

Figure 4 shows the losses recorded as a result of pest activity as a function of varieties. Analysis of the figure reveals that the difference in losses between varieties is not significant (p-value = 0.61).

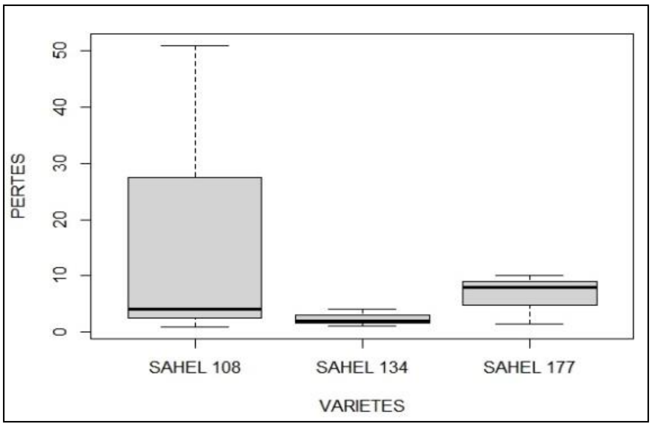


Fig 3: Losses recorded as a function of varieties

Discussion

In this study, results reveal that beetles, particularly those of Bostrychidae, Curculionidae, and Tenebrionidae families, represent 90.65% of the insects attacking rice stored in the Senegal River valley. Further, only 9.35% of lepidopterans of the Pyralidae family are recorded. Thus, identified species are: *R. dominica*, *S. oryzea*, *T. castaneum* and *C. cephalonica*. These results are in line with those obtained by [26] who identified these species in rice stocks with similar proportions. They are also in accordance with those of [17], who worked on rice and other cereals. Their results show other species in addition to those mentioned above. The study shows as well that rice stock predators have different abundances of different types and varieties of rice. In fact, *R. dominica* is the most prolific species during storage and occurs in all rice varieties. It is much more abundant in paddy rice than in white rice, with a very low frequency in the latter. This result differs from that of [26], which ranks this species as the second most important in rice stocks after *T. castaneum*. This difference could be explained by the fact that shops as well as sampled localities are not in similar conditions, which could lead to a difference in the degree of infestation. On the other hand, the fact that *R. dominica* is practically only present in paddy rice corroborates the results of [26] who considers this species to have a predilection for paddy rice. It is therefore considered to be a major primary pest of rice. This status is confirmed by the work of [9]. [21] Shows that in addition to rice, *R. dominica* has this status on a number of cereals. *Sitophilus oryzea is* the second most abundant species in rice stocks. It is classified as a primary pest according to [9]. It has been found in all varieties and types of rice, but its abundance is higher in white rice. In paddy, it is very poorly represented. This indicates that the pest has a particular preference for white rice. This result is similar to that of [26], but its rank as the second most abundant species does not correlate with its result that it is considered third in terms of abundance in rice stocks. It should also be noted that this result from [26] concerned both the local rice and the imported one (rice), unlike (the) results of this study, which focused only on local rice. *Tribolium castaneum* is the least abundant predator in rice stocks during these months of storage. It is present in both types of rice and varieties with very low frequency. This low abundance (near-absence) is thought to be due to the period of study, which was not favourable for its development or to the resistance of the rice to it. However, a strong proliferation of *T. castaneum* was noted in [26], making this species the most prolific pest of rice stocks. This could be related to the storage period and the diversity of its samples, which come from several localities (7). *Corcyra cephalonica*, is the only lepidopteran species recorded in rice stocks during the study.

It is found in all varieties of rice, but is mainly abundant in white rice. This is corroborated by the study in [5], which considers this species to be one of the most serious predators of stored rice. Its larvae cause significant damage because, in addition to feeding on rice, they weave silk cocoons in it.

In terms of diversity of predators in rice stocks, differences related to the type of rice were observed. These are thought to be due to the fact that the pests have a preference for one of these rice types. This may be related to the nature of mouthparts buccal apparatus pieces that allow the pest to feed easily on the most suitable type of rice. This preference may also be related to the presence or absence of husks which may be useful for the pest species. This correlates with the results of [9], which show that the presence of the pest may be due to the presence of husks in paddy rice. These envelopes would serve as a hiding place for the pest species according to [8]. In addition, the possibility of being able to develop their larvae may justify their presence in one of the types of rice [9]. This ability explains the high presence of *R. dominica in* paddy rice and *S. oryzea and C. cephalonica* in white rice. Study of pest diversity in relation to stored rice varieties shows differences between the latter. However, they are accentuated between the Sahel 134 Variety, which presents less diversity than the others. These differences are thought to be due, in part, to the delicacy of the husk surrounding the grain of some varieties. This characteristic favours the development of pests capable of attacking these envelopes. For white rice varieties, the differences may be related to the tenderness of the grains. Thus, when pests grow in varieties with tender grains, they tend to develop more efficiently. The species diversity results show an average diversity of predators. They appear gradually over time and their relative abundance is higher for a certain period of time before decreasing. This could be related to their development cycle, which takes place at different times. Losses on white rice are caused by the presence of a white powder. Their evaluation after 3 months of storage reveals that they are significant and amount to 11.11%. This result differs from that of [26] which recorded losses of 13.61% but with a longer storage period (6 months). This discrepancy would also be related to its damage assessment, which takes into account the types of rice, cultivars, sampled localities and storage types. It does not correspond with the result of [9], where losses are of the order of 8.44% in 6 months of storage. This disproportion with the latter would be related to its higher number of pests, which are divided into several families. A study of the damage caused by pests according to the most widely cultivated white rice varieties in the river valley shows that the damage caused is indiscriminate between varieties (p-value = 0.61). Thus, the damage caused would depend on the favourable living conditions for the pests that prevail in the stocks and the characteristics of the grain of the rice variety. These characteristics are the tenderness of the grain, its shape and its richness in nutrients. All these elements mentioned above are taken into account when judging the resistance of the grain. In support of this, the work in [9] shows a high attack rate and significant damage to parboiled rice, which has become more nutrient-rich compared to other types of rice.

Conclusion

In short, this work is part of the logic of participating in the effort to achieve national food sovereignty. In order to improve stock security and reduce post-harvest losses, several projects have been carried out. However, this study focusing specifically on stored rice varieties is approached for the first time. It has made it possible to identify the different species attacking these varieties, to determine their abundance and diversity, and to assess the losses they cause. In all, two orders of predators were identified: beetles and lepidoptera. The first order contains 3 pest species *R. dominica, S. oryzae* and *T castaneum* belonging to 3 distinct families which are Bostrychidae, Curculionidae and Tenebrionidae, respectively. The second order consists of a single species, belonging to the Pyralidae family, which is *C. cephalonica.* Studies on the abundance of these pests reveal that *R. dominica* is the most abundant species in the stocks and mainly occurs in paddy. *Sitophilus oryzae and C. cephalonica* are practically concentrated in white rice and are abundant in stocks. However, *T. castaneum* is the least abundant species. These species recorded during this storage time have a lower diversity in paddy than in white rice. Among varieties, this diversity is low in Sahel 134 and medium in the others. The study of losses caused by pests involved three varieties of white rice. It shows significant damage amounting to 11.11%. Damage ascertained is independent of varieties.

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