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Post-Harvest Constraints: Fungi and Insects Responsible for Rice (*Oryza* spp) Losses during Storage in Cameroon

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Abstract

The magnitude of rice grain losses during storage is huge and warrants critical attention. We investigated the diversity of fungi and insect contamination related to losses of domestic and imported rice from local mills and markets, stored under room conditions for 10 weeks in Cameroon. The highest percentage discolored grain was on imported milled white rice (3.5%), 10 weeks after storage. In general, imported rice samples contained the highest fungal load with a proportion of 65.90% compared to 34.3% for domestic samples. Weight loss due to insect damage was up to 19.9% in white milled domestic rice. Among the 67 isolated fungi strains, the genus *Aspergillus* had the highest prevalence (63.8%). From all the samples, 877 insects were collected with 719 (81.9%) of *Sitophilus.* It is urgent to develop sustainable and affordable storage methods to limit insect and fungi infestation on rice in Cameroon.

Keywords

Loss, Quantity, Quality, Safety, Cameroon

1. Introduction

Paddy rice (*Oryza* spp, Poaceae) production in Cameroon was estimated at 332,534 t in 2019, harvested from 288,637 ha, with an average yield of 1.152 t/ha [1]. The current food crisis is a global issue of food shortage that intensified with the COVID 19 pandemic and the Russian invasion of Ukraine. It is expected that more people will experience food insecurity in 2023 if nothing is done to regulate the consequences from these two crises like grain and fertilizer price hikes. The situation is more complicated because about 1/3 of food produced is lost along the harvest and post-harvest operations. Effective post-harvest management will thus be one of the solutions to tackle food shortage. After production, care should be taken during rice post-harvest management and strategies developed to effectively reduce losses, through adoption of improve practices, techniques and technologies. In sub-Saharan Africa, rice is ranked among the five most important staples together with maize, cassava, wheat and palm oil [2]. In addition to being an important staple, rice is also a strategic commodity in international trade and a political crop, thus affecting the economy and the livelihood of most countries in Africa [3]. With all these food security, political and economic potential, domestic rice production and overall quality in Cameroon and sub-Saharan Africa are faced with numerous abiotic and biotic constraints resulting in low yields, poor quality and compelling consumers to heavily depend on international trade [3] [4]. There are several factors that influence post-harvest management such as the environmental conditions (favorable relative humidity and temperature for the growth and development of fungi and insects in rice), the know-how and agricultural practices of the different actors, the equipment and techniques used during harvesting and post-harvest operations. An earlier study, [5] showed that the physical quality of rice is determined by the agro-ecological zone of production, production system, and agricultural practices. Production and postharvest handling practices along the rice value chain in Cameroon are still artisanal owing to low skills, lack of technology and infrastructure [5] [6]. Huge quantities of rice are lost because of poor harvest and post-harvest operations in Cameroon; which in addition reduce the physical quality of rice, with a high proportion of impurities and broken grains [4]. Rice post-harvest management is therefore constrained by huge losses, be it qualitative or quantitative.

The degradation in rice grain quality during storage results from fungal infestation and insect invasion that subsequently leads to quantitative losses. This is further exacerbated by climate change and the actual agroecological characteristics of Cameroon, favoring the growth and proliferation of fungi and insects [7]. In addition, authors [6] [8] showed that inadequate parboiling (soaking, steaming and drying) can lead to losses during storage. Globally, rice quality and quantity losses during storage range from 1% - 100% of the total harvest [9] [10]. To counter losses during storage, authors [11] [12] showed that hermetic storage in airtight bags protects rice from rodents, insects and fungal infestation. However, the hermetic storage technology is not easily accessible and as such not currently used in local mills or markets in Cameroon. Inadequate rice storage practices such as improper moisture content, use of poor storage bags, storage in uncleaned and wet environments can lead to quality degradation and physical grain losses caused by pests, sprouting, discoloration or contamination with mycotoxins [13] [14]. Rice is usually retailed in small quantities (even 1 Kg) in open jute and plastic bags, making the hygroscopic grains vulnerable to the fluctuating atmospheric relative humidity, temperature and dust settlement. In addition, rice remaining after marketing is stored in jute and plastic bags under inappropriate conditions with no or minimum control against insects, rodents, and humidity exposure. Grain open to pest infestation, temperature and humidity fluctuations is prone to fungal contamination. The occurrence of mycotoxin producing fungi and some mycotoxins including aflatoxin, ochratoxin and zearalenone in rice collected from markets in Nigeria was reported [15]. Fungal contamination of rice affects grain appearance and aroma which are important quality traits that attract consumers in African markets [16]. In addition to deteriorating rice grain quality and price, fungal contaminated grains will also exert mycotoxigenic effects on consumers due to mycotoxins secreted by the contaminating fungi. In Cameroon, authors [17] reported fungal contamination and mycotoxin occurrence at low levels in twelve local rice samples collected from smallholder farmers. However, a greater proportion of the rice consumed in the country is imported and reports on the fungi and insect infestation of imported and home-produced rice in Cameroon are scarce. It is therefore imperative to assess the storability of both imported and domestically produced rice to contribute to consumer safety and food security in Cameroon. The aim of this study was to investigate the occurrence of insects, fungi and discolored grains on domestic and imported rice samples in Cameroon and to quantify the losses in grains during storage.

2. Materials and Methods

2.1. Sample Collection

Paddy, parboiled and white milled rice samples were collected from mills in the Ndop rice development hub (RDH) of Cameroon in August, 2014. Parboiling is a hydrothermal treatment of rice paddy which strengthens the rice kernels and preserves its colour when done properly [18] [19]. Parboiling consists of soaking, steaming and drying of the rough rice. RDHs are basins (rice ecologies) of intensive rice production and consumption where research outputs are integrated across the rice value-chain to achieve the desired development outcomes and impact [20]. Ndop was classified as highland zone (cool zone) within the humid tropics [21]. The climate of Ndop is characterized by two main seasons: a dry season from November to mid-March and a wet season from mid-March to October. The Average rainfall varies between 1300 - 3000 mm annually with a mean at 2000 mm. Minimum and maximum temperatures are estimated at 15.5˚C and 24.5˚C, respectively. The soils are variable but fluvisols and ultisols are dominant [22]. Imported white milled samples were collected from the Mokolo market in Yaounde (a major urban consumption zone and the political capital of Cameroon). A total of twenty domestic and imported rice samples of at least 5 kg each, divided into five groups (Milled white imported (7), Milled parboiled imported (3), milled white domestic (4), Parboiled paddy domestic (3) and non-parboiled paddy domestic (3) were sampled for storage (Table 1). It is important to note that, all the milled parboiled imported and the parboiled paddy domestic rice samples available in the market were used in this study.

Storage of rice samples

Three samples of 5 kg each for each rice group were stored in jute bags at room temperature at the Institute of Agricultural Research for Development (IRAD) Yaounde from August 3rd to October 16th where the rice samples were held at an average relative humidity and temperature of 80% and 26˚C respectively measured with a digital data logger [23]. Data on physical quality and grain contamination by insects and fungi were evaluated at two weeks intervals during the whole storage period.

Table 1. Domestic parboiled and non-parboiled paddy and milled rice, imported milled parboiled and non-parboiled rice samples used in the study.

Rice variety or brand name	Origin	Type of rice	Group (code)	Number of samples
Main dans la Main	Imported	Milled white	Milled white imported (MWI)	7
Word rice	Imported	Milled white		
Neima	Imported	Milled white		
Bijou	Imported	Milled white		
Lion	Imported	Milled white		
Sona	Imported	Milled white		
Lion prestige	Imported	Milled white		
Uncle benz	Imported	Milled parboiled	Milled parboiled imported (MPI)	3
Champion	Imported	Milled parboiled		
Vikor	Imported	Milled parboiled		
Nerica L56	Domestic	Paddy	Non-parboiled paddy domestic (NPPD)	3
Tox 3145	Domestic	Paddy		
NERICA3	Domestic	Paddy		
Parboiled paddy 1	Domestic	Parboiled paddy	Parboiled paddy domestic (PPD)	3
Parboiled paddy 2	Domestic	Parboiled paddy		
Parboiled Tox 3145	Domestic	Parboiled paddy		
Bamunka	Domestic	Milled white	Milled white domestic (MWD)	4
Jehovah	Domestic	Milled white		
UNVDA	Domestic	Milled white		
Ndop rice	Domestic	Milled white		

Physical quality analysis

The moisture content of rice grains was determined using a Satake Rice Moisture meter (Satake Co. Ltd., Tokyo, Japan) according to manufacturer's instructions and expressed as a percentage. The determination was done in triplicates for each rice sample.

Discolored rice grains were evaluated using a sample of 100 g of rice. Rice grains presenting any yellow, black or purple color, visualized under magnifying glass were manually selected from the normal grains and weighed. The evaluation was done every two weeks till the 10^{th} week of storage to observe the evolution of discolored rice grains. Discolored rice grains were expressed as a percentage. The determination was done in triplicates for each rice sample.

2.2. Isolation and Characterization of Fungal Species Infesting Rice during Storage

The Potato Dextrose Agar (PDA) and Malt Extract Agar (MEA) media were used to isolate and purify the fungal strains from the rice grains. The direct and recommended Ulster method for fungal characterization in food allowed the detection, separation and overall analysis of the fungal species on the rice samples. Briefly, carefully selected 20 intact rice grains were arranged in isolation on a moisten filter paper and incubated for 5 to 7 days with ventilation for 12 hours per day in a hermetic plastic contained in the dark. Thereafter, triplicates of the observed strains were aseptically transferred under the laminar flow hood into new PDA and MEA culture media for purification. This operation consisted of transferring 0.6 cm mycelium disc of the isolated strains from the growth end of the colonies into new culture media severally and kept at ambient temperature (24˚C - 28˚C) until pure strains were obtained. The growth radius of the isolates was evaluated on daily basis following 48 hours of incubation, following the method proposed [24]. Briefly, the diameters (d1 and d2) of the mycelium were measured on one of the two straight lines that formed a right-angle triangle with the center of the explant. The diameters, together with that of the initial explant were then used to compute the radius (Equation (1)).

$$D = \left(d_1 + d_2\right) - d_0/2 \tag{1}$$

where d_0 is the diameter of the initial explant; d_1 and d_2 are the diameters of culture mycelium measured in both perpendicular directions.

For the morphological characterization, we made use of observational properties like back of boxes, color, colony relief, aspect and texture of the colonies in the Petri dishes. These were complimented with microscopic structures for the characterization of the genus. After the 7 days of incubation, the identification key developed [25] was used to characterize the fungi in the rice grains. The characterization was guided by the growth rate and the appearance of the colonies.

2.3. Isolation and Characterization of Insect Species Infesting Rice at Storage

Insect characterization was done in 100 g of rice from each sample. Isolation and identification were done using the identification key "Pests of Stored Grain in Cameroon and their control". Following the identification of the insects present in each sample, the next step consisted of determining the family then genus and if possible, the species to permit classification.

2.4. Quantification of Rice Grain Damage by Insects during Storage

The criteria for the estimation of grain damage consisted of evaluating the percentage of attack and the percentage of weight loss from 1000 grains. After sampling the one thousand (1000) grains, the healthy grains were sorted from attacked grains, the percentages of attack and weight loss were determined following the Pointel method [26], (Equations (2) and (3)). The evaluation was done in triplicates for each rice sample.

$$\text{Percentage of attack:} \quad \text{PA} = \text{Na} \times 100 / (\text{Na} + \text{Ns}) \tag{2}$$

where Ns is the number of healthy grains and Na the number of grains attacked by insects and molds.

$$\text{Percentage loss:} \quad \text{PP} = (\text{PsNa} - \text{PaNs}) \times 100 / \text{Ps}(\text{Na} + \text{Ns}) \tag{3}$$

where Ps is the weight of healthy grains and Pa the weight of grains attacked by insects and molds.

2.5. Data Analysis

Data was analyzed for normality and homogeneity of variance using Kolmogorov-Smirnov test and Levene's test, respectively. Data on all dependent variables were subjected to one-way analysis of variance (ANOVA $P < 0.05$) to test the effects of the different treatments as categorical predictors. Significant means was separated using Turkey's (Turkey's HSD $P < 0.05$). All analyses were done using SPSS (Ver. 25) while Microsoft Excel was used to create graphs and tables.

3. Results

3.1. Evolution in the Moisture Content of Rice Grains during Storage for Ten Weeks

The average initial moisture content of the rice samples within each group ranged from 13.63% in the domestic white milled rice to 15.18% in the imported milled white rice. The initial moisture content of the domestic parboiled paddy, imported milled white and non-parboiled domestic paddy were respectively 14.25%, 14.38% and 14.87% (**Figure 1**). In general, the level of moisture content in all the samples was above 13% which is not a suitable moisture content value for grain storage. Being hygroscopic, all the rice samples witnessed slight increases

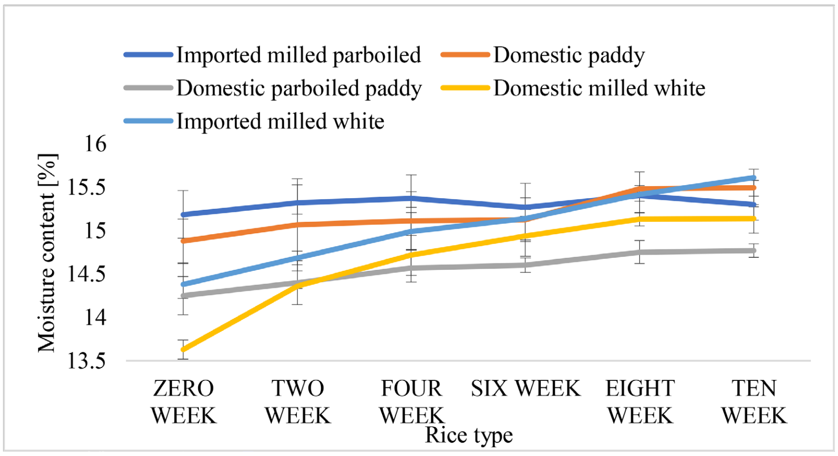

Figure 1. Evolution in moisture content during storage over ten weeks of five rice types in the center region of Cameroon.

in moisture content during storage, with the highest increase of 1.5 unit in the domestic milled white sample. The lowest increase of 0.12 units occurred in the imported parboiled milled sample. At ten weeks after storage at room temperature, the moisture content of all rice samples showed a linear increase; suggesting that storing rice grains at room temperature allows them to re-absorb moisture. These rice samples already had high moisture content at sampling date, around 14%, suggesting that once the moisture content of rice has dropped upon drying, it can increase by some units, but cannot easily increase above 17%.

3.2. Rice Grain Discoloration

All the rice samples irrespective of type and origin presented discolored grains at the start of storage. The level of these discolored rice grains increased with time ($P < 0.05$) and at significantly ($P < 0.05$) different levels across the different rice types evaluated (results not presented).

The percentage of discolored grains at 10 weeks after storage was significantly highest in the white and parboiled milled imported samples compared to all the domestic rice samples (**Figure 2**).

3.3. Fungi Species Infesting Rice Grains during Storage

3.3.1. Isolated Fungal Species of Rice during Storage

The observed level of expression of the fungi species on the rice samples was different between the fungal species as observed from the differences in growth rate (appreciated through the measurement of growth radius and results not presented here) and abundance on rice samples. Each of the rice group showed the co-occurrence of at least two different fungi species (**Table 2**). The paddy samples showed the lowest loads of fungi species with two strains (*A. niger* and *Circinella* sp.) isolated in the non-parboiled domestic paddy (NPPD) and three strains (*A. parasiticus*, *penicillium* sp. and others (unidentified) in the parboiled domestic paddy (PPD)). Paddy rice samples (parboiled or non-parboiled) were

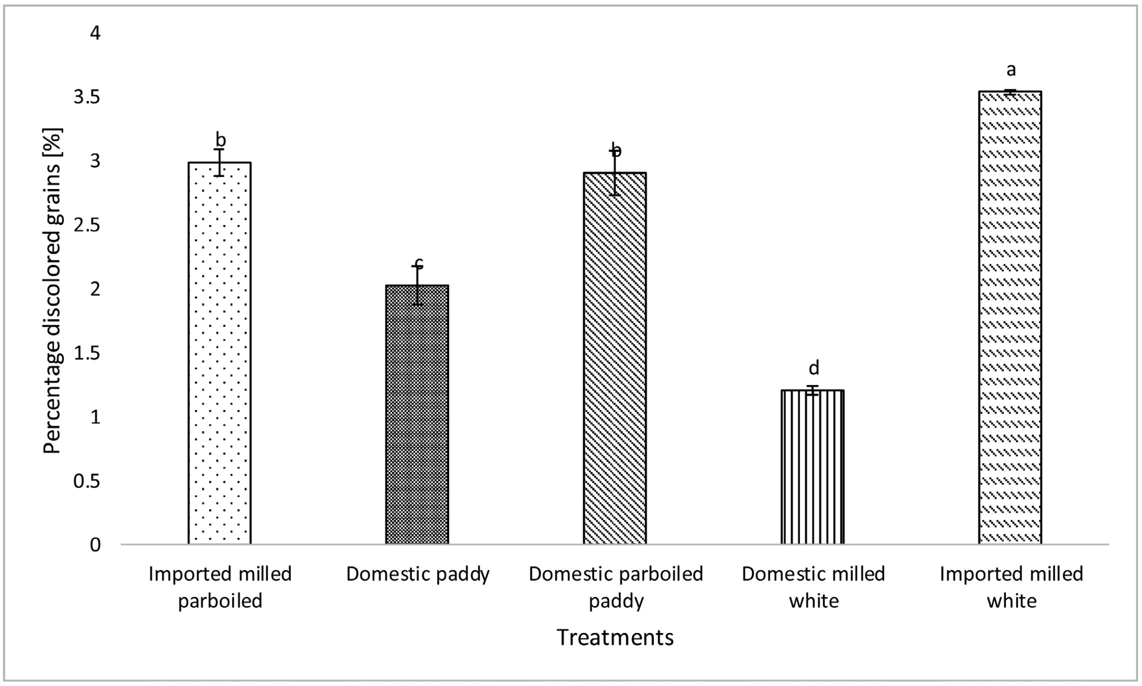

Figure 2. Percentage of discolored rice grains per rice type 10 weeks after storage Percentages with the same letter are not significantly different at $P < 0.05$ (Tukey's HSD, $P < 0.05$).

Table 2. Identified fungi per rice type.

Fungi	Rice type				
	WMI	PMI	WMD	NPPD	PPD
A. flavus	++++	--	+++	----	----
A.fumigatus	++++	--	----	----	----
A. japonicus	++++	--	++	----	----
A.niger	+++	--	++	++	----
A. ochraceus	++	--	----	----	----
A. oryzae	++++	++++	++	----	----
A. parasiticus	++++	--	++	----	++
Penicillium sp	--	--	++	----	++
Mucor sp	++	++++	++	----	----
Circinella sp	++	--	---	++	----
Others	++++	++	+	----	++
Total Number (67)	33	10	16	4	4

WMI = White milled imported, PMI = Parboiled milled imported, WMD = White milled domestic, NPPD = Non-parboiled paddy domestic, PPD = Parboiled paddy domestic.

the least contaminated, suggesting that the intact husk of the paddy rice grain serves as a protective barrier against fungi. This result also explains why mostly paddy rice is stored before processing from paddy to white milled rice. Two fungi strains (*A. oryzae* and *Mucor sp.*) with relatively high loads were isolated in the parboiled milled samples in addition to other unidentified species. The highest number of strains was isolated in the white milled samples with the imported samples expressing the heaviest loads of over ten occurring strains compared to seven strains in the white milled domestic samples.

3.3.2. Characterization of the Isolated Fungal Species of Rice at Storage

In terms of prevalence, the genus *Aspergillus* dominated with a total of 63.8% as compared to the other strains. The genus *Penicillium*, *Mucor* and *Circinella* presented respectively 13.4%, 8.9% and 4.4% (**Figure 3**). Of the 63.8% prevalence expressed by the genus *Aspergillus*, the species *A. flavus* was most dominant with a prevalence of 19.4%, seconded by *A. parasiticus* (10.4%) then *A. niger*, *A. penicillium*, *A. oryzae*, *A. japonicus* and lastly *A. ochraceus*.

3.4. Insects Infecting Rice during Storage

3.4.1. Diversity of Entomofauna in Rice during Storage

During the observation period, the most frequent insects encountered were Curculionidae (*Sitophilus oryzae*), Tenebrionidae (*Tribolium confusum*), Curcujidae (*Oryzaephilus surinamensis*) and Silvanidae (*Cryptolestes ferrugineus*) all belonging to the order Coleoptera. The results obtained allowed the identification of several genus (**Figure 4**): *Sitophilus*, *Oryzaephilus*, *Tribolium*, *Cryptolestes* respectively in the proportions: 81.9%, 8.7%, 4.7%, 2.2% and other genus accounting for 2.5%. In general, from all the samples, 877 insects were collected as follow: 719 (81.9%) of *Sitophilus*, 74 (8.4%) of *Oryzaephilus*, 42 (4.7%) of *Tribolium*, 22 (2.5 %) and 20 (2.2%) of *Cryptolestes* and for others (**Table 3**). The abundance of

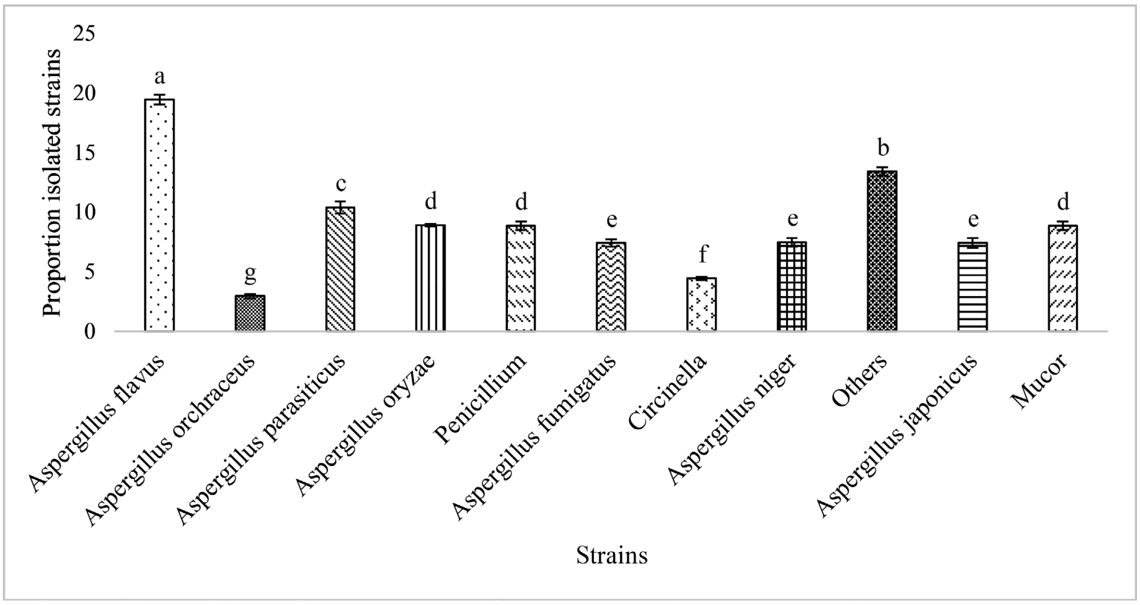

Figure 3. Prevalence (in percentage) of isolated strains infecting rice samples in Cameroon Percentages with the same letter are not significantly different at $P < 0.05$ (Tukey's HSD, $P < 0.05$).

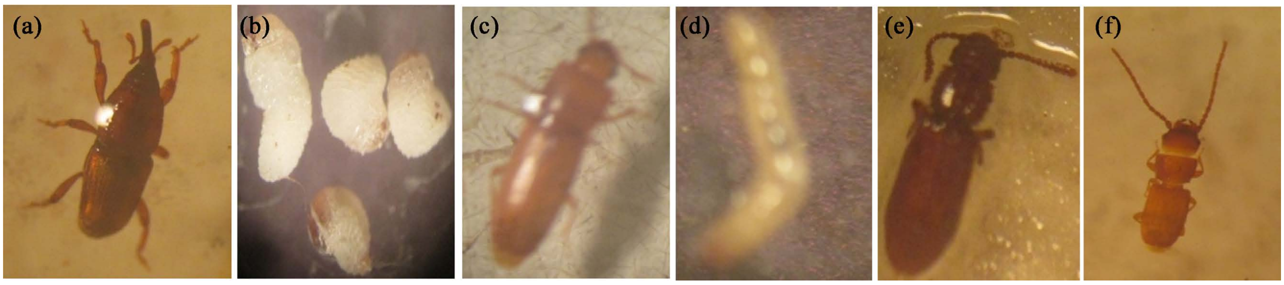

Figure 4. Different species of insects identified (magnify 120); (a) *Sitophilus oryzae* (L); (b) *Sitophilus* larva; (c) *Tribolium confusum* (L); (d) *Tribolium* larvae; (e) *Oryzaephilus surinamensis* (L); (f) *Cryptolestes ferrugineus* (L) (Douksouna photos).

Table 3. Number of insect per rice sample type in Cameroon.

Insect classification			Rice types					Total
Order	Genus	Species	NPPD	WMD	WMI	PMI	PPD	
Coleoptera	*Oryzaephilus*	*surinamensis*	0	0	74	0	0	74
	Tribolium	*confusum*	0	0	42	0	0	42
	Sitophilus	*oryzae*	147	105	439	28	0	719
	Crytolestes	*ferrugineus*	0	0	20	0	0	20
	Other genera		0	0	22	0	0	22
	Total		147	105	597	28	0	877

WMI = white milled imported rice, PMI = parboiled milled imported rice, WMD = white milled domestic rice, NPPD = non-parboiled paddy domestic, PPD = parboiled paddy domestic.

Sitophilus oryzae could be explained by the environmental conditions favorable to its development.

3.4.2. Insect Infestation and Resulting Grain Damage of Rice during Storage

The white milled imported rice samples were more susceptible to insect attack, harboring 68% of the total number of life and death insects counted in all the samples. This was followed by the non-parboiled domestic paddy (17%), the white milled domestic (12%) and the parboiled milled imported rice (3%). There were no insects in the domestic parboiled paddy samples throughout the storage period. The primary insect pest of rice during storage was *Sitophilus oryzae* (weevils), (**Table 3**). The damage intensity expressed as percentage weight loss was highest for the white milled imported samples, followed by the non-parboiled domestic paddy, the white milled domestic and finally the parboiled milled imported samples (**Figure 5**). It should be noted that the domestic parboiled paddy was less attacked and the percentage insect damage was negligible.

4. Discussion

Rice grain quality which is the mainstay of rice eating and market value [27]

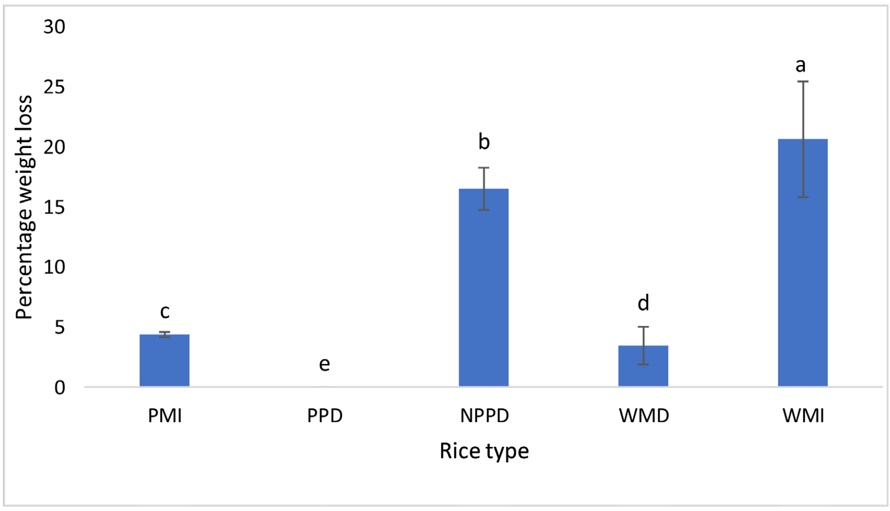

Figure 5. Percentage weight loss in rice due to insect damage at 10 weeks after storage Percentages with the same letter are not significantly different at $P < 0.05$ (Tukey's HSD, $P < 0.05$).

greatly deteriorates during storage due to differences in storage temperature, relative humidity, grain moisture content and gas (mostly carbon dioxide and oxygen) exchanges between the storage confinement and the atmosphere [28] [23]. Differences in moisture content usually arise from the farmer sun drying practices determined by the sun intensity, duration of sunny hours per day (longer in the dry season) and the number of days the rice is sundried. The moisture content in the samples presented in this study were reasonably suitable for about 2 weeks short term storage (requiring 14% moisture content) except for the imported parboiled milled sample, with 15.61% moisture content. Although earlier studies found moisture content up to 20.23% [17], the potential issues related to high moisture content level are the rapid proliferation of contaminant mold, toxin contamination, grain discoloration, viability loss, quality deterioration and respiration loss [7] [29]. In addition to respiratory and quality loss linked to fungal contamination, physical grain losses may occur in storage due to moisture shrinkage, rodents and insect infestation and subsequent price discounts for damaged grains [13] [14] [29]. The rice grain is largely composed of starch, rendering it hygroscopic. During drying under uncontrolled atmospheric conditions (e.g. sun drying) the consequence of the hygroscopic ability is moisture reabsorption of atmospheric water vapor to equilibrate its moisture level with that of the atmosphere. Conversely, at high moisture content, grains desorb moisture to the environment when the atmosphere is dry, especially during sunny days. The increase in moisture content during storage was probably influenced by the high relative humidity of the storage environment and the porous nature of the storage bags. At high relative humidity, rice grains take up moisture from the environment in a bid to reach equilibrium (the equilibrium moisture) with the atmospheric humidity. As such, samples with the lowest moisture content end up absorbing more moisture than those with high moisture values. The maintenance of the appropriate moisture (below 14%) throughout the storage period assures the conservation of rice grain quality. Fluctuations in the moisture equilibrium will result to grain discoloration and the subsequent infestation by fungi and mycotoxin secretion [30]. Moisture adsorption can occur on rice paddy in the field, or wherever low moisture grains are exposed to a humid environment [31]. Drying temperature and high storage relative humidity produce fissures in rice grains, before milling [32]. Paddy rice grains with stress fissures break more readily than sound kernels during processing and thereby reduce the quality and market value of the rice grain [33].

The milled rice samples with high level of discolored grains (**Figure 6**) are found in large quantities in local markets of sub-Saharan Africa, commonly qualified as "low quality" and usually sell at low prices [4]. With the poor handling practices by retailers, combined to the average daily temperatures (25˚C - 30˚C) and 80% relative humidity, grains discoloration will persist, favoring fungi infestation and subsequently mycotoxin secretion [29]. Discoloration in paddy is also observed on the husk which is the outer protective layer of the rice seed and is most often prone to both field and storage fungi infestation [34]. The consequences of discoloration in non-parboiled paddy can be extended to reduced seed viability [23] [35], low percentage head rice after milling and most importantly huge qualitative post-harvest losses. Although fungal identity is not discernable under the scanning electron microscope (SEM), a plethora of studies reviewed [29] empirically evidence the presence of *Aspergillus* sp., *Alternaria* sp., and *Fusarium* sp. in discolored rice grains with different mechanisms of invasion. For instance, *Aspergillus* invades the grains through crevices or cracks in starch grains to extensively colonize the internal grain starch milieu [36]. After invasion, the *Aspergilli* growth, coupled to the secretion of starch digestive enzymes results in wide

Figure 6. Discolored rice grains on a sample of milled white rice (Douksouna photos).

crevices and larger cracks or fractures on the contaminated grains.

The level of discolored rice grains in both white milled and parboiled milled imported samples was equal to or higher than 3%, meaning that they cannot be graded premium or grade 1 rice, according to the Quality Standard for milled rice in the Philippines for instance [37]. This high level of discoloration results from poor handling (rice grains exposed in the market, improper packaging, poor ventilation, poor storage package equipment) and environmental conditions [34]. The prevention of rice loss during storage can be achieved with hermetic bags, which do not allow air circulation between the environment and the grains, allowing quality maintenance for long storage duration. Rice actors using hermetic bags contribute to ensuring food security, the maintenance of good seed quality for next planting season, no qualitative deterioration nor physical degradation of grains [38].

From the mycoflora morphological characteristics [39], we identified several fungal genera. Although we did not characterize the isolates using molecular tools due to limitations in logistics, we systematically followed the identification keys [39] to characterize the fungi genus to the species level. For the genus *Aspergillus*, seven species were isolated. The species were: *A. niger*, *A. flavus*, *A. ochraceus*, *A. fumigatus*, *A. oryzae*, *A. japonicas* and *A. parasiticus*. The other genera that were isolated include: *Penicillium*, *Mucor* and *Circinella.* These fungal strains have been identified in rice samples in Nigeria [40].

In this study, a total of four fungi genus: *Aspergillus*, *Penicillium*, *Mucor* and *Circinella* were isolated in the samples, an indication that all the rice types were colonized by fungi. The genus *Aspergillus* with over seven different species occurred in all the five rice groups and this corroborated with reports for samples collected from local retail markets and mills in the Mwea Thika communities of Kenya [41]. The genus *Penicillium* occurred in the white milled domestic and parboiled domestic paddy. We did not identify *Penicillium* in the white and parboiled milled imported and non-parboiled domestic paddy samples (**Table 2**). In earlier studies, *Penicillium* spp. was detected in very low levels in domestic white and parboiled rice collected from mills in three agroclimatic zones of sub-Saharan Africa [42]. In contrast to the non-identification of *Penicillium* in imported rice, Tonon *et al.* [43] identified three *Penicillium* species in surface disinfected and transversally cut paddy and milled rice from North Eastern Argentina and Southern Paraguay. The *Aspergillus* genus is known for the secretion of all aflatoxin classes including the most prevalent and lethal aflatoxins B1, B2, G1 and G2 [43] [44]. The high prevalence of *Aspergillus* also confirms earlier reports for rice samples from local markets and mills in Kenya [41].

The results on insect diversity in stored rice are in line with those [45] [46] [47] who identified similar populations of the order Coleoptera in stored cereal grains including rice. In the same order of species susceptibility to grain infestation, it was also found that *Oryzaephilus* sp., *Tribolium* sp., *Sitophilus* sp. and *Cryptolestes* sp. were common in stored rice [46] [47]. Authors [46] counted a total of 9893 insects captured in 99 cage traps in large storage facilities in Brazil while a total of 8605 insects across three warehouses were recorded in Malaysia [47]. It is important to note here that the respiration of the abundant insects in infested stored grains is linked to an increase in moisture content and temperature of the grain bulk, susceptible of promoting fungal proliferation and consequently quality deterioration.

The high abundance of insect pest in imported white rice might be linked to longer durations during the transportation and distribution cycles before reaching the market. The importation of white milled rice, its storage and retailing conditions, like packaging material, relative humidity and temperature might be favorable to the increases in grain moisture content, the development of colored grains, molds development and insect infestation. The consequence of insect infestation of cereal grains during storage is damage and huge quantitative losses that are also linked to economic, nutritional and quality losses [48]. The low level of insects in parboiled rice and the complete absence in domestic parboiled samples might be explained by the fact that parboiling heals the crevices on grains and further hardens the rice starch following gelatinization, rendering the grains resistant to insect invasion. *Sitophilus oryzae*, the most abundant insect pest registered in this study damages intact grains through their rostrum which allows the larvae to develop inside the grains. They also allow the infestation by secondary and tertiary pests for which damaged grains are a source of food. During the storage period, the pests attack the grains and hollow them out. The damage on the rice grain is caused by both larvae and very voracious adults. They are manifested by the presence of many damaged, light, empty and sometimes dark grains.

It is the role of the government to ensure the safety of rice available in the markets for domestic consumption or exportation. For the government to improve the monitoring of the rice grain quality through post-harvest management, the following actions can be operationalized: For rice produced locally, the government should intensify investments on rice quality sensitization among the small-scale rice actors, build their capacity on rice harvest and post-harvest management for qualitative and quantitative loss reduction. She can support rice actors to obtain appropriate equipment and facilities for rice harvesting, threshing, drying, parboiling, milling and storage through subsidies and custom free importation of agricultural machinery. For rice importation, the government with the other actors can ensure appropriate packaging and transportation conditions (adequate grain moisture content (<14%) relative humidity (<70%), temperature (ambient temperature and airtight packaging material). She can encourage importation of paddy which will be milled, packaged and stored locally, providing appropriate logistics like milling equipment and packaging material. Furthermore, systematic quality control should be done on imported and locally produced rice by competent quality assurance and quality control agencies.

5. Conclusion

This study evaluated some rice samples from the Yaounde and Ndop rice development hub, which are respectively the zones of high rice commercialization/consumption and rice-production area in Cameroon. The collected rice samples consisted of imported milled rice brands and domestically produced paddy or milled rice produced in Ndop. It was found that the different rice samples were contaminated by molds; certainly because of their high level of moisture content. The group of milled rice samples were more contaminated by molds (all the seven species of *Aspergillus* identified, *Circinella* sp, *Mucor* sp and non-identified fungi species) as compare to paddy rice samples, be it parboiled or non-parboiled. The fungal charge was high in imported rice brands as compared to locally produced rice, suggesting that these rice samples may be imported or stored and sold in poor conditions, leading to the development of molds. The isolated mycoflora was diverse. Four genera were found: *Aspergillus*, *Penicillium*, *Mucor* and *Circinella. Aspergillus* species dominate followed by *Penicillium* and *Mucor*. In addition, parasitic insects were identified in rice grains during storage. There were: *Sitophilus oryzae* (L), *Tribolium confusum* (L), *Oryzaephilus surinamensis*, and *Cryptolestes ferrugineus* (L), which attacked and damaged rice grains at different levels. The group of white milled imported rice samples in addition to having the highest fungi charge also had the highest weight loss almost 20%, due to damage intensity caused by insects' attacks. We therefore suggest that paddy rice should be imported into Cameroon before processing to white milled rice and proper packaging, relative humidity, and temperature should be applied or rice during its importation, storage and selling. This study evaluated paddy and milled rice samples, imported or produced in Cameroon, but could not make it for all the rice brands available in Cameroon. In perspective, further studies will take into consideration all imported rice brands and rice samples produced locally and sold in local markets in Cameroon and assess the presence of toxin like aflatoxin in the grains.

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Author Contribution Statement

Mapiemfu-Lamare Delphine, Ambang Zachée, Douksouna Youmma, Tang Erasmus Nchuaji, conceived, designed and performed the experiments and interpreted the data; contributed in obtention of reagents and wrote the article. Ngome Ajebesone Francis, Suh Christopher, Tatah Blaise Nangsingnyuy, contributed in obtention of reagents and other laboratory materials, data analysis and edited the article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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