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Influence of Agro Ecology on Rice Varietal Resistance to *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Sitotroga cerealella* (Lepidoptera: Gelechiidae) in Benin

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Abstract

The rice weevil, *Sitophilus oryzae* (L.) and the Angoumois grain moth, *Sitotroga cerealella* (Oliv.), are serious pests of stored rice in Africa. This study aims to evaluate the influence of growing environments to rice resistance to these pests. Thus, eleven rice varieties including 6 upland NERICA, 2 *Oryza glaberrima* and 3 *O. sativa* were grown at four agro ecological zones of Benin. After harvest, samples of 1500 grains of each genotype were infested with 20 adults of *S. oryzae* (10 males and 10 females) and 1500 additional ones were infested with 50 eggs of *S. cerealella*. Results showed significant effect of agro ecological zones on pest incidence and on varietal resistance as well. *O. glaberrima* varieties (TOG 5681 and CG 14) were the most resistant in each location whereas the resistance of NERICA and Sativa varieties varied from tolerant to susceptible according to the growing ecology. This result highlights the impact of growing environment on rice resistance status and will provide the best advice to farmers on how to choose best genetic material according to cropping ecology.

Keywords

Rice, Agro Ecology, Storage Pests, Resistance, Habitat Management

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1. Introduction

The rice weevil, *Sitophilus oryzae* (L.) and the Angoumois grain moth, *Sitotroga cerealella* (Oliv.), are serious pests of stored grains [1]. Female moths deposit eggs on grain kernels. After hatching, larvae begin feeding on the endosperm or germ. Then the last instar larva creates a large hole to allow the adults exiting out of the grain [2]. *S. oryzae* deposits its egg directly into the kernel where the larva hatches and completes development until the adult stage, and gets out throughout the hull [3]. Most of the losses occurring during cereal storage can primarily be attributed to biotic agents such as insects, diseases, and rodents ([4] cited by [5]), but the contribution of insects is predominant. According to FAO [6], half of the storage losses are usually caused by insects. Stored grain pest damage differed in different stored grains, including rice causing serious economic loss nationally [7]. Because of the high adoption of improved varieties in Benin such as NERICA and the subsequent high production between 0.5 and 1.1 t per ha depending of the country in SSA [8], grain storage has gradually become a common practice by farmers [9]. Consequently, storage losses due to insect pests, which were not considered as key issue in Benin, began a serious threat for producers, processors and traders. Also, Togola *et al.* [9] reported that, the incidence of insect pest to the different farmer storage units depended on the storage duration and regions where samples were collected. Thus, economic losses in paddy storage are estimated at 2 FCFA (Franc of the African Financial Community) for each kilo of rice stored over 2 - 3 months. Varietal resistance appears as good solution of stored rice losses [10]. Several studies designed genetic traits and morphologic characters as key parameters contributing to varietal resistance ([11]-[13] cited by [14]). Also, Cogburn and Bollich [15] noted that environmental or biochemical factors may also influence susceptibility or tolerance of rice varieties. But some recent studies such as those of Arthur *et al.* [3] noted that growing environment can also influence susceptibility to stored products insects. This ecological factor needs to be explored as key option of habitat management of storage insect pests. Therefore the objectives of this study were to identify environmental influences on resistance to *S. cerealella* and *S. oryzae* in NERICA varieties and their parents.

2. Material and Methods

2.1. The Study Area

This study was conducted in North, Center and South region of Benin. Malanville (North) lies between 11.5˚ and 12˚ latitude from north to south and 50 km from east to west on 60 km [16]. It climate is Sudano Sahelian type with one dry season (from November to April). The average rainfall is 750 mm per year and temperature differences vary between 16˚C and 25˚C. Soils are sandy clay, ferruginous [16]. Rainfall during the wet season (from June to October 2012) was 728.8 mm, the mean temperatures ranged from 26˚C and 29˚C and relative humidity varies from 70% to 81% [16]. Glazoue (Center) lies between 7˚30' and 8˚90' latitude north and 2˚05' and 2˚22' longitude East [17]. It has a sub-equatorial climate with two rainy seasons and two dry seasons. In recent years due to climate change, we observed a late onset of rains and dry pockets inside the rainy season. The soil is tropical ferruginous with several variants namely sandy white, sandy black and hydromorphic [17]. Rainfall during the wet season (from June to October 2012) was 838.6 mm, the mean temperatures ranged from 25˚C and 28˚C and relative humidity has varied from 77% to 81% [17]. Lokossa (South) lies between 6˚37'60" latitude North and 1˚43'0" longitude East and is characterized by a subequatorial climate. The rainfall average varies between 900 and 1100 mm per year. The soil is mostly hydromorphic [18]. Rainfall during the wet season (from June to October 2012) was 857.5 mm, the mean temperatures ranged from 26 and 28°C and relative humidity has varied from 82 to 85% [18]. International Institute of Tropical Agriculture (IITA) is located in the town of Abomey Calavi. His geographical coordinates are 6˚25' north, 2˚19' east. His climate is of type subequatorial. The soil is sandy [19]. Rainfall during the wet season (from June to October 2012) was 748.9 mm, the mean temperatures ranged from 26 and 28°C and relative humidity has varied from 82% to 85% [19]. **Figure 1** below shows different sites of study.

2.2. Plant Materials

Eleven rice varieties were selected representing the six upland NERICA certified and grown (NERICA1, 2, 3, 4, 14 and 15) by several African countries as well as their parents, three *O. sativa* (WAB 5650, WAB 56104 and WAB 18118) and two *O. glaberrima* (TOG 5681 and CG 14). These varieties were collected from Africa Rice Center (AfricaRice) at Cotonou, Benin.

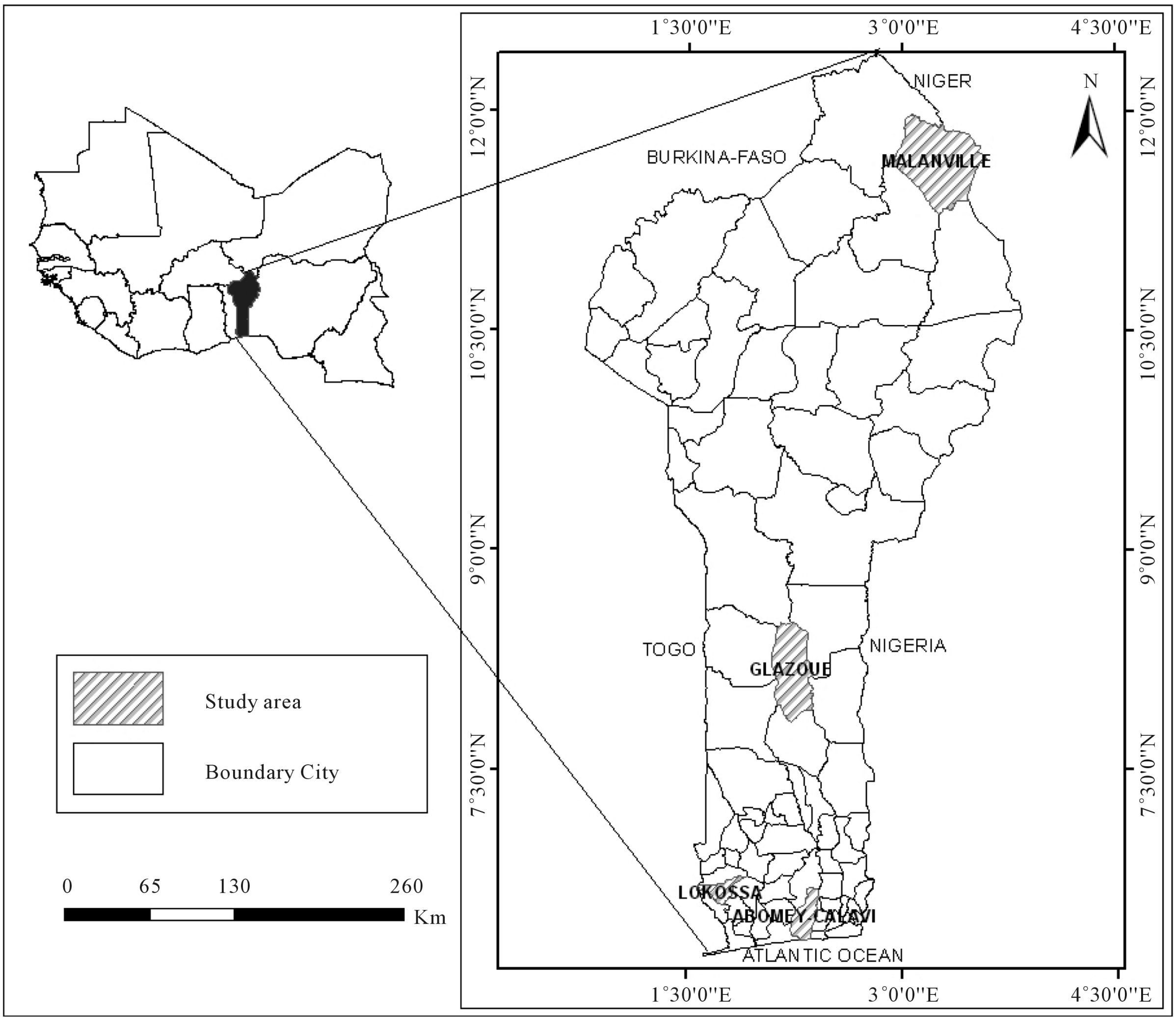

Figure 1. Map of Benin showing the different sites of study.

2.3. Experimental Design and Crop Management

The first experiment was carried out with the objective to evaluate environmental influences on phenotypic variability of rice during rainy season 2012 in the four agro ecological zones of Benin mentioned above. A randomized complete block design with 3 replications in each site was used. Plot size for each genotype was 5 m^2 with 25 rows, 1 meter long and 40 cm apart from each other. Plots were fertilized with 200 $kg \cdot ha^{-1}$ as a basal dressing at 21 DAS and with 50 $kg \cdot ha^{-1}$ of urea at 45 DAS. Standard agronomic practices (such as weeding and fertilizers application) were followed during crop growth stages. Number of panicle and 1000 grains weight were recorded on four plants randomly identified and labeled, selected from the middle row in each experimental plot. At maturity, number of panicles and 1000 grains weight were taken. Before sowing, soil samples at 0-20 cm depth were collected separately at each block to determine major chemical components and soil physical characteristics. A second experiment including screening of rice varieties for resistance to *S. cerealella* and *S. oryzae* was set up. Seeds were stored at 4˚C for two weeks to kill any insects or mites present into the samples. Insects reared in the laboratory were used for this experiment. The laboratory was conditioned at a temperature of 25˚C ± 1˚C, a relative humidity of 70% ± 5% and 12/12 hours light/dark. The following methods are used for the screening.

2.4. Classification Status of These Insects

- **Rice weevil**

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta
Order: Coleoptera
Family: Curculionidae
Genus: *Sitophilus*
Species: *S. oryzae*
Binomial name: *Sitophilus oryzae* (Linnaeus, 1763)

- **Angoumois grain moth**
  Kingdom: Animalia
  Phylum: Arthropoda
  Class: Insecta
  Order: Lepidoptera
  Family: Gelechiidae
  Genus: *Sitotroga*
  Species: *S. cerealella*
  Binomial name: *Sitotroga cerealella* (Olivier, 1789)

2.5. Method of Screening for Resistance to Rice Weevil (*S. oryzae*)

Samples of 1500 grains of paddy rice of each varieties were put in glass jars (6 cm: diameter × 11 cm: height) top covered using cloth tissue with aerated lid. Each sample was infested with 20 adults of *S. oryzae* (10 males and 10 females) obtained from the laboratory strain [20]. The strain of *S. oryzae* used in this study was maintained on susceptible rice varieties for two years at 25˚C ± 1˚C, 70% ± 5% RH. The samples were stored in the laboratory for three months. The experiment was replicated three times in randomized complete block design. After the storage, adult progeny per sample was counted and recorded. Number of damaged grains was separated, counted, weighed and recorded.

2.6. Method of Screening for Resistance to Angoumois Grain Moth (*S. cerealella*)

Paddy samples (1500 grains) of each varieties were placed in glass jars (6 cm: diameter × 11 cm: height) top covered using tissue with aerated lid. Eggs were collected by exposing folded paper (black or grey) booklets to large numbers of moths in a glass container for 4 days (oviposition period) [21] [22]. When the paper was unfolded, bits of paper with adhering clusters of eggs could be cut from the booklet pages without damage. Eggs were counted under a binocular microscope and papers carrying at least 50 eggs were placed on each sample contained in a sample jar as described above [20] [22]-[24]. All samples seeded with eggs, were kept under laboratory conditions. The experiment was replicated three times using the same design as earlier. Eggs hatched and adult emergence (male and female) were counted and recorded in each treatment after the completion of the first generation (40 days). Number of damaged grains was separated, counted, weighed and recorded.

3. Statistical Data Analysis

The collected data were subjected to analysis of variance with two factors (ANOVA) to determine the site- varieties interactions. When the interactions are significant, another ANOVA was performed for each site to evaluate significant parameters that established the resistance of varieties to the 2 insect pests. The Student Newman Keuls test (SNK) was also performed to separate the various means of parameters. The data were analyzed with the software Genstat release 14.

4. Result

4.1. Variation of Physic-Chemical Components of Soil from Study Locations

Based on Jamagne [25] triangle test, the soils textures from Lokossa and Glazoue were found to be sandy silty, those from IITA station were sandy and those from Malanville were silty. The results about the Hydrogen potential analysis showed that soils from IITA station and Malanville were acidic, and those from Lokossa and

Glazoue were slightly acidic. The soils of four locations displayed a low Carbon and Nitrogen ratio (C/N), which was between 10 and 14 with a low Effective Cation Exchange Capacity (ECEC). The concentration in Phosphorus was low in soils from Lokossa, Glazoue and Malanville but high in soil from IITA. **Table 1** showed the results of physico-chemical analysis of the soils from each location.

4.2. Climatic Variations in the Different Locations

The graph above (**Figure 2**) shows the variation in rainfall during the study period in the different study areas. Histograms of rainfall values of IITA, Lokossa and Glazoue have a bimodal rainfall, with rainfall maxima in June and October at IITA and July and September at Lokossa and Glazoue. The rainfall histogram of Malanville meanwhile has a unimodal rainfall regime with a small pocket of drought in August probably due to climate perturbations. The following two curves (**Figure 3** and **Figure 4**) show the temperature and humidity fluctuations during the rainy season (June to October) in four study areas. In South of Benin (IITA and Lokossa), the air temperatures are constant (25˚C - 27˚C) and humidity is high (75% - 85%) while in the Centre (Glazoue) and the North (Malanville), temperatures are high (28˚C - 29˚C) and humidity is also high (80%).

4.3. Variation of Agro-Morphological Characters of Rice Plant from the Different Locations

- **Number of panicle per plant**

The combined analysis of variance for number of panicles per plant showed highly significant ($P < 0.01$) differences between locations and varieties but no interaction was observed between these 2 parameters. The highest

Table 1. Physico-chemical characteristics of soil samples collected from different locations.

Location	Depth (cm)	pH	C/N	Meh P (mg/kg)	ECEC	Clay (%)	Silt (%)	Sandy (%)
IITA station, Bénin	0 - 20	5.0	10	25.0	0.8	7	3	90
Lokossa	0 - 20	6.3	10.5	3.5	8.4	15	25	60
Glazoue	0 - 20	6.2	12.5	5.4	4.2	6	33	61
Malanville	0 - 20	5.7	14	2.1	4.7	13	40	47

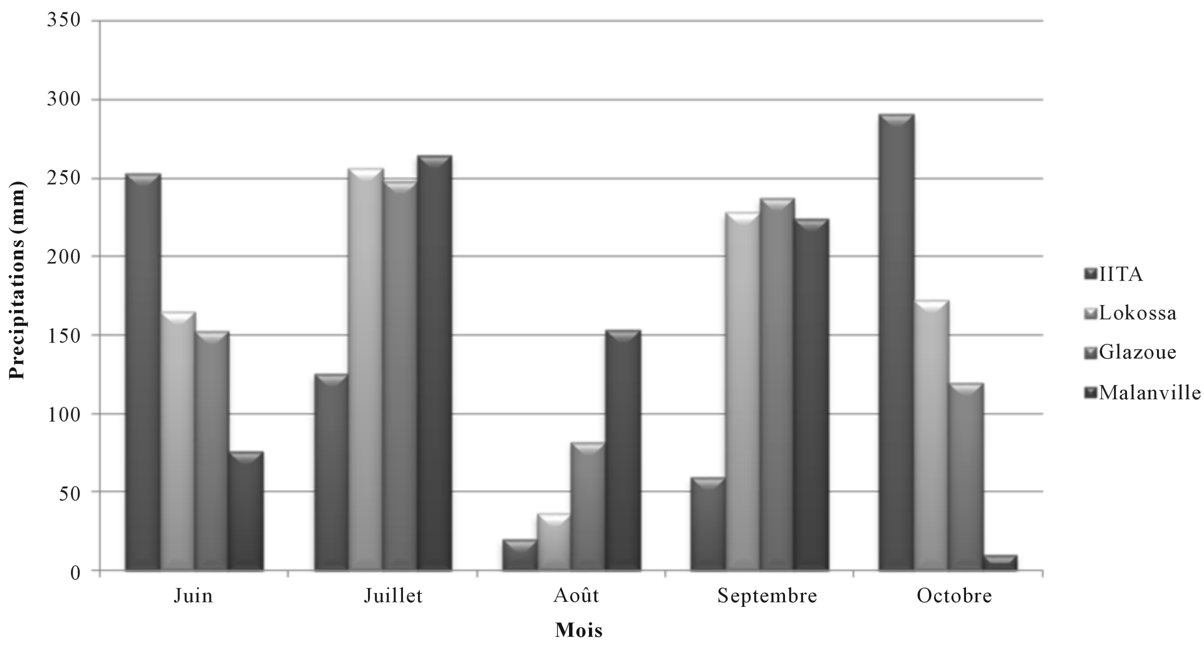

Figure 2. Rainfall of different locations in 2012.

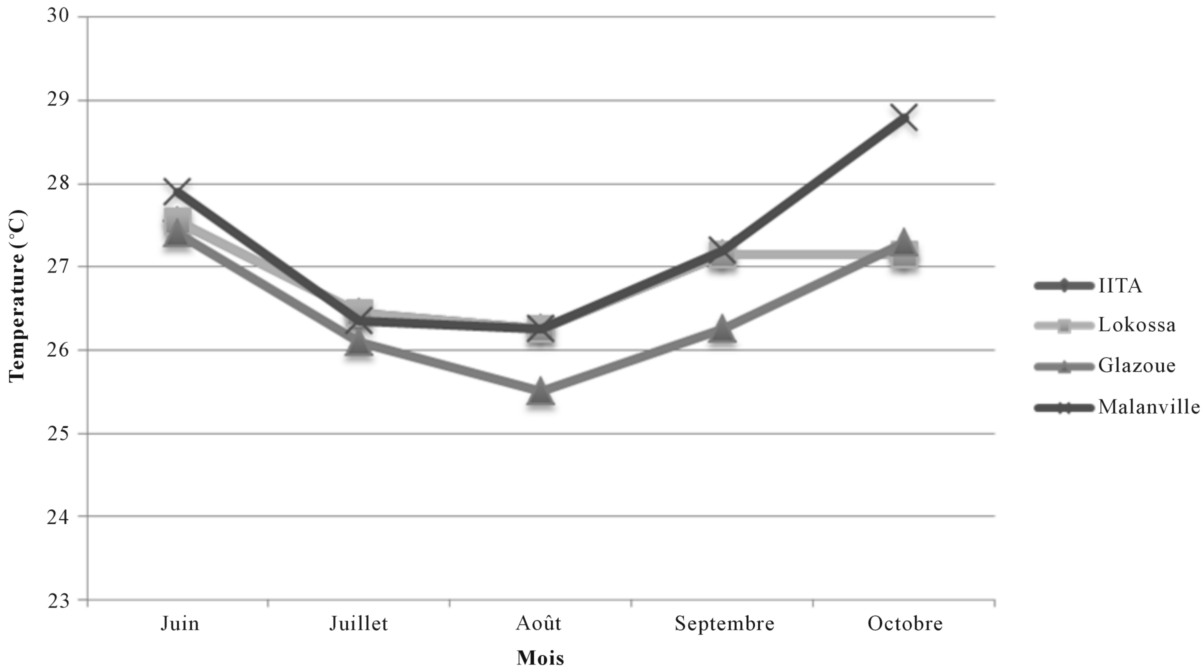

Figure 3. Temperatures of different locations in 2012.

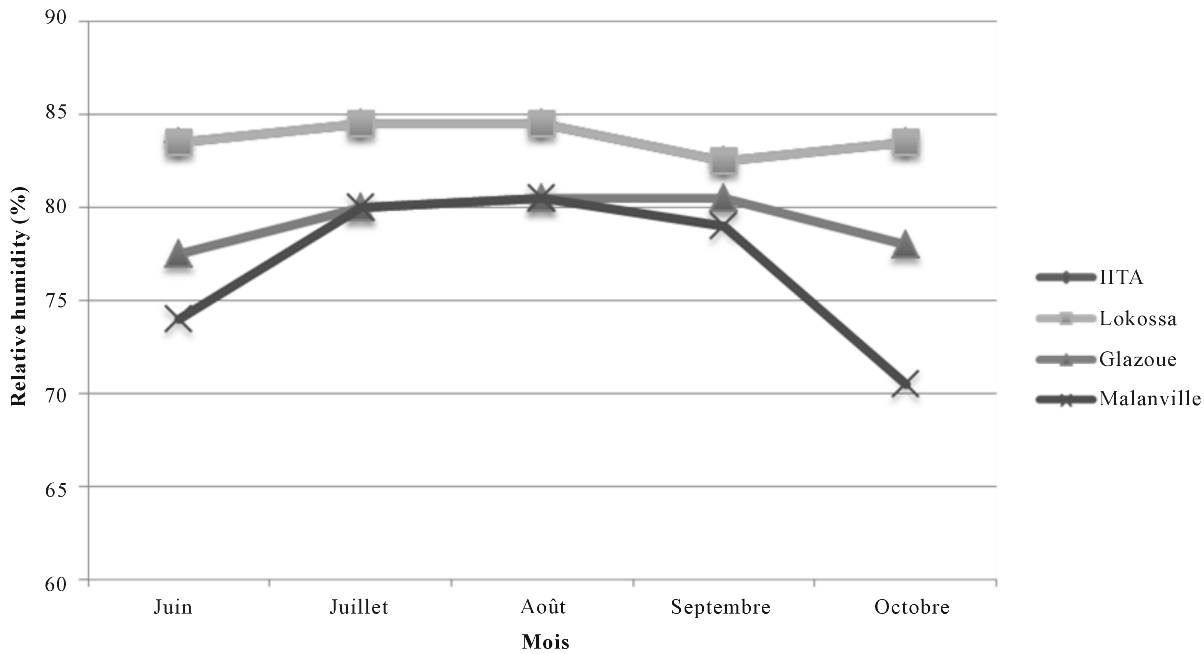

Figure 4. Relative humidity of different locations in 2012.

panicles number was produced at Glazoue followed by Malanville with an average of 9.2 and 9.1 respectively; whereas, the lowest panicles number was recorded at Lokossa (6.758) and IITA (5.879). Highly significant differences ($P < 0.01$) existed between varieties from IITA. The *O. glaberrima* varieties TOG5681 and CG14 have obtained the maximum number of panicles per plant 10.9; 11.8 respectively, while the NERICA varieties and their sativa parents (WAB5650, WAB56104 and WAB18118) have recorded between 3.4 and 5.5 panicles per plant. The same clustering was observed in the other locations but the number of panicles per plant was higher than in the previous site (Table 2). For each variety, the number of panicles varied significantly according to the growing

Table 2. Phenotypic variability of 11 rice varieties grown in four agro ecological locations.

Sites	Glazoue		IITA		Malanville		Lokossa	
Varieties	Number of panicles	Weight of 1000 grains	Number of panicles	Weight of 1000 grains	Number of panicles	Weight of 1000 grains	Number of panicles	Weight of 1000 grains
Nerica 1	6.92 ± 0.22ab	32.42 ± 0.20bc	5.58 ± 0.72a	28.85 ± 0.89de	8.17 ± 0.87a	31.33 ± 2.25cde	7.67 ± 0.96abcd	32.08 ± 0.47ef
Nerica 2	7.83 ± 0.82ab	28.64 ± 0.83a	4.33 ± 0.65a	24.46 ± 0.71ab	8.67 ± 0.44a	29.67 ± 0.45bcd	6.33 ± 0.58abc	27.46 ± 0.11b
Nerica 3	7.33 ± 0.16ab	32.22 ± 0.39bc	5 ± 0.80a	26.96 ± 0.98cd	7.08 ± 0.36a	29.46 ± 0.89bcd	5.67 ± 0.88ab	29.59 ± 0.29c
Nerica 4	7.58 ± 0.58ab	31.08 ± 0.77b	4.67 ± 0.46a	25.97 ± 0.29bc	8.5 ± 1.04a	28.5 ± 0.85bc	5.08 ± 0.36ab	30.3 ± 0.10cd
Nerica 14	7.75 ± 0.52ab	36.1 ± 0.02d	5 ± 0.38a	31.97 ± 0.14f	7 ± 1.28a	34.22 ± 0.36e	5.25 ± 0.66ab	32.21 ± 0.17ef
Nerica 15	5.42 ± 0.46a	34.22 ± 0.49c	3.42 ± 0.41a	28.87 ± 0.11de	9.4 ± 0a	29.76 ± 0bcd	4.5 ± 0.43a	30.58 ± 0.41cd
WAB 5650	7.67 ± 0.16ab	32.83 ± 0.79bc	5.17 ± 0.71a	27.32 ± 0.57cde	7.17 ± 0.58a	31.7 ± 0.35cde	5.42 ± 0.60ab	29.8 ± 0.45c
WAB 56104	7.92 ± 0.46ab	34.1 ± 0.27c	4.5 ± 0.28a	29.5 ± 0.19e	7.17 ± 0.58a	30.21 ± 0.45bcd	5.92 ± 0.71abc	31.26 ± 0.11de
WAB 18118	8.83 ± 0.82b	33.64 ± 0.18c	4.25 ± 0.52a	28.8 ± 0.22de	7.25 ± 0.90a	32.91 ± 0.89de	5.83 ± 0.91ab	33.01 ± 0.23f
CG 14	15.83 ± 0.74c	28.78 ± 0.26a	11.83 ± 079b	24.06 ± 0.25a	17.25 ± 1.25b	26.55 ± 0.43a	10.5 ± 2.15bde	24.54 ± 0.27a
TOG 5681	18.42 ± 1.15d	28.2 ± 0.48a	10.92 ± 0.74b	22.73 ± 0.74ab	15.75 ± 1.88b	23.01 ± 0.78b	12.17 ± 3.16e	28.07 ± 0.64b
Grand Mean	9.23	32.02	5.88	27.23	9.4	29.76	6.76	29.9
Test F^2	**	**	**	**	**	**	**	**
CV%	2.3	0.7	1.4	0.9	7.2	3	20.3	0.5

Signification to Test F: ** = significant at 1%, CV= Coefficient of variation; Means followed by the same letter not significant at 5%.

locations. NERICA varieties had high number of panicles in Malanville site while *O. sativa* and *O. glaberrima* parents got high number of panicle in Glazoue.

- **Weight of 1000 grains**

The analysis of variance showed significant differences ($P < 0.01$) of 1000 grain weight according to growing locations, varieties and locations across varieties. The 1000 grain weight of cultivars grown at Glazoue, Malanville and Lokossa were higher than the cultivars from IITA. Varieties of *O. sativa* and NERICA had higher grain weight than varieties of *O. glaberrima* (**Table 2**).

4.4. Varietal Resistance to *S. oryzae* and *S. cerealella*

- **Resistance to *S. oryzae***

The analysis of variance (**Table 3**) for rice resistance parameters showed highly significant ($P < 0.01$) differences between locations, varieties and varieties across locations interactions (**Table 3**). The clusters analyses between locations showed that rice varieties grown in IITA were more susceptible (with 39.24 damaged grains) compared to Lokossa (5.15), Glazoue (1.61) and Malanville (1.22). Nevertheless, damage were highly significant ($P < 0.01$) between varieties from IITA station, Lokossa and Glazoue but not significant ($P < 0.05$) for the varieties from Malanville. The *O. glaberrima* CG14 and TOG5681 showed low numbers of damaged grains at all locations ($N \leq 12$ damaged grains). Among the cultivars grown in IITA, the varieties NERICA1, NERICA14, NERICA3, NERICA4 and the *O. sativa* parent (WAB 5650 and WAB 56104) had high number of damaged kernels ranging from 47.3 to 87.3 damaged grains. Conversely, the varieties NERICA15 and the *O. sativa* parent WAB 18118 have recorded intermediate number from 19 to 20 damaged grains. However, for the remaining three localities (Lokossa, Glazoue and Malanville) the same varieties have obtained very low damaged grains ranged from 0 to 12 grains maximum (**Table 4**). Adult progeny of *S. oryzae* were not significant ($P < 0.05$) among the cultivars from Lokossa, Glazoue and Malanville except for the cultivars from IITA station. For the IITA station, the highest number of insects were observed on varieties NERICA 1, NERICA14, NERICA3, NERICA4 and parents *O. sativa* WAB 5650 and WAB 56104 ranged from 27 to 53 insects while the varieties NERICA2, NERICA15, WAB 18118, CG14 and TOG5681 have had the lowest numbers from 20 to 25 insects. The insects population did not increased on the varieties from the three remaining locations (**Table 4**).

Table 3. Mean squares of resistance parameters (to *S. oryzae*) obtained from the analysis of variance.

Sources of variation	DF	Mean squares		
		Number of damaged grains	Adult developed after 1st generation	Weight loss (%) after storage
Varieties	10	686.29**	133.82**	0.5265**
Repetition	2	77.81**	84.42**	0.0266**
Localities	3	11144.04**	1474.84**	4.2104**
Varieties*Localities	29	525.73**	117.27**	0.4737**
Error	84	78.78	50.6	0.1071
Total	128	-	-	-
CV %	-	75.2	30.2	110.3

Table 4. Adult progeny and damage caused by *S. oryzae* on 11 cultivars from IITA Station, Lokossa, Glazoue and Malanville.

Varieties	IITA		Lokossa		Glazoue		Malanville	
	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains
NERICA1	53 ± 17.38c	87.3 ± 21.75c	21.67 ± 1.66a	3.33 ± 1.33ab	20 ± 0.33a	3.67 ± 0.33c	21.33 ± 0.88a	5.33 ± 2.33a
NERICA2	26 ± 3.51b	19 ± 7.09b	20 ± 0a	2.33 ± 0.33a	20 ± 0.33a	2.33 ± 0.33bc	20 ± 0a	4.33 ± 3.38a
NERICA3	42.7 ± 17.90bc	57.7 ± 15.77bc	20 ± 0a	11.67 ± 0.66c	20 ± 0.33a	0.33 ± 0.33a	20 ± 0a	3.33 ± 1.33a
NERICA4	43 ± 1.52bc	55.3 ± 3.92bc	20 ± 0a	2 ± 1.15a	20 ± 0.57a	1 ± 0.57b	21 ± 1a	2 ± 0.57a
NERICA14	47.7 ± 6.17c	73.7 ± 10.83c	21.67 ± 1.66a	10.33 ± 1.45c	20 ± 1.20a	2.33 ± 1.20bc	20 ± 0a	1.67 ± 0.33a
NERICA15	20.3 ± 0.33a	20.3 ± 8.51b	21 ± 1a	6.67 ± 1.76b	20 ± 0.88a	1.67 ± 0.88b	20.33 ± 0a	0 ± 0a
WAB 5650	44 ± 6.02bc	47.3 ± 7.38bc	20.67 ± 0.66a	4 ± 0ab	20 ± 0.57a	3 ± 0.57c	20 ± 0a	0 ± 0a
WAB 56104	27.3 ± 2.96b	32.7 ± 3.28bc	22.67 ± 1.76a	8 ± 1bc	20 ± 0.33a	1.67 ± 0.33b	20 ± 0a	0.33 ± 0a
WAB 18118	23 ± 0.57ab	19.7 ± 1.45b	20 ± 0a	4 ± 0.57ab	20 ± 0.33a	0.67 ± 0.33ab	21 ± 1a	0.33 ± 0.33a
CG14	21.7 ± 0.88a	6.3 ± 3.38a	20 ± 0a	3.33 ± 1.33ab	20 ± 0.33a	0.67 ± 0.33ab	20 ± 0a	1 ± 1a
TOG 5681	20.7 ± 0.33a	12.3 ± 5.36ab	21 ± 1a	1 ± 0a	20 ± 0.33a	0.33 ± 0.33a	20 ± 0a	0 ± 0a
Grand Mean	33.6	39.2	23.57	11.81	20	1.61	20.33	1.8
Test F^2	*	**	NS	**	NS	**	NS	NS
CV (%)	40.4	42.8	8.8	36	0	62.7	4.7	133.9

Signification to Test F: NS = Not significant at 5%, ** = significant at 1%, CV= Coefficient of variation; Means followed by the same letter not significant at 5%.

- **Resistance to *S. cerealella***

The results from the analysis of variance for rice resistance parameters (**Table 5**) showed highly significant (P < 0.01) differences between locations, cultivars and locations × cultivars. The number of damaged grains from IITA location was greater than those from other sites. This trend remains the same as well for number of emerged *S. cerealella* as for number of damaged grains. The analysis of variance for resistance parameters was performed on all varieties from each environment. Significant differences (P < 0.05) existed between the varieties for all parameters for each location. On the cultivars from IITA, adult progeny was most important, except from the *O. glaberrima* parent CG14 (20 insects). Fewer damaged grains was recorded on TOG5681 (5 grains) and CG14 (16.33 grains) from Lokossa location followed by WAB5650 (19.33 grains) and NERICA4 (20 grains). In opposite, NERICA14, WAB56104 and WAB18118 were the most damaged varieties with 39.67, 38.67, 35.67

damaged grains respectively. The remaining varieties (NERICA15, NERICA2, NERICA1, NERICA3) were moderately tolerant *to S. cerealella*. As for Glazoue location, CG14 and TOG5681 still drew few *S. cerealella* population with 6.33 and 7 emerged adults. They were followed by NERICA15 (11.33 individuals), WAB18118 (20.33 individuals) and NERCICA3 (20.67 individuals). As for damage status, WAB56104 and WAB5650 were as much infested as, NERICA14, NERICA1 and NERICA2 ranging from 27 adults to 45.67 adults. The same trend was shown by samples from Malanville location (**Table 6**). All these results enabled us to identify three groups of varieties according to their level of susceptibility to *S. cerealella*. The *O. glaberrima* varieties TOG5681 and CG14 proved the most resistant regardless of the site while the *O. sativa* (WAB5650, WAB56104 and WAB18118) and some NERICA (NERICA14, NERICA1 and NERICA2) were identified as the most sensitive. The remaining varieties were tolerant regardless of the site.

Table 5. Analysis of variance of 3 resistance parameters of rice produced at 4 locations to *S. cerealella*.

Sources of variation	DF	Mean squares		
		Number of damaged grains	Adult developed after 1st generation	Weight loss (%) after storage
Varieties	10	1269.44**	861.99**	0.881**
Repetition	2	53.59**	48.35**	0.01199**
Localities	3	2273.9**	770.85**	2.08379**
Varieties*Localities	29	277.94**	214.96**	0.40781**
error	84	45.70	27	0.05447
Total	128	-	-	-
CV %	-	19.3	18.4	21.3

Table 6. Adult progeny and damage caused by *S. cerealella* on 11 cultivars from IITA Station, Lokossa, Glazoue and Malanville.

Varieties	IITA		Lokossa		Glazoue		Malanville	
	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains	Adult developed (number)	Number of damaged grains
NERICA1	42 ± 2.08bc	63 ± 4.36c	24.33 ± 1.76ce	28 ± 0.58c	43 ± 3.78d	57 ± 2.30f	49 ± 3.78d	54.67 ± 3.92e
NERICA2	32.67 ± 0.33b	35.33 ± 2.40ab	25.67 ± 1.43de	27.33 ± 1.67c	45.67 ± 6.69d	59.33 ± 6.06f	29 ± 1.52bc	35.33 ± 3.71c
NERICA3	33.67 ± 1.76b	41 ± 7.02abc	27.67 ± 2.03e	28.33 ± 1.76c	20.67 ± 2.66abc	24.33 ± 0.88abc	24.33 ± 1.45bc	29.33 ± 4.05bc
NERICA4	40 ± 2bc	47.33 ± 2.60abc	17.67 ± 1.86bc	20 ± 1.53b	21.67 ± 4.09abc	31.67 ± 5.23bcd	31 ± 1.52bc	36 ± 3.05c
NERICA14	31.67 ± 2.73b	50.33 ± 6.06abc	38 ± 2.52f	39.67 ± 2.33d	41.33 ± 4.66bd	52.33 ± 4.91df	42.67 ± 2.90d	47.33 ± 1.20e
NERICA15	39 ± 2.31bc	55.33 ± 2.40bc	24.33 ± 1.86cde	27 ± 2c	11.33 ± 2.72a	15.33 ± 3.17ab	29.1 ± 0bc	33.8 ± 0bc
WAB 5650	37 ± 2.08bc	45 ± 5.77abc	18.67 ± 2.67bcd	19.33 ± 2.03b	37 ± 2.64bcd	47.33 ± 6def	31.67 ± 3.52bc	36.33 ± 2.18c
WAB 56104	32 ± 2b	45 ± 3.06abc	36.33 ± 2.03f	38.67 ± 0.88d	27 ± 6.80abcd	41 ± 8.71cdef	33.67 ± 4.48c	38.67 ± 3.17c
WAB 18118	43.67 ± 2.91c	55.33 ± 2.19abc	34 ± 2.08f	35.67 ± 1.45d	20.33 ± 7.88ab	31.67 ± 6.98abcde	21 ± 2.64b	24.67 ± 2.40b
CG14	20 ± 2.31a	28.67 ± 6.77a	13.33 ± 0.88b	16.33 ± 1.33b	6.33 ± 0.66a	13 ± 1ab	25.33 ± 2.18bc	32 ± 0.57bc
TOG 5681	32.33 ± 2.03b	40.33 ± 8.33abc	3.67 ± 0.88a	5 ± 0.58a	7 ± 1.15a	9.67 ± 0.33a	3.33 ± 0.33a	3.67 ± 0.33a
Grand Mean	34.91	46.06	23.97	25.94	25.58	34.79	29.1	33.8
Test F^2	**	*	**	**	**	**	**	**
CV (%)	11	20	13.5	10.5	32.2	24.9	14.8	12.2

Signification to Test F: NS = Not significant at 5%, ** = significant at 1%, CV= Coefficient of variation; Means followed by the same letter not significant at 5%.

5. Discussion

In this study, the experiments were conducted in different locations of Benin especially in upland ecologies where climate and soil characteristics were quite different. The result showed that pH values under the different environments were between 5 and 6, suitable enough for rice cultivation [26]. As for soil nutrient, it varied significantly from a location to another. The soil of IITA was poorer in organic matter and in nitrogen than the soils of Glazoue, Lokossa and Malanville. According to Ralijaona [27], soil nutrient such as nitrogen (N), phosphorus (P) and potassium (K) ensure the proper development of rice plant. Therefore, they have a significant effect on the grain yield. Also, high variability of soils textures was observed. The component was sandy at IITA station-Benin, sandy silty at Lokossa and Glazoue and silty at Malanville. The sandy silty soils have a greater capacity to retain water than sandy soils and can allow rice to grow better on this type of soil. Genotype-Envi− ronment interaction effect was evaluated in order to describe the morphological variability between varieties used. Genotype across environment interaction was not significant for the agro morphological traits except weight of 1000 grains implying differential response of genotype under four locations for this last character. Similar report was earlier made by Asad *et al.* [28] and Sreedhar *et al.* [29] for paddy yield. This result could be explained by the combined action of soil fertility and water regime.

Genotypic variability is another factor of resistance to insect pests. Indeed, highly significant differences were observed between the tested materials. The *O. glaberrima* parents TOG 5681 and CG 14 showed significantly higher panicles number under the different environments. While the *O. sativa* parents WAB5650, WAB56104, WAB18118, NERICA1, NERICA2, NERICA3, NERICA4, NERICA14 and NERICA15 exhibited low panicle number under the same environments. NERICA varieties and their parents have behaved in the same way for all the characters studied in the different locations.

Phenotypic variability observed in the same genotype under different locations indicated that environmental factors can greatly influence on rice cultivation. The results of this study are similar to those of Steel [30] and Morkinyo and Ajibade [31] who showed that morphological variations can be observed with the same genotype due to environmental conditions such as fertility of soil, water regime, light and temperature. In addition, Moukoumbi *et al.* [32] reported similar results with the lowland varieties.

Growing NERICA rice varieties and their parents in different environments strongly influenced their susceptibility to infestation by the rice weevil and the Angoumois grain moth. The results indicate that interaction between varieties and location was significant. Significant differences existed between locations and varieties for all parameters studied. Progeny production and damaged grains of both *S. oryzae* and *S. cerealella* were greater on cultivars from IITA than at Glazoue, Lokossa and Malanville. NERICA varieties except NERICA2 and NERICA15 from IITA were highly susceptible to *S. oryzae* while the same varieties from Glazoue, Malanville and Lokossa were resistant. The *O.sativa* parents WAB 5650, WAB56104, WAB 18118 exhibited the same trend. More *S. cerealella* progeny and more feeding damage were produced on cultivars from IITA except CG 14. Damage and adult progeny among varieties that were relatively susceptible varied widely among locations. Thus, NERICA varieties and parent *O. sativa* ranged from susceptible to tolerant in the remaining locations. Similar results were obtained by Cogburn *et al.* [33] and Arthur *et al.* [3], who screened different cultivars of rough rice for resistance to *S. oryzae* and *S. cerealella*, and in a later test grew cultivars that appeared to be resistant in different geographic locations and tested the seeds from those cultivars for resistance. Some cultivars showed consistent results in progeny production regardless of growing location, while results for other cultivars appeared to be influenced by location. Furthermore, Cogburn *et al.* [33] reported that environmental influences more strongly susceptible varieties than resistant ones. This seems to be strong evidence for a genetic basis for resistance. The *O. glaberrima* parents CG14 and TOG 5681 were found to be resistant to infestation by *S. oryzae* and *S. cerealella* in all locations confirming the relatively good resistance of *O. glaberrima* previously reported by Sauphanor [20]. Other factor such as pest status can play a key role on varietal resistance independently to the effect of cropping location. For instance, number of damaged grains of CG14 and TOG 5681 was higher at IITA than Glazoue, Lokossa and Malanville to infestation by *S. cerealella*. Rizwana *et al.* [23] showed that no variety was completely immune to the infestation of this pest. The same conclusions were reported by Pandey *et al.* [34], Khatak and Shafique [35], Qayyum [36], Khatak and Shafique [37], Ratnasudhakar [38], Tirmizy *et al.* [39] and Khatak et al [40]. Also, Haryadi and Fleurat-Lessard [41] reported that climatic conditions and cropping techniques of the rice are factors contributing to the physical or chemical characteristics of each variety and consequently can explain different level of their resistance. Authors such as Breese [42], Russell and Cogburn [22], Chanbang *et al.* [43], Rizwana *et al.* [23] reported that infestation of *S. oryzae* and *R. dominica* were not found in rice grains with an intact husk and the mode of entry was assumed to be through a crack in the hulls caused either by natural means, through breakage from harvesting, or from the drying process. Moreover, Shafique and Chaudry [44] affirmed that resistance in paddy to storage insects has been attributed to various physico-chemical characteristics of rice grains such as intact hulls and tough siliceous hull of rough rice. Positive correlations were observed between protein, moisture, ash contents and the insect progeny, grain weight loss and damage [23]. Finally, Russell and Cogburn [22] concluded that more than one mechanism were operating against the insects and that insects developed more slowly on resistant varieties than on susceptible ones.

6. Conclusion

We can conclude that rice resistance to *S. oryzae* and *S. cerealella* is the result of a range of factors, including soil fertility, climatic conditions, water regime, physico-chemical characteristics of grains and pest status. Above all, the environmental factors such as soil fertility (nutrients content) are more important because they can influence the other factors.

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