

Effets de damage by wheat bug, *Aelia germari* [Hemiptera : Pentatomidae], on grain quality and on reproductive performance of the rice weevil, *Sitophilus oryzae* [Coleoptera : curculionidae]

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Résumé de l'article

La punaise des céréales, *Aelia germari*, cause des dégâts au champ, avant la maturité du grain, qui ont pour conséquence majeure une réduction de la valeur boulangère du blé destiné à la panification. Pour tenter de mettre en évidence les modifications induites par les attaques de punaises sur la valeur nutritive du grain, un essai biologique a été réalisé sur le charançon du riz *Sitophilus oryzae*, qui se développe dans l'endosperme du grain. Le charançon du riz a été élevé sur des échantillons de blé du cultivar 'Manondemias', dans lesquels ont été incorporés des taux différents (0, 4, 8, et 13%) de grain attaqué par la punaise phytophage *A. germari*. Sur les échantillons de blé punaïsés à 4, 8 ou 13%, la durée moyenne de développement de *S. oryzae* était plus courte que sur le grain non punaïsé. Cependant, le calcul des corrélations sur les variables prises deux à deux a montré que ni l'indice de sensibilité Dobie aux attaques d'insectes, ni la descendance par femelle de charançon, ni la perte de poids du grain consécutive au développement complet de *S. oryzae*, n'étaient corrélés avec le pourcentage de grains punaïsés dans l'échantillon. À partir d'une analyse multivariée globale, associant les propriétés physicochimiques ou rhéologiques des grains avec les paramètres décrivant la réponse biologique du charançon *S. oryzae*, il a été montré que le blé sans attaque apparente de punaise pouvait être associé à une longue durée de développement pour *S. oryzae*, un nombre plus faible de descendants, une force boulangère, une teneur en azote et un temps de chute élevés, ainsi qu'à une faible teneur en cendres et en azote assimilable du grain.

Effects of damage by wheat bug, *Aelia germari* [Hemiptera: Pentatomidae], on grain quality and on reproductive performance of the rice weevil, *Sitophilus oryzae* [Coleoptera : Curculionidae], on harvested grain

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The wheat bug, *Aelia germari*, feeds on developing wheat kernels, causing a loss in baking quality of the harvested wheat (*Triticum aestivum*). The possible nutritional changes in the bug-damaged kernels after the harvest were tested in a bioassay using the rice weevil *Sitophilus oryzae*, which feeds on the kernel endosperm. The weevils were reared on baking wheat cultivar 'Mahon demias', grown in Algeria, with different levels (0, 4, 8 and 13%) of wheat bug (*A. germari*) damaged kernels. Rice weevil reared on 4, 8 or 13% damaged wheat had a shorter development time than on wheat with no damage. However, pair-wise correlations showed that Dobie's index for susceptibility of grain for stored-products insect attack, number of progeny per female and kernel weight loss were not correlated with the percentage of damaged kernels. Using multivariate analysis, the general characteristics of high quality grain were associated with long development times for *S. oryzae*, low number of progeny, high baking strength, high falling number, high nitrogen, low ash content, and low assimilable nitrogen.

[Influence des attaques en culture de la punaise des céréales, *Aelia germari* [Hemiptera : Pentatomidae], sur la valeur nutritive du blé et le développement du charançon du riz, *Sitophilus oryzae* [Coleoptera : Curculionidae], après la récolte]

La punaise des céréales, *Aelia germari*, cause des dégâts au champ, avant la maturité du grain, qui ont pour conséquence majeure une réduction de la valeur boulangère du blé destiné à la panification. Pour tenter de mettre en évidence les modifications induites par les attaques de punaises sur la valeur nutritive du grain, un essai biologique a été réalisé sur le charançon du riz *Sitophilus oryzae*, qui se développe dans l'endosperme du grain. Le charançon du riz a été élevé sur des échantillons de blé du cultivar 'Mahon demias', dans lesquels ont été incorporés des taux différents (0, 4, 8, et 13%) de grain attaqué par la punaise phytophage *A. germari*. Sur les

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échantillons de blé punaïsés à 4, 8 ou 13%, la durée moyenne de développement de *S. oryzae* était plus courte que sur le grain non punaïsé. Cependant, le calcul des corrélations sur les variables prises deux à deux a montré que ni l'indice de sensibilité Dobie aux attaques d'insectes, ni la descendance par femelle de charançon, ni la perte de poids du grain consécutive au développement complet de *S. oryzae*, n'étaient corrélés avec le pourcentage de grains punaïsés dans l'échantillon. À partir d'une analyse multivariable globale, associant les propriétés physico-chimiques ou rhéologiques des grains avec les paramètres décrivant la réponse biologique du charançon *S. oryzae*, il a été montré que le blé sans attaque apparente de punaise pouvait être associé à une longue durée de développement pour *S. oryzae*, un nombre plus faible de descendants, une force boulangère, une teneur en azote et un temps de chute élevés, ainsi qu'à une faible teneur en cendres et en azote assimilable du grain.

INTRODUCTION

Aelia germari Kuster [Hemiptera : Pentatomidae] is the most damaging wheat bug pest in Algeria, and is a problem in all southern Mediterranean areas where wheat (*Triticum aestivum* L.) is grown. Wheat bugs also cause important damage to wheat in New Zealand (Swallow and Every 1991). Like the migratory grasshopper (*Locusta migratoria* L.), *A. germari* is a strong flier and infestations can spread rapidly, causing widespread damage in Algerian wheat fields (Gaffour-Bensebbane 1979). This pentatomid feeds on developing wheat kernels by inserting its stylet into the kernel, injecting enzymes and sucking up the extra-oral digested material. Damaged kernels can be detected as feeding causes a black speck surrounded by a whitened circle.

Although damaged kernels are about the same size as sound ones, the damaged kernels have less dry matter and more importantly, greatly reduce bread baking quality (Dubois and Validzic 1952; Gaffour-Bensebbane 1979; Menadi 1989; Mzali 1977; Swallow and Every 1991; Zoubovsky 1955). Wheat varieties with a high baking strength index (W) can still produce usable flour even with 1% wheat bug damaged kernels (Zoubovsky 1955). However, wheat varieties with a medium W become unusable for bread making at the same level of attack. There are numerous variables that determine the effect of

wheat bug feeding on baking quality : the pest species, the number of punctures per kernel and the initial baking quality of the wheat flour (W, elasticity and stickiness of flour dough). Consequently, simply using the rate of bug-damaged grain is not a good predictor of baking quality. The effects of the bug attack may be more exactly assessed by biochemical and technological tests. Currently, we do not have a rapid chemical test that will accurately predict bread making quality in harvested wheat. In addition, the prediction of baking quality with technological tests or rheological test remains difficult, or impossible when there is only a small quantity of wheat available.

Primary insect pests living inside grain after the harvest, such as the cosmopolitan species *Sitophilus oryzae* (L.) [Coleoptera : Curculionidae], are known to be sensitive to slight changes in nutritional value of kernel endosperm for different cereals (Davis and Sosulski 1976; Leclercq and de Bast 1965; Loschiavo *et al.* 1969). *Sitophilus oryzae* may be a discriminant species to test the susceptibility of bug-damaged kernels to stored-grain insects and to characterize the global changes in nutritional quality of the grain endosperm that occur after wheat bug feeding. The present investigation was undertaken to determine the relationship between the level of damage caused by the wheat bug to the kernels and biological response of the rice weevil on bug-dam-

aged grain and to correlate these results with traditional assessment of the extent of bug damage by rheological and analytical measurements on the extracted flour.

MATERIALS AND METHODS

Biochemical and technological analyses on wheat

The changes in biochemical composition of grain and in technological properties caused by the wheat bug damage were assessed using mainly standard methods. The germination capacity was measured on four replicates of 100 seeds at 20°C on wet filter paper following an ISTA (International Seed Testing Association) standard procedure (1976). The weight per hL of grain, usually used to assess the bulk density, was evaluated by using Algerian Standard for cereal grain NA - 1 613-90, weighing 1 L of grain in standard conditions. The determination of the weight of 1000 kernels followed Algerian standard NA - 7-31-90, in agreement with French Standard NF V 03-702. The calibration of the size of kernels was performed on two 1000-kernel grain samples, one originating from harvest with a 4% bug damage level and the other constituted from 100% externally-visible damaged kernels selected out from the 4% bug-damaged initial grain batch. Each grain sample was separated into three classes of size: % large kernels, size > 2.9 mm; % medium size kernels, size < 2.9 and > 2.3 mm; % small size kernels, size < 2.3 mm (no replication, each 1000-kernel sample was sieved). The grain hardness was assessed on a 100-kernel sample by a "hardness tester", Pharmatest® PTB 311, which determined the resistance to penetration into the kernel of a needle, converted into power applied for penetration in Newton units. The percentage of ash was obtained by using French standard NF V 03-760, which involves burning 5 g of grain in a special oven at 550°C. The protein content was derived from nitrogen content analysis using the Kjeldahl standard method (French Standard NF V 03-050; N % x 5.7). The percentage of

degradable nitrogen (or assimilable nitrogen) was obtained using the Aufrere method (Aufrere and Michalet-Doreau 1988). This method is used to predict the percentage of assimilable nitrogen in feed products through enzymatic digestion of the sample.

The bread making quality was assessed by the falling number test (Hagberg index) measuring the changes in α -amylase activity that relates to the starch paste viscosity (Algerian Standard NA 1176-90 = NF V 03-703), and alveographic analysis for the estimation of baking strength index (W) and rheological characteristics of the bread dough (P/L ratio with tenacity P and extensibility L, and G index relative to its inflation capacity) using Algerian Standard NA 1188-90, consistent with French Standard NF V 03-710 (Alvéographe Chopin®). The alveographic test needed to be modified to obtain a normal alveographic curve with bug-damaged wheat cv. 'Mahon demias', since this variety has a poor natural baking strength index. We mixed 5% of the bug-damaged grain (0, 4, 8, and 13% damaged kernels) with sound grain of a standard variety of wheat with a good bread-making quality. Thus, the final % bug-damaged wheat in the samples was respectively 0, 0.2, 0.4, and 0.65%. The resting time of the dough before alveographic analysis was increased to 3 h instead of the standard 20 min. The "virulence index" (V) of bug attack, describing the alteration of rheological properties of bread dough, was calculated from results obtained with this modified method:

$$V = \frac{W_c - W_b}{W_c} \times 100$$

where:

V = virulence of bug attack (%)

W_c = baking strength index W of control (sound) wheat (10⁻⁴ J g⁻¹ of dough)

W_b = baking strength index W of wheat with bug-damaged kernels (10⁻⁴ J g⁻¹ of dough)

Bioassay with insects

The initial batch of wheat cultivar 'Mahon demias' was harvested with a 4% level of wheat bug-damaged kernels, and it was stored free of insecticide treatment before the experiments. From this grain, damaged kernels were selected out to make up a sample of 100% damaged kernels, which was diluted with sound wheat to give additional samples with 13, 8, 4, and 0% damaged kernels. A 13% damage level was chosen because it is the legal limit for food-grade wheat in Algeria. *Sitophilus oryzae* was chosen for the bioassay because it has a short life cycle, is a common pest of stored grain in regions where the wheat bug is also a pest and the larvae feed internally on the grain endosperm. We used a French strain of this species that has been reared for 20 yr in laboratory conditions at 25°C, 70% relative humidity (RH) on whole wheat grain. Five pairs of *S. oryzae* adults were chosen during the first mating after emergence from the kernel (4-7 d old), and placed on 50 g of wheat at 25 ± 1°C, 70 ± 10% RH. The grain was held at these conditions 1 wk before infestation with the weevils to allow for moisture content equilibrium. The adults were removed after a 12-d oviposition period. Four wk after adults were placed on the grain samples, emerging adults (first generation progeny) were counted and removed daily. The progeny emergence was considered finished when there were five consecutive days without any weevil emergence. Each bioassay had five replicates.

Biological indexes

The median developmental time (MDT) was obtained by a simple calculation of the time lasting between the median day of the oviposition period (6 d after introduction of the weevils on the grain sample) and the time when 50% of the weevil population has emerged (Bekon and Fleurat-Lessard 1988; Haryadi 1991).

$$MDT = Dx + \frac{n_{50} - n_x}{n_y - n_x} \times (Dy - Dx)$$

where :

MDT = median developmental time (d)

Dx = the last day before 50% emergence of the weevil population occurs (d)

Dy = the first day after the time of 50% emergence (d)

n_x = cumulative number of weevils emerged at Dx

n_y = cumulative number of weevils emerged at Dy

n_{50} = 50% of the total number of emerged weevils at the end of assay

Dobie's index of susceptibility for insect attack of grain (Dobie 1974) can be calculated using MDT from above and the mean number of progeny per female (F) :

$$\text{Dobie's Index (DI)} = 100 \{ \ln (F \text{ MDT}^{-1}) \}$$

In the current study, we used a simplified calculation in including directly into Dobie's formula the mean progeny of five females instead of the mean number of progeny per female. Weight losses caused by the development of one generation of *S. oryzae* were assessed by using the 1000-kernel weight measurement (Adams and Schulten 1978).

Statistical analysis

Variation in single criteria and variables was assessed by an ANOVA with one-way analysis and the means were compared using Newman-Keuls test (with significance established at $P \leq 0.05$). When correlation between variables was suspected, simple correlations were calculated and the global influence of bug attack on the wheat flour quality for the weevils was estimated from a full combination of influent variables into a principal component analysis. This illustrated the interrelations of all criteria and parameters involved in, or affected by bug attack of wheat grain. All the statistical analyses were performed with STAT-ITCF software (ITCF 1988).

RESULTS AND DISCUSSION

Effect of wheat bug feeding on baking quality

The increased levels of bug attack on wheat caused a significant reduction in 1000-kernel weight ($r = 0.998$; $P = 0.04$; Table 1). The distributions of kernel size classes established for 100% bug-damaged kernels and sound ones were significantly different ($\chi^2 = 5.26$; $P = 0.024$). This reduction in the size of a bug-damaged kernel was confirmed by the radiographic picture of damaged grain compared to sound grain (Fig. 1) where we detected that the bug puncture induces a hole in the wheat kernel and a malformation that often reduces its length. The amplitude of these modifications could depend on the degree of ripening when the bug fed on the kernel. The mean hardness of grain was greatly reduced in damaged kernels, in relation to the increased brittleness of the part of the grain where bug saliva has been injected. The difference in the density of internal structure of the kernel endosperm was visible on the radiographs (Fig. 1). Bug-damaged

kernels had lower rates of germination (Table 1). This type of damage is of particular importance for wheat which is grown for seed production. The ash content of grain increased directly with the degree of kernel damage (Table 2). It may be that the percentage of external layers of the grain (especially bran layers) remains unchanged after insect puncture, whereas endosperm proportion decreases in the attacked grain. The ratio of outer layers, which contain up to 67% of mineral matter (Hinton 1959), to internal endosperm increased and so did the ash content. Although the nitrogen content was not significantly modified, the percentage of degradable nitrogen increased regularly with the level of damaged grain. This may be caused by the injection of proteolytic enzymes by the wheat bug into the kernel, which causes extra-oral protein degradation, and the bug being not able to remove all the digested endosperm. We concluded that this increase in digestibility was mainly related to the gluten fraction of albumen, as there was only a small reduction in falling number index, indicating no significant changes in the properties of

Table 1. Effect of wheat bug attack on technological properties of wheat grain^a cv. 'Mahon demias', with 4 or 100% damaged kernels compared to sound kernels

Analytical results	Bug-damaged kernels (%)		
	0	4	100
Moisture content (% dm)	10.4	10.9	— ^b
Bulk density (kg hL ⁻¹)	78	77	—
Dry weight of 1 000 kernels (g)	30.4	29.8	24.8
Kernel size calibration (%):			
> 2.8 mm	42.2	—	38.6* ^c
< 2.8 and > 2.3 mm	23.1	—	24.6*
< 2.3 mm	34.7	—	36.8*
Hardness (N)	77.7	—	66.8
Germination capacity ^d	100	98* ^e	87* ^f
Protein content (% dm)	17.3	16.9	—
Zeleny index (mL)	29	24	—
Falling number (= Hagberg index) (s)	422	428	—
Fat acidity (H ₂ SO ₄ , % dm)	0.037	0.032	—

^a Data concerning the grain batch taken directly in the field.

^b Missing value because of the lack of the minimum quantity required or unable to take the measurement.

^c Distribution in each size class significantly different ($P = 0.024$) according to χ^2 test.

^d Average of four replicates.

^e Confidence limits 95 % : 93.0 to 99.8.

^f Abnormal germination (confidence limits 95 % : 78.8 to 92.9).

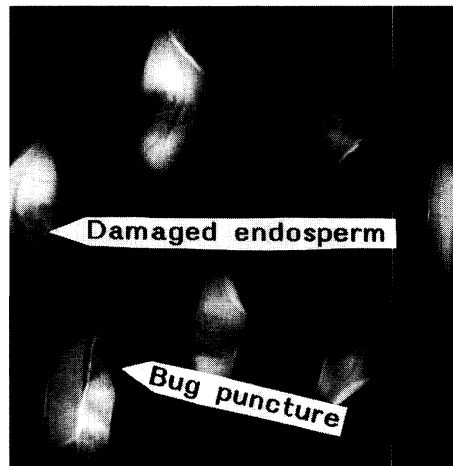
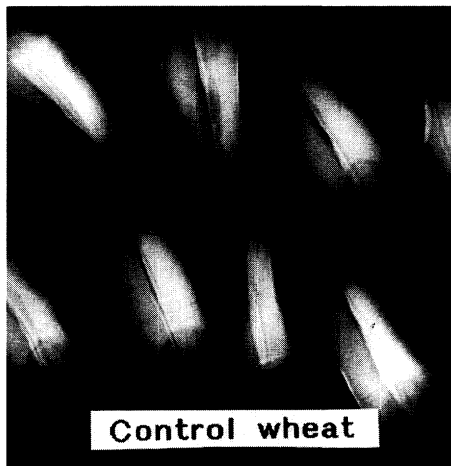


Figure 1. X-rays picture of sound wheat grain (left) compared to bug-damaged grain (right). The part of the kernel endosperm damaged by the bug puncture has a different density to X rays and appears darker on the radiograph picture.

starch. Nevertheless, the progressive reduction in falling number index was correlated to the natural logarithm of the level of bug damage (Table 2).

The most important effect was observed on baking strength index, *W*, as measured by the virulence index. The virulence index increased as the percent of bug-damaged kernels increased

(Table 2). The baking quality of flour extracted from sound grain (cv. Mahon demias), free of an observable bug puncture, was acceptable with a virulence index of less than 20%, the maximum level tolerated by baking industry. Above this level of 4% damaged kernels, the indexes related to bread-making quality deteriorated beyond the acceptable technological limit (Table 3).

Table 2. Analytical characteristics of wheat grain cv. 'Mahon demias' at different levels of damage by the wheat bug and linear regression between the percentage of damaged kernels and each characteristic

Damaged kernels (%)	Moisture content (% wb) ^a	Mineral ash (% dm)	Nitrogen content (% dm)	Degradable nitrogen (%)	Hardness index (N) ^b	Falling number (S) ^c	Virulence index (%)
0	13.3	2.23	3.1	13	77.6	391 ± 17	3.3
4	13.4	2.32	3.1	13	—	378 ± 14	20
8	13.4	2.45	3	15	—	368 ± 3	46.7
13	13.2	2.78	2.9	15	—	375 ± 10	60
100	—	—	3	21	66.8	365 ± 5	—
<i>r</i>	- 0.13	0.97	0.10	0.98	—	- 0.87 ^d	0.99
<i>P</i>	0.43	0.03	0.87	0.003	—	0.05	0.01
slope	nc	0.04	nc	0.076	—	- 5.29	4.54
intercept	nc	2.18	nc	13.5	—	386	4.12

^a Wet basis.

^b Newton unit.

^c ± Standard deviation.

^d Regression with natural logarithm (ln) transformation for abscissa (% bug damage).

— Missing value because of the lack of the minimum quantity required, or unable to measure.

nc Not calculated.

Table 3. Degradation of bread making properties of flour made from wheat damaged by wheat bug attack at different levels of damage. Determination of «virulence» (V) for bread-making strength (W) of wheat flour

Alveographic characteristics ^b									
Proportion of bug-damaged grain ^a	Standard protocol				Modified method (3 h resting time of dough)				Virulence index (%)
	W (erg g ⁻¹)	P (mm)	G (mL)	P/L	W (erg g ⁻¹)	P (mm)	G (mL)	P/L	
MD 100% sound (MD-0)	45	44.5	13.3	1.27	Incalculable				
MD 4% damaged (MD-4)	Incalculable				—	—	—	—	—
Control Wheat (CW)	—	—	—	—	150	66.1	17.2	1.1	0
CW + 5% (MD-0)	—	—	—	—	145	63.2	17.2	1.05	3.3
CW + 5% (MD-4)	—	—	—	—	120	53.9	17.4	0.87	20
CW + 5% (MD-8)	—	—	—	—	80	53.9	13.3	1.5	46.7
CW + 5% (MD-13)	—	—	—	—	60	44.8	13.4	1.23	60

^a MD = Wheat cultivar 'Mahon demias'; CW = control wheat for alveographic tests ; example : (MD-8) = MD with 8% bug-damaged kernels.

^b Alveographic coefficients : W = baking strength index ; P = elasticity coefficient ; G = inflation capacity ; P/L = meaningful ratio for bread-making dough.

Flour derived from 8% bug-damaged wheat had rheological properties so modified that it could not be used for bread making, with a virulence index of more than 40 %. This threshold is in good agreement with one of the first studies on this topic (Kosmin 1933).

Effect of wheat bug damage on *S. oryzae* development

The mean progeny per female weevil was not affected by the level of bug-damaged grain with 26 to 27 progeny

per parent weevil (Table 4). However, there was a decrease in the median developmental time (MDT) with the increase in the percentage of bug-damaged grain in the samples ($P = 0.013$). In 100% damaged kernels, MDT was reduced by about 3% compared to sound kernel controls (Table 4). For the other levels (4, 8 and 13%) of bug-damaged grain, the MDT was not different than for sound grain. Consequently, the modified Dobie's index, which involves MDT, did not change

Table 4. Progeny of 5 females, Median Developmental Time, modified Dobie's index of grain susceptibility to insects, and percentage of loss induced by a generation of *S. oryzae* reared on wheat, damaged by the wheat bug at different levels

Bug damage (%)	Mean progeny (5 weevils) ^a	Average MDT (d) ^a	Modified Dobie's index ^a	Mean weight loss (%) ^a
0	263 ± 24 a [‡]	44.2 ± 0.4 a	12.6 ± 0.2 a	3.4 ± 0.4 a
4	263 ± 22 a	42.7 ± 0.5 b	13.0 ± 0.3 a	3.1 ± 0.7 a
8	270 ± 56 a	43.1 ± 0.15 b	13.0 ± 0.6 a	2.8 ± 0.4 a
13	267 ± 7 a	42.9 ± 0.6 b	13.0 ± 0.2 a	3.1 ± 0.4 a
<i>r</i>	0.07	0.54	0.36	0.29
<i>P</i>	0.76	0.013	0.12	0.21
slope	nc	- 0.08	0.028	- 0.03
intercept	nc	43.7	12.8	3.3

^a Mean ± Standard deviation.

[‡] Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$) according to Newman-Keuls test.

nc Not calculated.

with bug attack level. However, the lowest value of the susceptibility index was observed with sound grain, while it was higher but unvariable for all other levels of incorporation of bug-damaged wheat as previously observed with MDT. The mean weight loss per kernel, caused by the development of internal stages of the rice weevil in the kernel did not change (Table 4). A weevil larva inside a kernel should eat about the same quantity of endosperm to complete its development, whether the kernel is bug-damaged or not.

Correlations between technological parameters and biological performances of rice weevils

Percent bug-damaged kernels was correlated with an increase in ash content and in level of damage for bread-making capacity (virulence) (Table 5) as it was in previous analysis on freshly harvested grain batch (Table 2). Other parameters such as degradable nitrogen, falling number and mean developmental time, were not significantly

correlated with percent bug-damaged kernels using pair-wise analysis (Table 5), although they were using other methods of analysis (Tables 2, 4). Degradable nitrogen was inversely correlated with nitrogen content (Table 5) but positively with the number of *S. oryzae* progeny produced. This link existing between the decrease in nitrogen content and the percent degradable nitrogen is reasonable as higher the level of bug damage and the withdrawal of digested endosperm by the wheat bug, lower the protein content remaining in the kernel. In addition, enzymes remaining in the grain endosperm after bug attack probably increased the percentage of degradable nitrogen, improving protein assimilation by *S. oryzae* larvae, inducing a slightly shorter MDT (Table 4). As to be expected, there was an inverse correlation between falling number and virulence. When the bug damage increases, both the bread-making capacity (assessed through the virulence index increase) and the falling number index decreased. This had been also shown in a previous work where W

Table 5. Correlation coefficients matrix showing pair-wise comparisons among the data characterizing the biological response of the rice weevil and the physico-chemical and rheological properties of wheat damaged by the wheat bug at different levels

Variables ^a	Virulence	Falling number	Ash	Degradable nitrogen	Moisture content ^b	Progeny 5 females	N content	% damaged kernels	MDT
Virulence	1								
Falling number	-0.92 ^c	1							
Ash	0.8	-0.54	1						
Degradable nitrogen	0.82	-0.77	0.81	1					
Moisture content	0.05	-0.35	-0.55	-0.29	1				
Progeny 5 females	0.76	-0.81	0.63	0.96*	-0.1	1			
N content	-0.65	0.54	-0.82	-0.95*	0.55	-0.88	1		
% damaged kernels	0.92	-0.73	0.97*	0.88	-0.34	0.74	-0.82	1	
MDT	-0.85	0.79	-0.53	-0.41	-0.37	-0.34	0.17	-0.66	1

* Error level of inter-variable correlation coefficient ≤ 0.05 (*t*-test).

^a Equilibrated statistical design with four data per variable.

^b Percentage on wet basis.

^c Underlined coefficient if marginal significance : $0.05 \leq P \leq 0.1$.

and falling number had been measured on a very high quality wheat cultivar mixed with different levels of bug-damaged kernels (Menadi 1989).

A principal component analysis was performed in order to show the main interactions in the changes caused by the progressive degradation of wheat kernel quality through bug damage (Table 6 and Fig. 2). Seven variables of physico-chemical, technological, or rheological properties as explanatory variables and two biological variables describing *S. oryzae* biological response were used for the PCA (Table 6). Principal component axis 1 describes grain quality (Fig. 2). High quality grain is associated with high nitrogen content, high falling number, low ash content, low virulence index, low % degradable nitrogen, longer developmental time for *S. oryzae* and fewer progeny. Percent bug-damaged grain points, co-ordinated on principal components correlation circle, are arranged in decreasing magnitude along the principal component axis 1. The second axis only described the variation caused by the moisture content and the weight loss induced by *S. oryzae* development. It was not consistent along damage levels which gradient was moving clockwise in the plan delimited by the two first principal components. The importance of this clear-cut segregation of the four levels of bug damage on principal components

correlation circle should not be minimized. This result indicated that the consequences of the bug damage increase for technological properties of wheat flour and for biological response of *S. oryzae* are probably more exactly related to the complex relationship existing between the measured variables than to the set of significant pairwise correlations. Progeny per female weevil should be more important in 8 and 13% level of damaged kernels, these highest levels of bug damage being associated with a higher mineral ash content. The importance of cellulose outer layers of the kernel as an oviposition enhancing factor has been demonstrated before for the rice weevil on brown rice kernels (Haryadi and Fleurat-Lessard 1994). The weight loss induced by a generation of weevils was inversely related to moisture content, as expected. Higher the moisture content of the kernel, easier the female weevil can bore a hole for egg laying and can the larva borrow its run. In addition, kernels with the highest level of bug attack had a lower moisture content, as if the bug damage to the kernel had allowed the kernel to dry more completely after the bug puncture and before complete dryness of kernel occurred before the harvest.

We have shown that the attack of immature grain by wheat bug in the field before harvest has severe conse-

Table 6. Principal components (PC) correlation matrix showing the relative importance of the variables on each principal component, the co-ordinates of the variables on PC1 and PC2 axes and the percentage of variability accounted for by each principal component

	Principal component 1 (PC1)	Principal component 2 (PC2)	Principal component 3 (PC3)	Co-ordinates of variables in PC1-PC2 delimited plan	
				PC1	PC2
Analytical variables					
Moisture content	0.179	- 0.98	0.086	0.176	- 0.981
Mineral ash	- 0.875	0.405	0.265	- 0.875	0.405
Nitrogen content	0.912	- 0.267	0.31	0.911	- 0.269
Degradable nitrogen	- 0.984	0.002	- 0.177	- 0.984	0.004
Loss in weight	0.418	0.891	0.174	0.421	0.89
Falling number	0.812	0.554	- 0.185	0.813	0.552
Virulence index	- 0.985	0.048	0.166	- 0.984	0.051
Biological variables					
Progeny of 5 females <i>S. oryzae</i>	- 0.92	- 0.22	- 0.33	- 0.922	- 0.214
Median Developmental Time	0.75	0.31	- 0.58	0.751	0.305
<i>Contribution to the variation</i>	62.9 %	32.9 %	4.2 %		

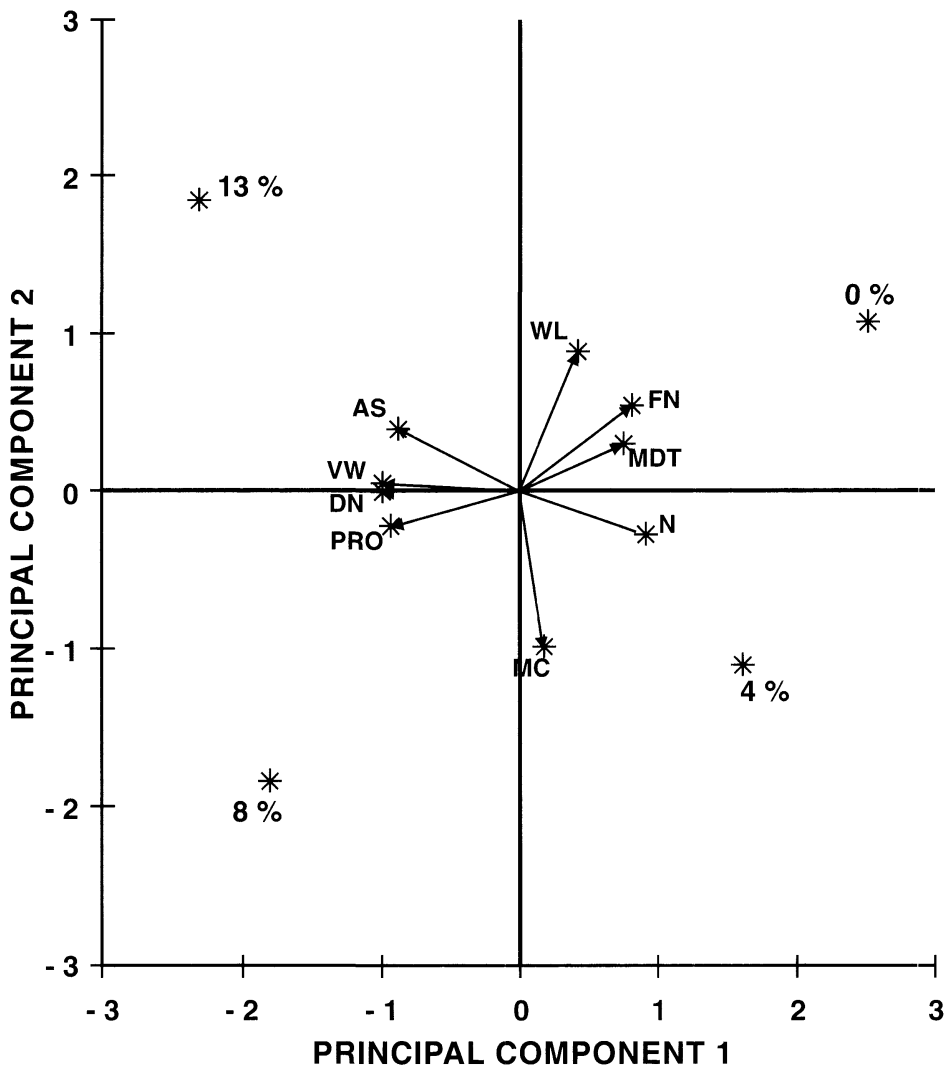


Figure 2. Correlation circle in PCA showing the linkage of the different levels of bug damage in wheat with technological parameters and biological characteristics of *S. oryzae* (as follows) :

Technological parameters :

MC = moisture content; AS = ash (mineral); N = nitrogen; DN = degradable nitrogen; WL = weight loss; FN = falling number; VW = «virulence» on baking strength (W).

Biological characteristics (of weevils) :

MDT = median developmental time; PRO = progeny per female.

Level of bug damage :

0 % = sound grain; 4 % = 4 % bug-damaged; 8 % = 8 % bug-damaged; 13 % = 13 % bug-damaged.

quences on rheological properties of bread-making dough at 4% damaged kernels, at a level lower than previously described (Gaffour-Bensebbane 1979; Menadi 1989; Swallow and Every 1991), and observed here as low as 4%. In addition, we assume that residual activity of enzymes remaining in harvested grain after bug damage is the prime cause of prevention of use for bread making of flour coming from wheat with more than 8% wheat-bug-damaged kernels. This threshold is far less than commercial tolerance in countries where wheat bugs are common pests, (e.g., threshold is fixed at 13% bug-damaged kernels in Algeria). The reduction in developmental time of *S. oryzae* could be due to a better assimilation of gluten and starch in grain endosperm during larval growth. The biological response of the weevil to nutritional quality changes in grain is detectable at low damage levels and it could be used as an indirect measure for protein and starch nutritive value alteration in bread making wheat. Nevertheless, this bioassay is too lengthy and a better approach would be an ELISA test with specific antibodies for the proteases remaining within bug-damaged kernels. This kind of test is already used for the detection of traces of insect muscle myosin within cereal grain or flours (Kitto 1991).

Although interactions among the wheat bug feeding during the growth of wheat and the quality characteristics of the harvested grain have been clearly demonstrated here, some other factors may affect wheat quality. Further studies are needed to determine the importance of factors such as the delay of time from the bug feeding to the grain maturity stage, the different pentatomids species involved in wheat crop attack, and the susceptibility of different wheat cultivars to bug attack.

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