116

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Relative susceptibility of stored pearl millet products and fonio to insect infestation

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Abstract

As ready-to-use cereal products become increasingly available in Sahelian countries, higher losses to stored products insects may be expected. The susceptibility of threshed fonio (*Digitaria exilis*) and of four food products derived from pearl millet (*Pennisetum glaucum*) to four major pests of millet was compared to that of whole millet kernels. *Tribolium castaneum*, *T. confusum*, *Corcyra cephalonica* and *Ephestia cautella* developed on all media, but striking differences in susceptibility to attack were observed. Successive processings of millet resulted in increased susceptibility, and millet flour and semolina (sankhal) were the most susceptible to all insects. Arraw, which is obtained from millet flour, was comparatively resistant to both Lepidoptera, but suffered heavy damage from both *Tribolium* species. Of all tested products, threshed fonio was the most resistant to *C. cephalonica*, but was heavily attacked by *T. confusum* and *E. cautella*. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Cereal foods; Sahel; Millet; Fonio; Susceptibility; Weight losses

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1. Introduction

Populations in the Sudano-Sahelian and Sahelian zones of Western Africa traditionally rely mainly on cereals for their subsistance. Pearl millet (*Pennisetum glaucum* (L.) R.Br.) and sorghum (*Sorghum bicolor* Moench.) constitute the staple foods of most populations in these areas (Fofana and Mbaye, 1990).

Fonio (*Digitaria exilis* (Kippist) Stapf), also called “hungry rice”, because of its low yields and the need for tedious hand-threshing, is cultivated in poor, infertile soils in restricted parts

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of Western Africa, mainly in the Fouta Djallon area in Guinea, in southeast Senegal and in Mali. However, the recent development of mechanical threshing offers promising prospects to this highly priced cereal (Anonymous, 1995).

In Senegal, pearl millet is traditionally stored as whole or broken panicles in granaries made of local plant material. The performance of this type of storage is quite impressive, with weight losses amounting to not more than 3% after one year storage in the Sahelian zone (Alzouma, 1992). One main factor responsible for this low level of grain damage is the aridity of the climate, with its well-known depressant effect on the reproductive and developmental rates of storage insects (see Roorda et al., 1982; Hagstrum and Throne, 1989). A survey in the Sahelian zone of Senegal (Gueye, unpublished) indicated that only *Leucohimatium arundinaceum* (Forskål), a coleopteran which does not feed on *P. glaucum* kernels but rather on its dry stems and leaves, was locally abundant on unthreshed pearl millet. In the more humid Sudano-Sahelian zone, *Sitotroga cerealella* (Olivier) is the dominant insect pest species on pearl millet panicles, and losses may be high, particularly during the rainy season (Seck, 1991).

Due to rapid urbanization and the development of strategic reserves, bulk storage of threshed millet has become a common practice. In a survey of strategic warehouses in Senegal, we identified five species of Coleoptera as millet grain feeders : *Cryptolestes ugandae* Steel & Howe was the most abundant species, followed by *Rhyzopertha dominica* (F.), *Tribolium castaneum* (Herbst), *T. confusum* Jacquelin du Val and *Trogoderma granarium* Everts. *Corcyra cephalonica* (Stainton) was the only lepidopteran pest recorded; it was present in all warehouses.

The aim of our study was to identify consistent differences in susceptibility to insects among dehulled pearl millet, fonio and pearl millet, millet semolina (sankhal), millet flour and arraw, a millet flour-based preparation. Whole pearl millet was used as a standard. It was also to determine whether the current evolution in consumer preferences from raw, unthreshed, to ground, parboiled, ready-to-use cereal foods might lead to increased storage losses. Rate of preimaginal development and progeny of *Tribolium castaneum* and *T. confusum*, survival of *Corcyra cephalonica*, and weight loss under given insect pressure were used as criteria of the susceptibility of the different products. *Ephestia cautella* (Walker), which is another pest of millet products in Africa (Allotey, 1991; Seck, 1991), was also included in the study. Tests were performed under constant relative humidity (r.h.) and temperature conditions compatible with optimum or nearly optimal development of the insects (Burges and Haskins, 1965; Russell, Schulten and Roorda, 1980; Dobie et al., 1984; White, 1987).

2. Material and methods

2.1. Millet products and fonio

Threshed pearl millet of the local variety "souna" was bought on a Dakar market, then cleaned in a dockage tester to remove immature grains and foreign material. Grain was kept for 8 days at −18°C to eliminate any hidden infestation, then allowed to equilibrate at room temperature. Seven kg of clean grain were left for 10 min in a PRL dehuller. Dehulled grain retained by a 0.5 mm sieve was used in the experiments. Sankhal and flour were obtained from dehulled grain in a Jet 13 mill without (sankhal) or with (flour) a 0.5 mm sieve. Sankhal was composed of 40% particles retained by a 1 mm sieve and 60% particles retained by a 0.5 mm sieve. Part of the flour was used to prepare arraw in a granulator with built-in water supply, without addition of any other component (Ndoye, 1997). The arraw was produced as balls which were then sun-dried.

Hand-threshed fonio was bought on a Dakar market. After a week at −18°C followed by temperature and humidity equilibration, it was sieved, and the fraction retained by the 0.5 mm sieve was used in the experiments. Grain size of the different products was evaluated using maximum and minimum dimensions in a 1000-grains sample and the weight of the same sample (Table 1).

2.2. Insect cultures

The stocks of insects used in the experiments were maintained in the laboratory for at least 3 generations on corn flour (*T. castaneum*), wheat flour (*T. confusum*) or groundnuts (*C. cephalonica* and *E. cautella*). Male and female pupae of the four species were held separately in Petri dishes. Upon emergence, *C. cephalonica* and *E. cautella* adults were isolated in 1 liter glass jars, and eggs were collected daily. *Tribolium* adults were used within 24 h after laying.

2.3. Experimental procedures

25-g samples of each product were placed in 9 cm glass Petri dishes and infested with 10 pairs (*T. castaneum* and *T. confusum*) or 10 eggs each (*C. cephalonica* and *E. cautella*). Samples were incubated at constant 32.2(±0.2)°C and 60(±5)% r.h., under natural daylight. These temperature and r.h. conditions were assumed to maximize the differential effects of diets on insect development (Lamb and Loschiavo, 1981).

Each experiment was replicated 10 times. Dishes were examined at regular intervals for date of first *Tribolium* adult emergence, which was a measure of pre-imaginal developmental rate. Forty-five days after initial infestation, the total number of progeny (larvae, pupae and first generation adults) in *Tribolium* infested samples and the number of *C. cephalonica* and *E. cautella* pupae obtained from the 10 initial eggs, were recorded. All adults, larvae and pupae were removed from the samples. Weight losses were computed as the difference between dry weight of samples on day 0 and dry weight on day 45 of the fraction of the same samples

Table 1
Particle and grain size range, and weight of 1000-grain samples of the different food media

	Grain size (mm)	Weight (g) of 1000 grains
Whole millet	2.5–4.0	6.42
Dehulled millet	2.2–3.8	4.85
Fonio	1.2–1.5	0.52
Sankhal	0.5–1.7	0.48
Millet flour	< 0.5	—
Arraw	2.5–4.8	17.68

retained by a 0.3 mm Retsch® VS1000 laboratory sieving machine run for 10 min. During this process, web tunnels built by *C. cephalonica* and *E. cautella* larvae were left intact, so that part of the food particles attached to them were retained by the sieve. Moisture content of the food media was determined on 10-g samples in a Sartorius® MA30 moisture analyzer, with temperature set at 100°C and automatic heating time setting.

Statistical comparisons of means for progeny, minimum preimaginal developmental time and weight losses were followed by Newman–Keuls' test (STAT-ITCF, Institut Technique des Céréales et des Fourrages, Paris).

3. Results

The moisture contents of the food media when in equilibrium with the 55–65% r.h. holding condition were: whole millet 6.5–8.0%, dehulled millet 7.5–9.3%, fonio 8.3–9.8%, sankhal 8.3–10.5%, millet flour 9.6–11.0%, arraw 10.1–11.8%. Time to first adult and number of progeny after 45 days were not significantly correlated ($r = -0.0117$ for *T. castaneum* and $r = 0.1188$ for *T. confusum*; $P > 0.05$). Weight losses of the different food media were not significantly correlated with time to first *T. castaneum* ($r = 0.1708$, $P > 0.05$) or *T. confusum* ($r = 0.2404$, $P > 0.05$) adult. Losses correlated well with number of *T. castaneum* ($r = 0.7034$, $P < 0\ .01$) and *T. confusum* ($r = 0.8540$, $P < 0.01$) progeny. They were also significantly correlated with the number of *C. cephalonica* ($r = 0.5238$, $P < 0.01$) or *E. cautella* ($r = 0.5689$, $P < 0.01$) larvae reaching the pupal stage.

Development of the four insect species tested was possible on the six diets; however larval mortality of *E. cautella* was greatly increased on arraw (Table 2). *T. castaneum* and *T. confusum* completed development rapidly on whole millet, but their number of progeny on this diet was significantly smaller than on flour (both species), arraw (*T. castaneum*), fonio and sankhal (*T. confusum*). On the same diet, *C. cephalonica* mean larval survival was high, whereas only 3.5 larvae of *E. cautella* out of 10 survived to pupal stage. *Tribolium* spp and *C. cephalonica* performed equally well on dehulled millet and arraw. Millet flour produced large

Table 2

Comparison of days (X ± SE) to first adult, numbers (X ± SE) of progeny and of larvae reaching pupal stage for each food medium. Means of ten replicates. (a–c) means followed by the same letter in a column are not significantly different ($P > 0.05$)

	Days to 1st adult		Number of progeny		Number of pupae	
	T. castaneum	*T. confusum*	*T. castaneum*	*T. confusum*	*C. cephalonica*	*E. cautella*
Whole millet	26.7 ± 1.3 a	30.0 ± 0.6 a	55.4 ± 7.1 a	72.7 ± 13.4 a	7.5 ± 0.8 bc	3.5 ± 0.6 b
Dehulled millet	27.1 ± 0.7 a	31.4 ± 0.5 ab	119.6 ± 23.0 abc	95.0 ± 15.6 ab	7.8 ± 0.8 bc	4.2 ± 0.8 b
Fonio	26.8 ± 0.5 a	30.8 ± 0.3 ab	96.9 ± 8.0 ab	123.2 ± 11.0 b	2.6 ± 0.9 a	4.9 ± 0.7 b
Sankhal	30.8 ± 0.2 b	31.8 ± 0.4 b	123.9 ± 22.0 abc	162.5 ± 6.0 c	8.1 ± 0.3 c	9.3 ± 0.3 c
Millet flour	29.5 ± 0.8 b	31.8 ± 0.5 b	186.4 ± 34.8 c	182.3 ± 9.3 c	7.8 ± 1.4 bc	3.5 ± 0.6 b
Arraw	25.8 ± 0.3 a	30.9 ± 0.4 ab	142.6 ± 12.6 bc	99.8 ± 11.5 ab	4.3 ± 1.3 ab	0.1 ± 0.1 a

progenies of *Tribolium* spp and *C. cephalonica*, much less of *E. cautella*. Fonio produced the second lowest progeny of *T. castaneum*, but the difference was significant only with the progeny on flour; it was slightly more suitable for *T. confusum* egg production and larval development. Larval survival of *C. cephalonica* was lowest on fonio and arraw. All species, especially *E. cautella*, performed well on sankhal.

Weight losses (Table 3) were low on whole millet kernels, and dehulling resulted in a significant increase of losses to all insect species. Fonio performed approximately as dehulled millet. Sankhal and millet flour experienced high losses to all insects. *Tribolium* spp caused equivalent losses to both media, and flour was most susceptible to *C. cephalonica* and *E. cautella*. The large particle size of arraw balls did not protect them from *Tribolium* larval feeding but they resisted *E. cautella* well, and to a lesser extent *C. cephalonica*. When data for all insects were pooled, whole millet appeared as the most resistant diet, and millet flour the most susceptible, followed by sankhal. The other diets were intermediate and of equivalent susceptibility.

4. Discussion

Correlations between insect development and physical properties of the food media (moisture content and particle size) were not assessed because of the composite nature of most media, and more importantly because particle hardness, a characteristic with a presumably major influence on insect development, could not be adequately measured. Also, because of practical limitations (the small amount of food given to the insects, short duration of the study, constant environmental conditions), the results of the experiment reported here should not be used as an indicator of the pest status of the four insect species.

Dehulled millet, sankhal, millet flour and arraw are nutritionally equivalent to each other, as they all derive from the same dehulled millet. The composition of these products differs only marginally from whole millet, which contains slightly more ash (9.7% dry matter against 9.5%) than dehulled millet (Gueye, unpublished). Fonio is richer in proteins (10.2% against 9.5%) and markedly poorer in fat (2.3% against 4.2%) than dehulled millet (Gueye, unpublished). In

Table 3
Weight loss (g) from initial 25 g samples (X ± SE) caused to each food medium by *T. castaneum* and *T. confusum* larvae and adults, and by *C. cephalonica* and *E. cautella* larvae. Means of ten replicates. (a–e) means followed by the same letter in a column are not significantly different ($P > 0.05$)

	T. castaneum	*T. confusum*	*C. cephalonica*	*E. cautella*	All insects
Whole millet	0.56 ± 0.05 a	0.31 ± 0.08 a	0.76 ± 0.07 a	0.19 ± 0.03 a	0.46 ± 0.05 a
Dehulled millet	1.72 ± 0.17 c	0.63 ± 0.12 b	1.77 ± 0.14 ab	1.01 ± 0.04 b	1.28 ± 0.09 b
Fonio	1.08 ± 0.11 b	1.09 ± 0.08 c	0.53 ± 0.06 a	1.47 ± 0.07 c	1.04 ± 0.07 b
Sankhal	1.81 ± 0.12 c	2.12 ± 0.11 e	2.35 ± 0.07 b	2.40 ± 0.09 d	2.17 ± 0.06 c
Millet flour	2.14 ± 0.15 c	2.04 ± 0.17 e	6.06 ± 0.82 c	2.77 ± 0.10 e	3.25 ± 0.35 d
Arraw	1.76 ± 0.23 c	1.51 ± 0.08 d	1.21 ± 0.19 ab	0.27 ± 0.02 a	1.17 ± 0.07 b

spite of these nutritional similarities, the food media differed significantly in their suitability for insect development.

Our data confirm the finding of Roorda et al. (1982) that *T. castaneum* larvae, like *T. confusum* larvae, can feed and develop on apparently undamaged threshed millet kernels. The increased numbers of *T. castaneum* progeny and weight losses in dehulled millet may indicate that larval feeding is greatly enhanced by damage sustained by kernels during the process of dehulling. *T. confusum* is known to be better adapted to undamaged cereal grains than *T. castaneum* (Dobie et al., 1984). Its performance is therefore less markedly improved on dehulled grain. The opposite relative susceptibilities of dehulled millet and fonio to the two *Tribolium* species possibly indicate a greater sensitivity of *T. confusum* to kernel size than *T. castaneum*, and/or a poorer nutritional efficiency of fonio for the development of *T. castaneum*, which is known as a pest of fat-rich stored products, particularly of oilseeds (Delobel and Tran, 1993).

C. cephalonica development is not significantly enhanced on dehulled millet as compared with whole kernels. This is in agreement with the fact that *C. cephalonica* is the major pest of bagged whole millet in the Sahelian region (Russell et al., 1980). Whole and dehulled millet are more resistant to *E. cautella* than to *C. cephalonica* larvae, which may explain why the former was absent from millet bags in strategic warehouses.

Seck et al. (1992) found a positive correlation between *T. castaneum* development and the proportion of broken kernels in millet diets given to the insect. This correlation is well documented in other cereals, wheat for example (Narayan Singh and Krishna, 1985). Our study shows that processing of millet kernels results in a significant increase in performance when the results for the four insect species were pooled, with sankhal and flour experiencing the most extensive damage (Table 3). In spite of a higher moisture content, arraw balls, which are nutritionally strictly equivalent to the flour from which they are made, are significantly less prone to insect (except *T. castaneum*) damage than flour. This stresses the importance of particle size and shape to explain the relative susceptibility of food media to insect attack.

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