FULL LENGTH RESEARCH ARTICLE

SUITABILITY OF SORGHUM GRAIN FOR THE DEVELOPMENT OF THE LARGER GRAIN BORER *Prostephanus truncatus* (HORN) (COLEOPTERA: BOSTRICHIDAE)

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ABSTRACT
Laboratory studies were carried out to determine the development of the Larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on sorghum grain. Substrate suitability, susceptibility and preference tests were conducted. Tests were conducted using *P. truncatus* on 3 sorghum (2 high-yield [Framida and Naga-White] and 1 native [mankaraga]) and 1 maize (native) cultivars. The beetle successfully completed its life cycle on sorghum grain, when stored as whole grain or finely ground grain flour. However, the beetle failed to develop on sorghum grain, when stored as coarsely ground grain. Mean development period of the grain borer was 36 to 60 days and differed with substrate type and grain cultivar. Mean number of first generation (F_1) adult beetles recovered ranged from 1.51 to 13.6 individuals. In a similar manner, the mean weight of beetles produced ranged from 1.70 to 3.02 mg. Furthermore, *P. truncatus* showed higher preference for the high-yield improved sorghum cultivars (Framida & Naga-White) than the native one (Mankaraga). These high-yield improved sorghum cultivars were also more susceptible to attack by the stem borer. These cultivars have relatively soft pericarp and endosperm texture which offered low resistance to the boring and tunneling activities of these beetles. This indicates that in the absence of its most preferred host (maize), *P. truncatus* can subsist on sorghum grain. Thus sorghum grain can serve as a reservoir for *P. truncatus*. These findings should be exploited when designing biological control programmes in sorghum growing regions of sub-Saharan Africa.

Keywords: *Prostephanus truncatus,* sorghum grain, substrate suitability, susceptibility index, grain preference, biological control

INTRODUCTION
The bostrichid beetle *Prostephanus truncatus* Horn 1878 was accidentally introduced from its area of origin in Mexico and Central America into East Africa in the late 1970s and West Africa in the early 1980s (Dunstan & Magazini 1981; Harnisch & Krall 1984). The beetle has since spread to at least 17 countries (Roux 1999; Farrell 2000) and has become the major pest of stored maize and cassava in sub-Saharan Africa, responsible for losses in weight of stored maize of up to 30% (Farrell & Schulten 2002). Initial control strategies focused on fumigants and insecticides, but for socio-economic reasons, chemical control strategy was not widely adopted by subsistence farmers (Agbaka 1996). Hence, a biological control agent, *Teretrius nigrescens* Lewis 1906 was introduced in various parts of Africa (Henning-Helbig 1995; Bell *et al*. 1999). However, lack of control has been reported already from Benin (Meikle *et al*. 2002) and Ghana (Birkinshaw & Hodges 2000).

Sorghum (*Sorghum bicolor* (L.) Moench 1936) is a viable food grain for people in Africa (FAO 2003; Gwary & Asala 2006). The grain is used in making instant soft porridge, malt extracts and as an alternative to barley for lager beer brewing. Unfortunately, it is among the crops most preferred by storage pests, and attacked by several species (Ayertey & Padi 1996)

Prostephanus truncatus is an outbreak pest causing spectacular damage and losses in Africa. Although much work has been conducted on the biology, ecology and its control on maize and cassava (Dick 1988; McFarlane 1988; Holst & Meikle 2003), there is very little information on the biology and ecology of this pest on sorghum grain. Effective and sustainable biological control or Integrated Pest Management (IPM) approach to manage *P. truncatus* in sub-Saharan Africa can only be attained with sufficient knowledge of the complex biology and ecology of this beetle. This experiment was initiated to investigate the suitability of sorghum grain as a breeding substrate for *P. truncatus*.

MATERIALS AND METHODS
Insect cultures: Laboratory studies were conducted at the Plant Protection and Regulation Services, Ministry of Food and Agriculture (PPRS/MOFA), Pokuase, Accra, Ghana. Initial laboratory cultures of *P. truncatus* were set up with individuals collected from the stock at PPRS/MOFA in Kpeve, Volta Region, Ghana. In each 1000 ml glass jars, 300 g of shelled maize was infested with 100 unsexed adult beetles and kept covered with a metal screen. All adult beetles were removed after 2 weeks to obtain a synchronized F_1 progeny.

Maize & Sorghum cultivars: One maize (Obatanpa [native]) and 3 sorghum (Framida [high-yield], Mankaraga [native] and Naga-White [high-yield]) cultivars were obtained from the Savannah Agricultural Research Institute (SARI), Council for Scientific and Industrial Research (CSIR), Tamale, Ghana. Undamaged grains were deep frozen for 2 weeks and then thermally sterilized at 45 ^{o}C for 4 hrs in a laboratory air-oven (Santhoy & Rejesus 1975). The grains were sterilized and conditioned for 21 days in the laboratory at 32 °C±3°C and 81 % ± 5 % RH under a 12 hr photoperiod.

Substrate suitability: About 100 g each of whole grains, coarsely ground grain and finely ground grain flour were kept in 500 ml glass jars. Each jar was infested with 20 unsexed adult beetles aged between 0-7 days old. 14 days post oviposition, the adult beetles were sieved out (Endecott sieves). Each treatment (substrate type) was replicated 5 times. The development period of the beetles was recorded as the time in days taken from the mid-point of oviposition

period to the time of emergence of 50 % of the F_1 generation adult beetles.

Grain susceptibility was determined as described by Dobie (1974), where susceptibility index = log e of the number of F_1 generation adults divided by mean development period multiplied by 100. Each adult beetle was weighed within 24 hrs of emergence using an electronic digital balance (Cahn 29) with an accuracy of 0.001 mg.

Grain properties: The length and breadth (mm) of 50 grains per cultivar were measured with the aid of a digimatic caliper (Baty). Measurements were replicated 5 times per cultivar. One-thousand grain weight was determined by weighing 1000 grains of each cultivar. Measurements were also replicated 5 times per cultivar. To determine grain density, 50 grains per cultivar were poured into a 250 ml graduated cylinder filled with 100 ml of 95 % ethanol. Grain density of each cultivar was calculated as the weight of grain divided by the volume of ethanol displaced. Grain hardness was determined as described by Pomeranz *et al.* (1985) with the aid of Hounsfield Tensile Strength Machine. Fifty-grain samples of all cultivars were equilibrated for 14 days in a humidity chamber maintained at 30 ºC and 70 % RH. Using the tensile strength machine, the compression force (Newton [N]) that cracked each individual grain was recorded per cultivar. Measurements were replicated 5 times per cultivar. Grain endosperm texture was determined using the 'Grind and Sieve Method' as described by Davey (1965). Fifty grain sample per cultivar was equilibrated as mentioned above. The grains were ground at a constant setting in a laboratory mill (Christy and Norris Hammer), the flour was then sieved through a 500 µm mesh (Endecott sieve). Percentage fraction of floury/corneous endosperm = weight of grains retained in the sieve (g) divided by the sum of the weight of grains that passed through the sieve (g) and weight of grains retained in the sieve (g) multiplied by 100.

Preference test: Grain preference by *P. truncatus* was determined as described by Chijindu (2002). For each cultivar, a 50 grain sample was placed on 10 mm diameter filter paper in a Petri-dish. Petri-dishes containing samples of different grain cultivars were arranged in a circular pattern, at least 10 cm apart, in an enclosed transparent trough. Forty adult beetles were then introduced in a separate Petri-dish at the centre of the trough to allow the beetles move freely to any cultivar of their choice. Observations were conducted at 4 hr intervals for a total of 16 hrs. On each occasion, the number of beetles found on each grain variety was recorded. This experiment was replicated 5 times.

Data analysis: All experiments were arranged in a complete block design. Count data were log (log [x + 1]) transformed (Zar 1999). All data were subjected to analysis of variance (ANOVA), using SAS software (version 6)(SAS 1989). The means of cases that were significantly different (P<0.05) were separated using Student-Newman-Keul (SNK) Test.

RESULTS

Sorghum grain: Mean development time of *P. truncatus* on whole grain was significantly (P<0.001) shorter on the high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga) (Table 1). The beetles could not develop on coarsely ground sorghum grains. Developmental time was much longer on finely ground grain flour. On grain flour, the development period of the beetles was significantly shorter (P<0.005) on the high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga). The mean number of F_1 generation adult beetles was higher on whole grain than on grain flour (Table 2). Irrespective of the substrate type, mean number of F_1 generation adult beetles were significantly (P<0.001) higher on high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga) (Table 2). Mean weight values of adult beetles were fairly similar on both whole grain and grain flour (Table 3). However, on whole grain, significantly (P<0.001) heavier beetles were produced on high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga). There were no significant (P = 0.06) differences in insect weight among sorghum cultivars on grain flour. Susceptibility indices were higher on whole grains than on grain flour (Table 4). On both whole grain and grain flour, susceptibility indices were higher on high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga). In a similar manner, beetles showed higher preference for the high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga) (Table 5). There was no significant difference (P = 0.12) (P = 0.07) (P = 0.10) in the mean grain length, densities and 1000-grain among sorghum cultivars, but the mean grain breadth, endosperm texture and grain hardness were significantly higher (P<0.05) on high-yield cultivars (Framida & Naga-White) than on the native one (Mankaraga).

Maize grain: Mean development time of *P. truncatus* was significantly faster (P<0.001) on maize than on sorghum grain (Table 1). Considering the substrate types, the development of the beetles was much longer on grain flour than on whole grain. Mean weight values of adult beetles were fairly similar on both whole grain and grain flour (Table 1). However, compared to sorghum, mean weight of adult beetles was significantly (P<0.001) heavier on maize when stored as grain flour. The mean number of F_1 generation adult beetles, susceptibility indices, varietal preference, grain length/breadth, endosperm texture and grain hardness were exceedingly significantly higher on maize than on sorghum grain (Tables 1-6).

DISCUSSION

These results from this study indicate that *P. truncatus* can complete its development from egg to adult stage on sorghum grain. The beetle also completed development on whole grain and grain flour, but not on coarsely ground grain, with the development being much faster on whole grain than on grain flour. This finding contradicts previous reports that *P. truncatus* can only breed in maize and cassava (Hill 2002). The ability of the beetle to develop on sorghum grain may be due to a number of reasons. First, the large mean length of sorghum grain (4.22 to 4.57 mm) probably accommodated the tunneling activities of the average size (3 to 4.5 mm) adult borers (Haines 1991) (Table 6) and secondly, the ability of the beetle to oviposit, feed and pupate in grain flour, supporting an earlier report (Bell & Watters 1982) that observed the pupation of the beetle in grain flour. On the contrary, coarsely ground grain proved to be an unsuitable substrate for development of borer as no adult emergence was recorded on this substrate. Given that grain size influences the survival and development of *P. truncatus* (Li 1988), insufficient size of coarsely ground grain may have deterred the beetles from breeding successfully on the coarsely ground grain substrate. Li (1998) had earlier reported that the beetle has some acoustic mechanism for appraising its host size with which it rejects regions in a substrate that have insufficient depth when selecting a suitable location to bore.

TABLE 1. MEAN DEVELOPMENT TIME OF *P. truncatus* ON DIFFERENT GRAIN CULTIVARS AND SUBSTRATE TYPES

Grain cultivar	Mean development time (days)		
	Substrate type		
	Whole grain	Coarse ground grain	Fine grain flour
Framida (sorghum)	37.40 ± 1.88[b]	0.00 ± 0.00[a]	5 1.40 ± 1.88[b]
Mankaraga (sorghum)	46.60 ± 1.16[a]	0.00 ± 0.00[a]	60.60 ± 1.16[a]
Naga-White (sorghum)	36.00 ± 3.43[b]	0.00 ± 0.00[a]	50.00 ± 3.43[b]
Obatanpa (maize)	27.00 ± 1.14[c]	0.00 ± 0.00[a]	41.00 ± 1.14[c]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

TABLE 2. MEAN NUMBER OF F_1 GENERATION ADULT BEETLES ON DIFFERENT GRAIN CULTIVARS AND SUBSTRATE TYPES

Grain cultivar	Mean number of F_1 generation		
	Substrate type		
	Whole grain	Coarse ground grain	Fine grain flour
Framida (sorghum)	13.6 ± 0.28[b]	0.00 ± 0.00[a]	2.17 ± 0.15[b]
Mankaraga (sorghum)	2.40 ± 0.23[a]	0.00 ± 0.00[a]	1. 51 ± 0.16[a]
Naga-White (sorghum)	11.0 ± 0.29[b]	0.00 ± 0.00[a]	2.33 ± 0.20[b]
Obatanpa (maize)	166.4 ± 0.45[c]	0.00 ± 0.00[a]	4.86 ± 0.14[c]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

TABLE 3. MEAN WEIGHT OF ADULT *P. truncatus* ON DIFFERENT GRAIN CULTIVARS AND SUBSTRATE TYPES

Grain cultivar	Mean number of F_1 generation		
	Substrate type		
	Whole grain	Coarse ground grain	Fine grain flour
Framida (sorghum)	2.98 ± 0.31[b]	0.00 ± 0.00[a]	2.18 ± 0.31[a]
Mankaraga (sorghum)	2.49 ± 0.13[a]	0.00 ± 0.00[a]	1.70 ± 0.13[a]
Naga-White (sorghum)	3.02 ± 0.27[b]	0.00 ± 0.00[a]	2.22 ± 0.27[a]
Obatanpa (maize)	4.91 ± 0.29[b]	0.00 ± 0.00[a]	4.11 ± 0.29[b]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

TABLE 4. SUSCEPTIBILITY OF GRAIN CULTIVARS TO ATTACK BY *P. truncates*

Grain cultivar	Mean number of F_1 generation		
	Substrate type		
	Whole grain	Coarse ground grain	Fine grain flour
Framida (sorghum)	7.14 ± 0.58[b]	0.00 ± 0.00[a]	3.02 ± 0.35[b]
Mankaraga (sorghum)	2.28 ± 0.61[a]	0.00 ± 0.00[a]	1.27 ± 0.37[a]
Naga-White (sorghum)	7.06 ± 0.93[b]	0.00 ± 0.00[a]	3.33 ± 0.34[b]
Obatanpa (maize)	19.09 ± 1.03[c]	0.00 ± 0.00[a]	7.72 ± 0.18[c]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

TABLE 5. THE PREFERENCE OF *P. truncatus* TO DIFFERENT GRAIN CULTIVARS

	Borer preference
Grain cultivar	Whole grain
Framida (sorghum)	9.80 ± 0.15[b]
Mankaraga (sorghum)	6.40 ± 0.15[a]
Naga-White (sorghum)	7.80 ± 0.14[b]
Obatanpa (maize)	14.80 ± 0.10[c]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

TABLE 6. PROPERTIES OF DIFFERENT GRAIN CULTIVARS

	Grain properties					
Grain cultivar	Length (mm)	Breadth(mm)	Density (g/cm^3)	1000-grain weight (g)	Endosperm texture (%)	Grain hardness (N)
Framida (sorghum)	4.35 ± 0.11[a]	3.95 ± 0.13[b]	0.84 ± 0.12[a]	25.00 ± 0.14[a]	47.88 ± 1.59[c]	45.84 ± 1.99[c]
Mankaraga (sorghum)	4.57 ± 0.13[a]	3.54 ± 0.11[a]	1.05 ± 0.11[a]	26.70 ± 0.14[a]	72.20 ± 1.12[a]	82.38 ± 3.15[a]
Naga-White (sorghum)	4.22 ± 0.10[a]	3.87 ± 0.11[ab]	0.92 ± 0.12[a]	24.30 ± 0.11[a]	56.12 ± 1.07[b]	59.18 ± 2.60[b]
Obatanpa (maize)	10.77 ± 0.18[b]	8.78 ± 0.12[c]	1.24 ± 0.14[a]	257.00 ± 0.24[b]	72.20 ± 1.12[a]	298.59 ± 8.48[d]

Means followed by the same letter in the same column are not significantly different at P = 0.05 (Student-Newman-Keul multiple comparison test).

The presence of first generation adult beetles with moderate weights observed in this study suggests that sorghum grain has sufficient nutrient to support breeding by *P. truncatus* (Tables 2 & 3) because nutritional quality of a substrate is an important factor for the development of the larvae (Diane 1993). In addition to feeding on the germ, it is also possible that the beetle obtain additional nutrients through indiscriminate feeding within the grain kernels (Ramirez Martinez & Silva 1983; Subramanyam *et al.* 1987; Vowotor *et al.* 1998).

Results from this work also showed that high-yield improved sorghum cultivars (Framida & Naga-White) were more susceptible to attack by *P. truncatus* than on the native one (Mankaraga) (Table 4), probably because of faster development periods (Table 1). These beetles also showed higher preference for the high-yield improved sorghum cultivars than the native one (Table 5). The differences in grain hardness and endosperm texture (Table 6) could be a possible factor for this difference since the amount of tunneling and size of egg batches laid depends on hardness of the substrate (Li 1988). Previous studies (Demianyk & Sinha 1988, Li 1998) recorded fewer egg deposits per period in relatively hard seeds during peak oviposition periods and consequently fewer adults emergence.

Despite its hard pericarp and endosperm, maize grain proved to be the most preferred breeding substrate for *P. truncatus* (Tables 1, 4 & 6), producing high numbers of heavier adult beetles (Table 2 & 3). It is possible that the larger mean length of maize grain compared to sorghum might have resulted in the offsprings of *P. truncatus* surviving better on maize, since it provide enough space for tunneling and oviposition than on sorghum.

In conclusion, these findings revealed that *P. truncatus* can successfully complete its development on sorghum grain, with whole grain substrate and high-yield improved sorghum cultivars showing higher susceptibility compared to grain flour substrate and the native sorghum cultivar, respectively. These indicate that in the absence of its most preferred host (maize), *P. truncatus* can subsist on sorghum grain as its reservoir. It is therefore imperative to take these findings into consideration when designing biological control programmes in sorghum growing regions of sub-Saharan Africa.

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