



## Impact of differing population levels of *Rhyzopertha dominica* (F.) on milling and physicochemical properties of sorghum kernel and flour<sup>☆</sup>

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### ABSTRACT

The effects of different population levels of *Rhyzopertha dominica* (F.), the lesser grain borer, on physicochemical properties of sorghum kernels and flour, were investigated through a laboratory study at 27 and 32 °C, and 57% relative humidity. Initial population level and temperature, and their interaction, were significant for the number of F<sub>1</sub> progeny and feeding damage ( $P < 0.01$ ). A strong positive correlation was also found between initial population size, number of F<sub>1</sub> progeny, percentage of insect-damaged kernels (IDKs) and feeding damage. The impact of *R. dominica* on the milling quality of sorghum was seen through a reduction in abrasive hardness, milling yield, and kafirin content. Initial population and temperature affected most pasting properties, and overall pasting viscosity increased with initial population, number of F<sub>1</sub> progeny, and percentage of IDK at 32 °C. Results show that *R. dominica* can potentially impact the milling quality of sorghum and also alter the physicochemical properties of sorghum flour.

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### 1. Introduction

*Rhyzopertha dominica* (F.), the lesser grain borer, is a major insect pest of many stored grains, including wheat (Pedersen, 1992; Toews et al., 2000; Jood et al., 1993; Bashir, 2002), corn (Demianyk and Sinha, 1987; Jood and Kapoor, 1993), rice (Jilani et al., 1989; Arthur et al., 2007), sorghum (Jood and Kapoor, 1992; Jood et al., 1993, 1996), as well as tubers such as cassava chip (Kumar et al., 1996). Infestations of *R. dominica* cause loss of biomass (Brower and Tilton, 1973; Swaminathan, 1977) and decrease grain quality through feeding damage (Williams et al., 1981) or contamination with insect fragments and uric acid (Swaminathan, 1977; Wehling et al., 1984; Jood and Kapoor, 1993). *Rhyzopertha dominica* infestation also reduces the essential amino acid content of wheat, maize, and sorghum (Jood et al., 1995), and depresses the germination and vigor of seeds (Jilani et al., 1989). Infested grain is then vulnerable to further damage caused by secondary pests and fungi (Mukherjee and Nandi, 1993). *Rhyzopertha dominica* can change dough properties of wheat and

negatively affect the final bread quality through offensive odors and low loaf volume (Sánchez-Mariñez et al., 1997).

*Rhyzopertha dominica* is often difficult to kill with insecticides applied directly to grains because the majority of the life cycle is spent inside the kernel (Arthur, 1992; Lorini and Galley, 1996; Huang and Subramanyam, 2005). Females lay eggs on the exterior of the kernel, and the first-instar larva hatches and bores inside, where it remains until emerging as an adult. The damaged kernel is often referred to as an 'insect-damaged kernel', or IDK, which is important for grading purposes.

Sorghum is an important staple food for many parts of the world, including Africa, Asia, and the drier parts of Central and South America (Dendy, 1995; Rooney and Waniska, 2000). However, most of the sorghum produced in the United States of America (USA) is utilized as feed. Recently, sorghum has received increased attention as a food grain in the USA, especially for persons suffering from celiac disease. Celiac disease is an autoimmune intestinal disorder caused by sensitivity to gluten from cereal grains such as wheat, durum, barley, rye, and triticale (Kasarda and D'Ovidio, 1999). Sorghum is more closely related to maize than those grains, and is therefore considered safe (Kasarda, 2001). In addition, sorghum is considered to have beneficial effects on human health because it has a high phenolic content and exhibits antioxidant activity (Awika and Rooney, 2004; Dykes et al., 2005).

As the interest and need for food and industrial usage of sorghum increase, production and eventual storage could also increase to meet the needs of this market. *Rhyzopertha dominica* is

Abbreviations: AHI, abrasive hardness index; IDK, insect-damaged kernel; RVA, rapid visco-analyzer; SKCS, single kernel characterization system.

<sup>☆</sup> This paper reports the results of research only. Mention of a proprietary product, trade name, or analytical procedure does not constitute a recommendation or endorsement by the US Department of Agriculture.

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known as a major insect pest on sorghum and other commodities, but there are no published estimates of damage levels or physicochemical changes of sorghum kernel and flour caused by *R. dominica*. The objectives of this study were (1) to determine progeny production from different levels of parental infestation, at 27 and 32 °C, on sorghum; (2) to correlate bioassay data with selected parameters and indicators of sorghum milling quality; and (3) to determine effects on physicochemical properties of sorghum kernel and flour caused by these infestations of *R. dominica*.

## 2. Materials and methods

### 2.1. Sample preparation

Approximately 300 1–2-week-old adult *R. dominica* were removed from established colonies grown on hard red winter wheat (variety Karl) and placed in each of several 0.95-l glass jars containing about 300 g of commercially available tannin-free, white-grained hybrid sorghum (Twin Valley Mills, Ruskin, NE, USA). After five to seven generations, colonies were established on the sorghum. The laboratory study was then initiated by weighing about 175 g of sorghum into each of 40 0.24-l glass jars. These jars were divided into two groups of 20, four replicate groups of five. A series of 0, 10, 20, 40, or 80 mixed-sex 1–2-week-old adult *R. dominica* were obtained from the larger colony and introduced into each of the five jars comprising a replicate. Four humidity chambers were created using plastic boxes containing saturated sodium bromide (NaBr) to maintain relative humidity (r.h.) at 57% (Greenspan, 1977), as described in detail by Arthur (2004). Each box held 10 jars, and two boxes containing all the replicates from one set of 20 were placed inside an incubator set at 27 °C, and the two boxes containing the second set of 20 jars were put inside a second incubator set at 32 °C. Temperature and r.h. inside the boxes were monitored with HOBO data loggers (Onset Computer, Bourne, MA, USA) inside each box.

After 5 days the parental adults were removed, and the jars containing sorghum were returned to the incubator for an additional 8 weeks. The adult  $F_1$  progeny were then removed from the sorghum by sifting through a #12 (1.7 mm) sieve, counted and tabulated. The ground sorghum and insect frass (hereafter referred to as feeding damage) from each jar were collected by sieving the sorghum through a #30 (0.6 mm) sieve to collect the feeding damage, which was then weighed. After this process was completed, the  $F_1$  adults and the feeding damage were discarded. A sub-sample of approximately 25 g from each jar was put inside a 40-ml plastic vial (25 mm in diameter, 80 mm tall), and held to count the number of IDK in the sub-sample. All kernels were examined under a stereo microscope so that an individual kernel could be manipulated with a probe to search for an exit hole. Because the total number of kernels varied in the individual sub-samples, the number of IDK was converted to a percentage of the total. The 40 jars containing the remaining 150 g of sorghum in each box were then stored at ca. –15.6 °C until they were further examined for quality deterioration.

### 2.2. Analytical procedures

The effects of different levels of *R. dominica* infestation on the physicochemical properties of sorghum were measured through standard analytical techniques. Kernel hardness was measured by two methods, abrasive hardness and single kernel characterization system (SKCS) hardness. The abrasive hardness index (AHI) was determined using a tangential abrasive dehulling device

(model 4E-110/220, Venables Machine Works LTD., Saskatoon, Canada) as previously described (Oomah et al., 1981; Bean et al., 2006). Milling yield of decorticated grain was determined as percentage weight of grit over whole grain (20 g) from 1–8 min at 1-min intervals using the tangential abrasive dehulling device. Changes in color value (*L*) were also measured at the same time using a chromameter (Model CR-300, Minolta). The single kernel hardness was measured using SKCS 4100 (Perten Instruments, Springfield, IL, USA) as described in Bean et al. (2006) and Pedersen et al. (1996).

Whole sorghum kernels were ground using an Udy mill (Udy Corp., Fort Collins, CO, USA) through a 0.25 mm screen. The whole sorghum flour was used for analysis of kafirin (sorghum storage protein) content and pasting properties. The kafirins were extracted and separated by reverse phase (RP)-HPLC as described by Park and Bean (2003). Total protein was measured using a nitrogen combustion method (LECO FP-528, St. Joseph, MI; Approved Method 46-30; Anon., 2000) and converted to protein (multiplying by 6.25). Pasting characteristics of sorghum flour were determined using a 13 min standard procedure with a rapid visco-analyzer (RVA, Newport Scientific Ltd. Warriewood, Australia; Approved Method 76-21; Anon., 2000).

### 2.3. Statistical analyses

Data for *R. dominica* progeny production, the percentage of IDK, and weight of feeding damage were analyzed using the general linear model procedure of the Statistical Analysis System (SAS Institute, 2001) with initial population level (0–80) and temperature (27 and 32 °C) as main effects. Data were extremely variable; hence individual values were transformed by square root in an attempt to normalize variances. The regression procedure of SAS was used to determine significance, with population level as the independent variable, and progeny, percentage of IDK, and feeding damage as dependent variables. When regression was significant, data were further analyzed by Table Curve software (SPSS, Chicago, IL, USA) to estimate equation parameters. Lack-of-fit tests (Draper and Smith, 1981) were conducted to determine the maximum coefficient of determinant ( $R^2$ ) for any model that could be fitted to the data set, and the actual  $R^2$  obtained expressed as a percentage of the maximum. The correlation procedure of SAS was used to estimate correlation of population level, progeny, percentage of IDK, and feeding damage, within each of the two temperatures. Differences due to the initial population level were analyzed by Waller–Duncan *k*-ratio *t*-test, and differences between 27 and 32 °C were analyzed by the *t*-test procedure of SAS, using the Satterwhite correction for unequal variances.

## 3. Results

### 3.1. Progeny production of *R. dominica* and associated correlations of bioassay data

The number of  $F_1$  progeny, percentage of IDKs, and feeding damage produced by different initial population levels at 27 and 32 °C are summarized in Table 1. At both 27 °C and 32 °C, progeny production increased as the initial population increased, except for the initial population level of 80 at 27 °C. Main effects initial population level and temperature, and their interaction, were significant ( $P < 0.01$ ) for the number of  $F_1$  progeny ( $F = 10.9$ ,  $df = 4, 29$ ;  $F = 22.5$ ,  $df = 1, 29$ ;  $F = 5.2$ ,  $df = 4, 29$ , respectively) and feeding damage ( $F = 18.3$ ,  $df = 4, 29$ ;  $F = 49.4$ ,  $df = 1, 29$ ;  $F = 8.2$ ,  $df = 4, 29$ , respectively). The percentage of IDK was affected significantly by initial population ( $F = 8.2$ ,  $df = 4, 29$ ,

**Table 1**  
Means  $\pm$  standard errors (SE) for number of F<sub>1</sub> progeny, percentage of insect damaged kernels (IDK), and feeding damage caused by different levels of parental *Rhyzopertha dominica* (per 175 g of sorghum) and their progeny<sup>a</sup>

Initial population	F <sub>1</sub> progeny		IDK		Feeding damage (mg)	
	27 °C	32 °C	27 °C	32 °C	27 °C	32 °C
0	0.0 a	0.0 c	0.0 a	0.0 c	0.0 b	0.0 c
10	16.5 $\pm$ 6.9 a	41.7 $\pm$ 16.8 bc	1.1 $\pm$ 0.4 a	1.4 $\pm$ 0.1 c	155.5 $\pm$ 37.1 ab	592.7 $\pm$ 98.0 c
20	38.2 $\pm$ 6.4 a	51.0 $\pm$ 3.7 b	1.8 $\pm$ 0.2 a	1.9 $\pm$ 0.7 bc	431.2 $\pm$ 57.9 ab	2474.2 $\pm$ 194.1 a
40	40.0 $\pm$ 19.6 a	104.0 $\pm$ 12.9 a	2.5 $\pm$ 1.3 a	4.7 $\pm$ 1.0 ab	488.0 $\pm$ 203.9 ab	1272.7 $\pm$ 219.4 b
80	26.7 $\pm$ 19.3 a	146.0 $\pm$ 29.9a	2.8 $\pm$ 1.6 a	6.9 $\pm$ 1.6 a	560.0 $\pm$ 241.4 a	1519.5 $\pm$ 378.3 b

Initial population levels were 0–80 on 175 g of sorghum held at 27 and 32 °C.

<sup>a</sup> Means within a vertical column followed by different letters are significantly different ( $P < 0.05$ , Waller–Duncan  $k$ -ratio  $t$ -test).

**Table 2**  
Parameters for significant regressions for percentage insect damaged kernels (IDK), feeding damage, and number of progeny as dependent variables, and initial parental population level of 0–80 as the independent variable<sup>a</sup>

		$P$	$b$	$R^2$	Max $R^2$	Max (%)
27 °C	IDK	0.04	0.06 $\pm$ 0.02	0.35	0.38	92.1
	Frass weight	<0.01	12.5 $\pm$ 3.6	0.45	0.53	84.9
32 °C	IDK	<0.01	0.08 $\pm$ 0.01	0.65	0.69	94.2
	Progeny	<0.01	1.7 $\pm$ 0.3	0.65	0.73	89.0

<sup>a</sup> Equations of the form  $y = b$ , all regressions through the origin, mean  $\pm$  standard error for  $b$ .  $R^2$  is actual  $R^2$ , max  $R^2$  is the maximum  $R^2$  for any equation that can be fitted to the data, max (%) is the actual  $R^2$  as a percentage of the maximum.  $P$  values for progeny at 27 °C and frass weight at 32 °C were 0.10 and 0.11, respectively.

$P < 0.01$ ) and temperature ( $F = 5.0$ ,  $df = 1, 29$ ,  $P < 0.05$ ), but there was no significant interaction between initial population and temperature ( $P \geq 0.05$ ).

Although the ANOVA showed a difference among population levels, regressions with population level as the dependent variable were significant ( $P < 0.05$ ) for only four of the six parameters measured, including percentage of IDK and feeding damage at 27 °C, and percentage of IDK and progeny at 32 °C (Table 2). If the level of 80 is removed from the analysis, regressions of progeny on population level also become significant ( $P < 0.01$ , data not shown). There were strong positive correlations between initial populations, F<sub>1</sub> progeny, percentage of IDK, and feeding damage (Table 3). All correlations were significant except for number of the initial population (parental adults) and F<sub>1</sub> progeny at 27 °C, and if data were eliminated for the parental level of 80 adults, all correlations were significant at  $P < 0.01$ . Both the percentage of IDK and feeding damage increased in response to F<sub>1</sub> progeny production at each of the two temperatures. It appears that the trend of increased percentages of IDK was more obvious at 32 °C ( $r = 0.83$ ,  $P < 0.01$  and  $0.93$ ,  $P < 0.01$  for initial population and F<sub>1</sub> progeny, respectively) than at 27 °C ( $r = 0.45$ ,  $P < 0.05$  and  $0.47$ ,  $P < 0.05$ , respectively). Initial population showed no significant correlation at 32 °C, or only weak but significant correlation ( $r = 0.55$ ,  $P < 0.05$ ) at 27 °C with feeding damage, whereas F<sub>1</sub> progeny showed a weak correlation with feeding damage at 32 °C ( $r = 0.51$ ,  $P < 0.05$ ) and a stronger correlation at 27 °C ( $r = 0.98$ ,  $P < 0.01$ ).

An analysis of the data in Table 4 showed that the percentage of IDK was not significantly greater at 32 °C than at 27 °C ( $P \geq 0.05$ ). We found greater progeny production and feeding damage at 32 °C than at 27 °C at only two levels of parental population; 40 and 80 for F<sub>1</sub> progeny, and 20 and 40 for feeding damage ( $P < 0.05$  for each; Table 4). Although the data were

**Table 3**  
Correlation coefficients between initial parent population levels, numbers of F<sub>1</sub> progeny, percentage of insect damaged kernels (IDK), and feeding damage<sup>a</sup>

		F <sub>1</sub> progeny	IDK	Feeding damage (mg)
27 °C	Initial population	ns	0.45*	0.55*
	F <sub>1</sub> progeny (number)		0.47*	0.98**
	IDK			0.71**
32 °C	Initial population	0.85**	0.83**	ns
	F <sub>1</sub> progeny (number)		0.93**	0.51*
	IDK			0.49*

<sup>a</sup> \*, \*\* =  $F$ -value is significant at  $P < 0.05$  and 0.01, respectively. ns = not significant.

**Table 4**  
Probability ( $P$ ) for greater progeny production, percentage of insect-damaged kernels (IDK), and feeding damage at 32 °C compared to 27 °C, 2-tailed  $t$ -test with Satterwhite correction for unequal variances

Initial population	Progeny	IDK (%)	Feeding damage
10	0.1	0.21	0.09
20	0.21	0.98	<0.01
40	0.03	0.14	0.02
80	0.03	0.11	0.07

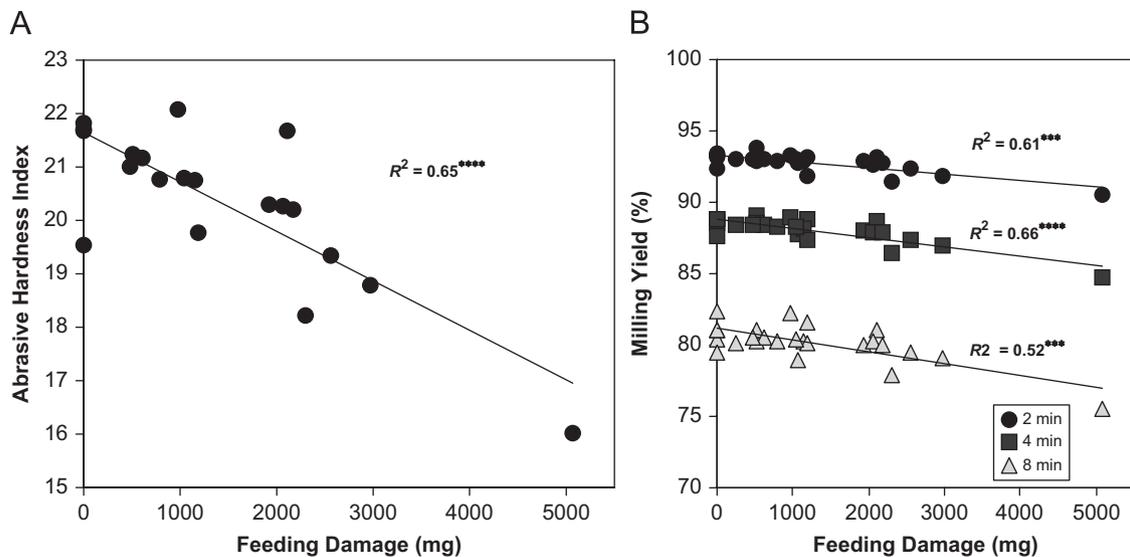
transformed, variations within the data set limited the power of the comparisons.

### 3.2. Influence on physicochemical properties of sorghum by *R. dominica*

Table 5 shows the ANOVA results of main effects initial population and temperature, and interactions, on quality traits of sorghum. Kafirin content was affected by initial population size. Neither the initial population of *R. dominica* nor the temperature affected the AHI or SKCS hardness index of the kernels. This was probably due to the weak or non-significant correlation between initial population and feeding damage (Table 3). Milling yield was not significantly affected by the initial population, but yields from infested grain after 2 or 8 min, though not 4 min, did appear to be significantly affected by temperature. Neither the initial population of *R. dominica* nor the temperature affected the color of sorghum flour, however, and several significant negative correlations among milling characteristics and feeding damage were found. Abrasive hardness was negatively correlated with feeding damage ( $r = -0.81$ ,  $P < 0.01$ ; Fig. 1A), and all milling yields for 2, 4, and 8 min showed significant negative correlations ( $r = -0.78$ ,  $P < 0.01$ ;  $-0.81$ ,  $P < 0.01$ ; and  $-0.72$ ,  $P < 0.01$ , respectively) with

**Table 5**F-values from analysis of variance for influence on the quality traits of sorghum kernel and flour (error df = 29)<sup>a</sup>

Quality trait	Initial population	Temperature	Initial population × Temp.
	df = 4	df = 1	df = 4
Kafrin content <sup>b</sup>	2.7*	ns	ns
<b>Pasting property</b>			
Pasting temperature (°C)	ns	5.5*	ns
Peak viscosity (RVU) <sup>c</sup>	ns	ns	ns
Peak time (min)	ns	10*	ns
Holding strength (RVU)	3.1*	11.1**	ns
Breakdown (RVU)	2.8*	15.0**	ns
Final viscosity (RVU)	4.2**	18.7**	ns
Setback from trough (RVU)	4.3**	19.7**	ns
<b>Milling</b>			
Abrasive hardness index	ns	ns	ns
SKCS hardness index	ns	ns	ns
Yield: 2 min	ns	8.2**	3.8*
4 min	ns	ns	3.0*
8 min	ns	5.7*	ns
Color: 0 min	ns	ns	ns
2 min	ns	ns	3.3*
4 min	ns	ns	ns
8 min	ns	ns	ns

<sup>a</sup> \*, \*\* = F-value is significant at  $P < 0.05$  and  $0.01$ , respectively. ns = not significant.<sup>b</sup> Area under the HPLC peak.<sup>c</sup> Rapid visco-analyzer viscosity unit.**Fig. 1.** Relationship between feeding damage and abrasive hardness index (A) and milling yield at 2, 4, and 8 min (B).

feeding damage (Fig. 1B). Kafrin content decreased as the initial population increased both at 27 and 32 °C (Fig. 2).

Many pasting properties were affected significantly by main effects, initial population and temperature, but not by interactions (Fig. 3, Table 5). The initial population size affected holding strength, breakdown, final viscosity, and setback viscosity, and temperature affected all pasting properties except peak viscosity (Table 5). Significant linear correlations were observed among pasting properties and initial population,  $F_1$  progeny, percentage of IDK, and feeding damage (Table 6). Pasting temperature did not show any significant correlations. At 32 °C,  $F_1$  progeny and percentage of IDK were positively correlated with peak viscosity, peak time, holding strength, final viscosity, and setback from trough, but negatively with breakdown viscosity (Table 6). There were only a few significant correlations found at 27 °C and with

feeding damage probably because of the large variations of the raw data (data not shown).

#### 4. Discussion

The results of our study show that *R. dominica* could affect the physical properties of sorghum kernels and affect milling quality. Damage caused by feeding of *R. dominica* affected both abrasive hardness and milling yield of the sorghum.

Feeding damage was correlated with increasing levels up to 40 insects per 175 g of sorghum (about 200–250/kg) of parental infestation, through both the development of the resultant larvae within the kernel endosperm and the ability of the adults to feed on the endosperm (Jood et al., 1993; Toews et al., 2000). When

wheat endosperm proteins are affected, the composition of proteins changes relative to the size distribution of polymeric glutenin proteins and their glutenin/gliadin ratios (Rosell et al., 2002; Sivri et al., 1999, 2004), resulting in adverse effects on baking quality (Matsoukas and Morrison, 1990; Every, 1992; Karababa and Ozan, 1998). Jood and Kapoor (1993) observed a

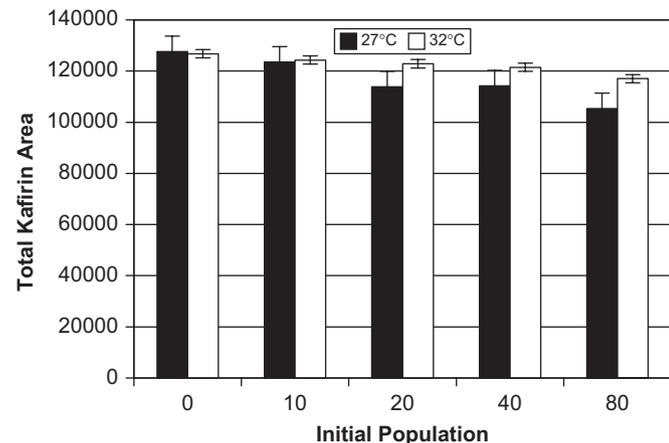


Fig. 2. Effects of initial population size of *R. dominica* on kafirin contents in sorghum kernels at 27 and 32 °C.

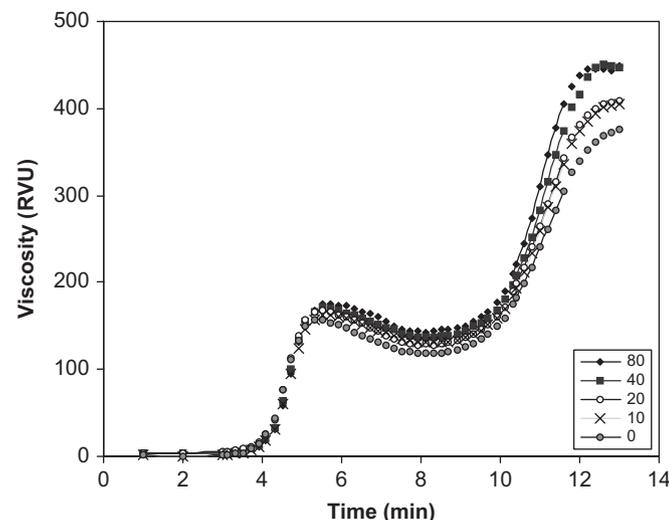


Fig. 3. Effects of initial population size of *R. dominica* on pasting properties of sorghum flour.

**Table 6**  
Correlation coefficients between initial parental population size, number of F1 progeny, percentage of insect damaged kernels (IDK), feeding damage (FD), and pasting properties<sup>a</sup>

Pasting property	27 °C				32 °C			
	Initial population	F <sub>1</sub> progeny	IDK	FD	Initial population	F <sub>1</sub> progeny	IDK	FD
Pasting temperature (°C)	ns	ns	ns	ns	ns	ns	ns	ns
Peak viscosity (RVU) <sup>b</sup>	ns	ns	ns	ns	NS	0.75**	0.66**	ns
Peak time (min)	ns	ns	ns	ns	0.46*	0.66**	0.64**	0.52*
Holding strength (RVU)	ns	ns	ns	ns	0.56**	0.82**	0.77**	ns
Breakdown (RVU)	ns	ns	ns	ns	-0.51*	-0.54*	-0.55**	ns
Final viscosity (RVU)	ns	0.56*	ns	0.65**	0.65**	0.84**	0.80**	ns
Setback from trough (RVU)	ns	0.58*	ns	0.68**	0.66**	0.83**	0.79**	ns

<sup>a</sup> \*, \*\* = F-value is significant at  $P < 0.05$  and  $0.01$ , respectively. ns = not significant.

<sup>b</sup> Rapid visco-analyzer viscosity unit.

gradual increase in total nitrogen and non-protein nitrogen in sorghum grain as the infestation level by *R. dominica* increased from 0% to 75%, whereas the content of protein nitrogen and true protein decreased. Previously, Jood and Kapoor (1992) reported a decrease in digestibility of sorghum starch and protein infested by *R. dominica*. Therefore, it is possible that proteolytic enzymes from *R. dominica* hydrolyzed the kafirin and released low molecular weight peptides during storage (Aja et al., 2004), thereby resulting in a quality deterioration.

An increase in the initial population level of *R. dominica* led to an increase in the overall pasting viscosity of sorghum flour. This is an unexpected result considering that we expected deterioration in the quality of starch. High pasting viscosity is generally considered as a desirable property of starch for the food industry because various types of thickeners (which generally have a high pasting viscosity) are widely used to improve or modify the properties of food products.

Physical or chemical disintegration of the protein structure by mandibular grinding and mastication and/or the release of proteolytic enzymes by feeding insects could cause individual starch granules to be exposed during the hot water treatment, thereby allowing them to swell freely, resulting in a higher peak viscosity than found in undamaged grains. In addition, intact kafirin, which is encapsulated in protein bodies, is usually non-functional until the body is opened up (Hamaker and Bugusu, 2003). However, the physically and/or enzymatically affected kafirin could interact with carbohydrates during the cooling stage, giving an increase in final pasting viscosity. During cooling, viscosity increases rapidly with re-association of starch, particularly amylose (Miles et al., 1985). Pasting viscosity was increased when a reducing agent ( $\beta$ -mercaptoethanol) was added to the sorghum flour, which could have disrupted the protein structure (Chandrashekar and Kirleis, 1988), thereby resulting in more starch granules becoming available for full gelatinization. Zhang and Hamaker (2005) also observed that the overall pasting viscosity of sorghum flour increased as the flours were treated with increasing amount of dithiothriol, a reducing agent, compared to flour without the reducing agent.

Pasting viscosity generally decreases with an increase in starch damage and increased amylase activity in the endosperm, and water absorption can increase with starch damage. In studies with stored grains, Jood et al. (1993) found significant changes in the levels of carbohydrates in grains stored for 2–4 months and infested with *R. dominica*. Based on our observation of an increase in pasting viscosity with increasing numbers of *R. dominica*, it seems that any starch damage caused by the physical chewing action by the insects or injection of amylolytic enzymes would be minimal. A more significant contribution would be the effects of swelling caused by freed starch granules on the pasting viscosity.

Further investigation is needed to elucidate how proteolytic and amylolytic enzymes affect the protein and starch structure and their impacts on food-processing properties.

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