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SUSCEPTIBILITY TO BRUCHIDS AMONG COMMON BEANS IN UGANDA

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ABSTRACT

The bean bruchids, *Acanthoscelides obtectus* Say and *Zabrotes subfasciatus* Boheman (Coleoptera: Bruchidae), are cosmopolitan pests of stored dry common beans (*Phaseolus vulgaris* L.), causing damage through reduction of grain quality and seed germination. Biological resistance to these bruchids was definitively established in non-cultivated bean accessions, and has been introgressed into a range of drybean market classes. However, existing resistance to bruchids in Uganda's common bean germplasm has not been systematically studied. In this study, 45 bean genotypes from the National Bean-Breeding Programme (25 genotypes) and agroecologically diverse bean growing areas in Uganda (20 genotypes), were evaluated for postharvest bruchid resistance. None of the evaluated bean genotypes expressed resistance to either bruchid species, with all the 45 bean genotypes supporting bruchid development, reproduction and feeding. All genotypes were severely damaged by bruchids feeding, resulting in significant ($P<0.05$) reduction of seed germination. Reduction in seed germination was related to the number of emergence holes and seed size; small bean seeds damaged by up to 2 bruchid emergence holes had a 7.1% reduction in germination, while large bean seeds with a similar number of emergence holes showed a 25% reduction in germination. Whereas this study further confirms bruchids as important storage pests of beans causing direct loss through consumption of the seed and indirect loss through viability deterioration, the resistance to bruchids in the evaluated range of Uganda's dry bean germplasm is inadequate for direct exploitation in a breeding programme.

Key Words: *Acanthoscelides obtectus, Phaseolus vulgaris*, *Zabrotes subfasciatus*

RÉSUMÉ

Les bruches du haricot, *Acanthoscelides obtectus* Say et *Zabrotes subfasciatus* Boheman (Coleoptera: Bruchidae), sont des ravageurs cosmopolites des haricots secs stockés (*Phaseolus vulgaris* L.), provoquant des dommages en réduisant la qualité des grains et le pouvoir germinatif des semences. La résistance biologique à ces bruches a été définitivement établie dans des lignées non cultivées de haricots et a été introgressée dans une gamme variée de haricots commercialisés. Cependant, la résistance actuelle aux bruches dans le matériel génétique des haricots communément répandus en Ouganda n'a pas été systématiquement étudiée. Dans la présente étude, 45 génotypes de haricots provenant du Programme national d'amélioration du haricot (25 génotypes) et de diverses zones agro-écologiques de culture de haricots en Ouganda (20 génotypes), ont été évalués pour leur résistance post-récolte aux bruches. Aucun des génotypes évalués n'a exprimé de la résistance aux deux espèces de bruches, et tous les 45 génotypes ont favorisé le développement des bruches, leur reproduction et leur alimentation. Tous les génotypes ont été gravement endommagés du fait de l'alimentation des bruches, ce qui a entraîné une réduction significative (P <0,05) de la germination des graines. La réduction du pouvoir germinatif était liée au nombre de trous causés sur les graines et à la taille des graines; les petites graines de haricot endommagées avec jusqu'à 2 trous ont montré une réduction de 7,1% de leur pouvoir germinatif, tandis que les grandes graines de haricots endommagées avec le même nombre de trous ont connu une réduction de 25% de pouvoir germinatif. Bien que cette étude confirme davantage que les bruches sont d'importants ravageurs en phase de stockage des haricots causant des pertes à la fois directe par la consommation de la graine et indirecte par la détérioration de la viabilité des semences, la résistance aux bruches dans la gamme étudiée du matériel génétique de haricots secs de l'Ouganda est insuffisante pour une exploitation directe dans un programme d'amélioration variétale.

Mots Clés: *Acanthoscelides obtectus, Phaseolus vulgaris*, *Zabrotes subfasciatus*

INTRODUCTION

The bean bruchids, *Acanthoscelides obtectus* Say and *Zabrotes subfasciatus* Boheman (Coleoptera: Bruchidae), are among the most important and widespread storage pests in all major dry common beans (*Phaseolus vulgaris* L.) growing regions world wide (Msolla and Misangu, 2002; Schmale *et al*., 2002; Nadir *et al*., 2005). These bruchid species have similar biology and coexist; with several adults of both *A. obtectus* and *Z. subfasciatus* infesting the same seed at the same time (Ware, 1988). They cause extensive grain weight and quality losses through their feeding (Giga *et al*., 1990; Nahdy, 1994), and product alterations such as reduction of nutritional and aesthetic value; alteration of cooking characteristics (Mulungu *et al*., 2007); and reduction in viability of bruchid-damaged seeds (Nahdy, 1990).

Losses in dry weight of bean grains due to bruchid damage, have been estimated at about 70%, especially where post-harvest management is poor (Nahdy, 1990; Songa and Rono, 1998; Mulungu *et al*., 2007). Ultimately, bruchid damage results in significant grain price discounts (Mshili *et al*., 2011), and bruchid damage in storage forces farmers to sell beans within 2 - 3 months after harvest, so as not to incur total grain losses (Giga *et al*., 1992).

One possible approach to sustainable bruchid management is the exploitation of host-plant resistance, an effective, economical, and environment friendly method of pest control (Miklas *et al*., 2006). Genetic resistance to bruchids was discovered in wild bean accessions from Mexico (Schoonhoven *et al*., 1983), and introgressed into a range of dry bean market classes (Cardona *et al*., 1990). Potential of resistance as a method of control to reduce losses caused by bruchids in beans has been illustrated in the arcelin containing inbred RAZ bean lines that have consistently shown complete resistance for bruchids (Cardona *et al*., 1992; Misangu *et al*., 2001). However, the success of breeding to transfer this resistance to wider germplasms has been limited and there is considerable variation in susceptibility to bruchid attack among most cultivars grown. For Uganda's common dry bean germplasm, the presence and distribution of bruchid resistance has not been systematically studied. The objective of this study was to evaluate bean genotypes existing among farmers in agroecologically different bean growing areas in Uganda for resistance against post-harvest infestation and damage by bruchids (*A. obtectus* and *Z. subfasciatus*).

MATERIALS AND METHODS

Culturing of bruchids. This study was conducted during 2011/2012 at the National Crop Resources Research Institute (NaCRRI) Namulonge and the National Agricultural Research Laboratories Institute (NARLI); Kawanda in Uganda. Bruchids initially collected from farmers' stored beans during the bean genotype collection were mass reared under ambient conditions within a laboratory, on bean varieties K20 and NABE 6 which are highly susceptible to bruchids (Padgham *et al*., 1992).

In 1-litre polystyrene jars, 400 g of dry bean seeds of either variety K20 or NABE-6 were placed and infested with 150 - 200 unsexed *A. obtectus* or *Z. subfasciatus*. The jars were closed with lid tops that were perforated to allow aeration, but prevent bruchid escape. The bruchids were left to oviposit on the seeds for 10 days and, then removed by sieving each culture medium through a 3 mm-mesh sieve.

The bean seeds were further incubated for 5 - 6 weeks. To ensure age uniformity, the first lot of emerged bruchids was sieved and discarded, and those that emerged 2 -3 days thereafter, were collected for use in the experiment. In order to maintain the source of bruchids, new stock cultures were initiated as soon as each new generation of adults emerged, following the same procedure above.

The infested grain was regularly replaced with fresh ones. Relative humidity and temperature of the room were recorded hourly, daily, using a data logger (Shenzhen Yuwen Sensor System Co., Ltd, China).

Bruchid progeny development periods, reproduction and bean damage. Newly-harvested grains of each of the 45 genotypes (Table 1) were sun-dried to a moisture content of less than 14%, and then solarised to kill carry-over bruchid eggs and/or adults, using a technique described by Agona and Nahdy (1998). Fifty seeds of each genotype were randomly picked, weighed and placed in transparent glass jars. They were then infested with 20 adult bruchids (1 - 3 days old) in a 50:50 female:male ratio. Sexing of *Z. subfasciatus* was based on the size of the insects and the characteristic colour of the elytra. That of *A. obtectus* was based on morphological characteristics of the genitalia or the last abdominal segments (pygidium) (Allen *et al.*, 1996).

All the jars were laid out on laboratory shelves at room temperature (21.5 - 28^{o}C), in a completely randomised design, with four replications. The bruchids were allowed to oviposit for 10 days before being discarded. Adult bruchid emergence was monitored daily and bruchids that emerged were sieved out using a coarse test sieve and counted. This was repeated until no more emergences were observed, indicating the end of the generation. The median bruchid development period (MDP) on each genotype was calculated at mid-period of oviposition (5 days from initial infestation time) to the emergence of 50% of the first generation (Derera *et al.,* 2010). The number of adult bruchids that emerged and median development period were combined to

TABLE 1. Common Uganda dry bean genotypes tested for resistance to *Acanthoscelides obtectus* and *Zabrotes subfasciatus*

Breeding lines (7)	Improved commercial varieties (18)	Farmers varieties (20)
NARBL 40-3 (Black-2)	NABE 1	Golden beans round
NARBL 50-1	NABE 2	Small seeded cream
NARBL 53-1	NABE 3	Mary meda
NARBL 53-3	NABE 4	Yellow round
NARBL-60	NABE 5	Bam
NARBL 244-1(Black-1)	NABE 6	Ocuc
NARBL-220	NABE 7C	Dark greyish spotted
	NABE 8C	Golden beans oval
	NABE 9C	Pinkish stripe oval
	NABE 10C	Purple brown
	NABE 11	Jewe
	NABE 12C	Cheparron
	NABE 13	Yellow long
	NABE 14	Yellow short
	NABE 15	Kaula
	NABE 16	Kigome
	K131	Gantagazose
	K132	Black big size
		Nambale short
		Kanyebwa

calculate the susceptibility index for each genotype, using Dobie's formula (Dobie, 1974):

Dobie's Susceptibility Index (SI)

$$\frac{Log_e(No.\ Adult\ emerged)}{Median\ Development\ Period\ (MDP)} X100$$

Based on the Dobie's susceptibility index, the bean genotypes were grouped into four categories as resistant: SI 0 - 3; moderately resistant: SI 4 - 7; susceptible: SI 8 - 10; highly susceptible: SI $\geq$ 11 (Sulehrie *et al.*, 2003). Additionally, grain weight loss, which is an economic loss indicator of bruchid feeding, was calculated as follows:

Grain weight loss (%) =

$$\left(\frac{Initial\ grain\ weight - Final\ grain\ weight}{Initial\ grain\ weight}\right) \times 100$$

Seed damage by the bruchids was estimated by counting the number of adult emergence holes per seed and the seeds with 0 - 1, 2 - 3, 4 - 5 and > 5 emergent holes were grouped and counted.

Seed germination. Seeds of three bean varieties differing in seed size: NABE 5 (small), NABE 6 (medium) and NABE 11 (big), where small = 0.5 - 0.9 cm diameter, medium = 1.0 - 1.5 cm diameter, and large = 1.6 - 2.0 cm diameter (IPGRI, 2001), were evaluated for the effect of bruchid damage on bean seed germination. One hundred seeds of each variety was placed in 150 ml polystyrene jars and infested with 60 (30 females and 30 males) 0-3 day-old adult *A. obtectus* that were allowed to mate and oviposit for seven days before being discarded. The jars were placed on laboratory shelves at ambient conditions (temperature = 21.5 - 28^o C and relative humidity 65 - 70%) in a completely randomised experimental design, with four replications. Adult bruchid emergence was monitored daily and emerged bruchids were removed and discarded. The experiment was discontinued after five days when no more weevils emerged. Un-infested seeds of each variety were also stored for the same period, to act as a control.

At the end of the experiment, the seeds of each variety were combined (a total of 400 seeds from the four replications per variety). Each seed in the combined lot per variety was inspected for bruchid emergence holes and sorted into 11 categories based on the number of bruchid emergence holes on the seed, namely 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10+ emergence holes per seed. Ten seeds from each of the eleven damage categories for each of the three varieties were picked randomly and planted into individual plates filled with sterilised moistened lake sand for 10 days to test their ability to germinate. Seedlings that had well-developed essential structures of the root system, shoot axis, cotyledons and terminal buds were considered "normal germination", and their proportion was recorded per variety

Data analysis. The data collected were subjected to analysis of variance, using the Generalised Linear Model (GLM) procedure of GenStat Version 13 statistical software (Lawes Agricultural Trust, 2010). Simple (Pearson) correlations between different parameters were explored. Further, Principal Component analysis was performed to estimate the important variable measured that had the greatest contribution to the variance observed in the data. The identified variable were then used to run regression analysis to estimate the relative performance of the different genotypes with respect to the two bruchid species, *A. obtectus* and Z. *subfasciatus*.

RESULTS

There were significant (P < 0.05) differences in total number of F_1 progeny that emerged, number of days to the first adult bruchid to emerge, number of days for 50% of adult bruchids to emerge, number of days for the last adult bruchid to emerge, median development period and susceptibility index between bruchid species on a specific bean genotype (Table 2). The bean gentoypes supported higher reproduction of *Z. subfasciatus* than *A. obtectus,* based on absolute values of fecundity of both bruchid species on the different genotypes (Tables 3 and 4, Fig. 1). Landrace "Kanyebwa" and elite genotype "NABE 15" recorded the highest adult *A. obtectus*

TABLE 2. Analysis of Variance of estimated emerged progeny, progeny development periods, F_1 emerged adult *Acanthoscelides obtectus* and *Zabrotes subfasciatus* populations, Susceptibility index, rain weight loss, and damage caused after incubation on 45 different common Ugandan bean genotypes for d" 100 days

Source	df	Total F_1 Progeny emerged	Median Development period	Seed damage (%)	Grain weight loss (%)	Susceptibility index
Total	89	7010.02	22.73	37.52	74.79	1.88
Bruchid species	1	334567***	876***	1462.09***	1254.34***	17.56**
Bean genotype	44	3759ns	13.03ns	21.72ns	75.63ns	1.79ns
Genotype x species	44	2817***	13.05***	20.95ns	47.13ns	1.61***
Error		1225.37	4.40	15.31	48.00	0.62
C.V (%)		21	4	9	45	7
Zabrotes subfasciatus						
Bean genotype	44	11953ns	69.23*	30.59*	374**	4.732ns
Acanthoscelides obtectus						
Bean genotype	44	10024**	29.84**	129.67*	154.07**	8.01*

Values are mean squares; *, **, *** = F value significant at P< 0.05, 0.01 and 0.001, respectively; ns = F value not significant at P = 0.05

emergence; while landrace "Golden bean round" and breeding line NARBL 40-3 (Black-2) recorded the lowest adult *A. obtectus* emergence. On the other hand, landraces "Purple brown", "Yellow round", "Kigome", "Kaula", and "Gantagazose" recorded the highest adult *Z. subfasciatus* emergence; while landraces "Golden beans oval", "Bam" and "Mary Meda" recorded the lowest adult *Z. subfasciatus* emergence.

Mean development period for *A. obtectus* of was significantly (P <0.01) shorter than for *Z. subfasciatus*. However, the days to first emergence of adult bruchids were significantly (P < 0.01) shorter for Z. *subfasciatus* than *A. obtectus*. In contrast, the number of days to the last emergence of adult bruchids was significantly (P < 0.01) longer for Z. *subfasciatus* than *A. obtectus* (Tables 3 and 4). Based on the Dobie's Susceptibility Index all the bean genotypes evaluated were susceptible or highly susceptible to *A. obtectus* and *Z. subfasciatus* (Table 5).

All the evaluated genotypes were severely damaged by the bruchids (Tables 6 and 7). Seed damage was significantly (P < 0.01) higher in *Z. subfasciatus* than *A. obtectus* infested seeds. *Acanthoscelides obtectus* damaged seeds were 77%, of which seeds having 1 - 3 holes constituted 55% of the damage, while, *Z. subfasciatus* damaged seeds were 93%, of which seeds having more than 4 holes contributed 58% of the damage. Bruchid damage resulted in varying degree of grain weight loss, being significantly (P <0.05) higher in *Z. subfasciatus* than in *A. obtectus* infested seeds.

Within each bruchid species, there were significant (P < 0.01) differences in grain weight loss among the genotypes. In *A. obtectus* infested beans, grain weight loss was highest in Kayebwa and Nabe 15 (27%) and least in NABE 4 (3.7%), Golden brown - rounded (3.3%), Dark grayish spotted (2.4%) and NARBL 40 – 3 (Black 2) (2.3%) (Table 6). In *Z. subfasciatus* infested seed, grain weight loss was highest in K131 and Yellow round (37%) and the least in NABE 11 (4.4%) (Table 7). Additionally, bruchid damage significantly (P<0.05) reduced germination in relation to number of emergence holes and seed size. Small bean seeds damaged by up to 2 bruchid emergence holes had small reduction in emergence and seedling vigour; while large bean seeds with similar number of emergence holes showed a significant reduction in germination (Fig. 2).

TABLE 3. Estimated progeny development periods and F_1 emerged adult populations of *Acanthoscelides obtectus* after incubation on 45 different common Ugandan bean genotypes for < 100 days (Mean ± SEM)*

Bean genotype	Total adult weevils emerged	Days for first adult weevil to emerge	Days for 50% adult weevils to emerge	Days for last adult weevil to emerge	Median Development period
Kanyewa	295.7 ± 82.1	34.0 ± 0.0	40.0 ± 1.7	57.0 ± 3.1	40.0 ± 0.9
NABE 15	243.7 ± 65.5	34.0 ± 0.0	41.3 ± 0.3	61.3 ± 4.9	41.9 ± 0.7
Gantagazose	231.0 ± 110.1	34.0 ± 0.0	39.7 ± 2.9	53.0 ± 3.5	42.3 ± 0.3
NARBL 244 (Black 1)	212.3 ± 76.1	34.0 ± 0.0	42.0 ± 0.6	57.0 ± 3.2	43.0 ± 0.7
Kigome	164.0 ± 43.9	34.3 ± 0.3	39.3 ± 1.8	57.0 ± 6.5	42.7 ± 0.5
Golden Beans Oval	160.7 ± 76.4	36.0 ± 2.0	42.3 ± 0.3	57.0 ± 7.6	44.1 ± 2.0
NABE 11	146.3 ± 42.5	35.4 ± 0.5	41.0 ± 0.4	54.0 ± 2.2	40.9 ± 0.4
Kaula	146.0 ± 40.7	34.3 ± 0.3	40.7 ± 0.7	62.0 ± 5.2	42.6 ± 0.4
NABE 16	142.7 ± 14.2	34.0 ± 0.0	41.3 ± 0.3	61.3 ± 6.9	41.3 ± 0.7
K132	139.9 ± 17.9	37.0 ± 1.1	43.7 ± 0.9	57.3 ± 2.0	44.1 ± 0.8
Black Big Size	132.7 ± 32.2	34.0 ± 0.0	37.7 ± 2.7	51.0 ± 0.0	41.0 ± 0.8
NARBL 220	132.3 ± 87.1	36.0 ± 1.5	42.0 ± 1.2	64.7 ± 4.2	45.2 ± 2.7
Nambale short	130.3 ± 23.4	34.0 ± 0.0	38.7 ± 1.5	62.0 ± 3.5	38.9 ± 0.7
NABE 13	126.4 ± 18.5	38.0 ± 1.4	44.0 ± 1.0	55.4 ± 1.1	45.3 ± 0.6
NABE 14	126.4 ± 33.9	38.0 ± 1.4	43.6 ± 1.6	56.0 ± 1.7	45.0 ± 0.9
NARBL 60	113.3 ± 59.7	34.0 ± 0.0	42.0 ± 0.0	57.7 ± 6.6	40.5 ± 2.2
Yellow Long	109.3 ± 37.9	34.0 ± 0.0	42.0 ± 0.6	54.3 ± 3.3	41.8 ± 0.1
NABE 1	107.1 ± 24.5	38.6 ± 1.6	44.7 ± 0.8	55.1 ± 1.4	45.5 ± 0.8
NABE 9C	106.7 ± 22.1	36.9 ± 1.1	42.7 ± 0.5	57.0 ± 1.4	42.4 ± 0.8
Pinkish Stripe Oval	106.7 ± 56.8	43.3 ± 9.3	47.0 ± 7.6	59.7 ± 4.3	58.1 ± 16.9
Purple Brown	105.0 ± 54.6	34.7 ± 0.3	39.7 ± 0.9	61.3 ± 5.8	42.9 ± 0.4
Cheparron	100.7 ± 26.7	34.7 ± 0.3	42.3 ± 1.3	53.3 ± 3.0	43.8 ± 0.5
Jewe	99.7 ± 44.1	34.0 ± 0.0	39.7 ± 2.4	59.3 ± 5.2	42.8 ± 1.3
NARBL 53 - 3	99.0 ± 38.6	35.3 ± 1.3	41.3 ± 0.7	50.3 ± 5.5	43.6 ± 1.3
NABE 5	97.9 ± 12.5	35.4 ± 0.8	41.9 ± 0.3	53.0 ± 1.7	42.7 ± 0.3
NABE 8C	93.6 ± 23.8	37.1 ± 1.1	42.6 ± 1.2	56.3 ± 2.3	44.0 ± 0.6
NARBL 53 - 1	89.7 ± 36.2	34.0 ± 0.0	40.0 ± 0.6	53.7 ± 4.9	41.6 ± 1.0
NABE 4	85.9 ± 8.5	38.4 ± 1.4	43.9 ± 1.1	59.1 ± 2.4	45.6 ± 0.5
Yellow Short	85.0 ± 33.1	34.7 ± 0.7	41.3 ± 2.0	49.7 ± 2.0	43.5 ± 1.7
NABE 2	80.3 ± 12.7	37.9 ± 1.3	43.7 ± 1.1	55.9 ± 2.5	44.0 ± 1.1
NABE 3	79.6 ± 21.6	37.6 ± 1.2	43.9 ± 0.6	50.6 ± 1.1	43.9 ± 0.6
NABE 12C	76.9 ± 43.7	39.3 ± 1.9	44.3 ± 1.1	52.7 ± 2.0	44.4 ± 1.1
NABE 6	75.0 ± 18.6	38.0 ± 1.4	43.6 ± 1.2	52.4 ± 1.4	44.4 ± 0.8
NABE 10C	72.3 ± 12.0	38.6 ± 1.6	45.3 ± 1.2	57.1 ± 3.1	46.0 ± 0.8
NABE 7C	68.7 ± 18.5	37.9 ± 1.3	43.3 ± 1.4	55.9 ± 2.7	45.3 ± 0.8
Ocuc	65.3 ± 14.3	35.0 ± 1.0	40.3 ± 0.7	48.0 ± 2.0	41.9 ± 1.8
Dark Greyish Spotted	64.7 ± 17.7	34.0 ± 0.0	39.3 ± 2.2	51.7 ± 3.2	40.0 ± 1.2
Bam	60.7 ± 25.3	37.7 ± 2.0	49.0 ± 6.6	60.7 ± 4.5	47.4 ± 3.9
Yellow Round	58.3 ± 14.0	34.7 ± 0.3	40.7 ± 0.9	53.3 ± 5.9	43.3 ± 0.2
K131	57.7 ± 14.4	37.9 ± 1.4	43.4 ± 0.9	57.6 ± 2.5	44.4 ± 0.6
NARBL 50 - 1	57.3 ± 32.3	34.0 ± 0.0	40.3 ± 1.2	46.7 ± 3.3	39.8 ± 1.6
Mary Meda	57.0 ± 19.5	34.0 ± 0.0	40.3 ± 1.9	58.3 ± 3.8	43.0 ± 0.8
Small Seeded Cream	56.0 ± 24.1	36.7 ± 2.2	41.0 ± 0.0	53.0 ± 3.6	46.8 ± 4.0
Golden Beans Round	37.3 ± 12.4	34.3 ± 0.3	39.7 ± 1.9	59.0 ± 4.6	40.1 ± 1.9
NARBL 40 - 3 (Black 2)	37.3 ± 16.7	36.7 ± 0.9	40.7 ± 1.2	53.7 ± 4.3	47.0 ± 0.8
LSD (0.05)	78.0	3.6	3.2	6.9	2.2
F probability	0.002	0.044	0.007	0.128	0.004

*sorted in descending order by total adult weevils emerged

TABLE 4. Estimated progeny development periods and F_1 emerged adult populations of *Zabrotes subfasciatus* after incubation on 45 different common Ugandan bean genotypes for < 100 days (Mean ± SEM)*

Bean genotype	Total adult weevils emerged	Days for first adult weevil to emerge	Days for 50% adult weevils to emerge	Days for last adult weevil to emerge	Median Development period
Purple Brown	388.3 ± 114.2	28.3 ± 0.9	49.7 ± 2.9	65.7 ± 1.5	51.4 ± 2.0
Yellow Round	348.7 ± 20.7	28.3 ± 1.3	46.0 ± 1.2	64.7 ± 1.7	49.7 ± 1.0
Kigome	342.3 ± 53.2	28.3 ± 1.3	44.7 ± 0.9	61.7 ± 3.4	47.4 ± 0.4
Kaula	323.0 ± 92.4	30.0 ± 3.0	47.3 ± 3.3	65.3 ± 1.8	51.8 ± 5.9
Gantagazose	319.7 ± 65.1	29.3 ± 1.9	48.7 ± 3.2	63.3 ± 1.8	51.5 ± 4.1
NARBL 53 - 1	312.7 ± 140.3	27.0 ± 0.0	47.0 ± 3.5	61.3 ± 2.9	46.4 ± 2.4
Nambale short	299.7 ± 72.8	28.3 ± 0.9	49.7 ± 2.8	63.7 ± 1.2	51.4 ± 3.1
Cheparron	282.0 ± 62.1	27.0 ± 0.0	46.7 ± 2.7	62.7 ± 0.3	46.7 ± 1.0
Dark Greyish Spotted	280.0 ± 146.3	27.0 ± 0.0	49.7 ± 3.2	63.0 ± 0.6	49.5 ± 2.0
Kanyewa	273.3 ± 76.5	30.3 ± 1.8	46.7 ± 3.7	61.0 ± 3.2	51.4 ± 3.5
K131	271.0 ± 42.3	33.9 ± 1.9	43.1 ± 1.6	56.7 ± 2.4	46.0 ± 3.5
Jewe	264.7 ± 80.7	35.7 ± 6.3	49.0 ± 3.0	61.7 ± 3.9	58.1 ± 8.1
NABE 16	254.7 ± 110.5	27.0 ± 0.0	46.7 ± 1.8	61.0 ± 2.6	47.7 ± 1.2
NARBL 50 - 1	246.3 ± 42.9	27.0 ± 0.0	50.0 ± 3.0	63.3 ± 0.7	50.3 ± 1.7
NABE 8C	246.0 ± 30.2	35.0 ± 1.0	43.4 ± 1.9	57.6 ± 2.4	47.2 ± 3.6
NABE 1	244.6 ± 19.0	33.0 ± 1.3	43.9 ± 2.3	59.7 ± 2.3	45.6 ± 2.8
NABE 5	242.1 ± 46.9	32.4 ± 2.0	43.4 ± 1.4	55.9 ± 2.0	43.9 ± 1.4
NARBL 53 - 3	238.3 ± 90.7	27.0 ± 0.0	46.7 ± 3.7	61.7 ± 2.0	45.9 ± 1.8
NABE 9C	236.0 ± 32.1	32.0 ± 1.7	43.3 ± 1.9	55.3 ± 3.3	44.2 ± 1.9
Pinkish Stripe Oval	236.0 ± 126.0	31.7 ± 3.7	48.7 ± 2.0	64.3 ± 0.9	54.5 ± 4.5
NABE 2	229.9 ± 33.9	33.0 ± 1.7	43.6 ± 2.0	56.7 ± 2.3	44.6 ± 1.7
NABE 4	227.9 ± 33.8	32.7 ± 1.6	44.0 ± 2.3	56.4 ± 3.3	45.4 ± 2.6
NABE 10C	227.0 ± 27.0	32.9 ± 1.8	45.0 ± 2.3	56.9 ± 2.6	45.8 ± 2.2
NABE 3	225.0 ± 41.2	32.1 ± 1.8	43.1 ± 1.8	54.0 ± 3.0	43.7 ± 1.9
NARBL 40-3 (Black 2)	221.7 ± 19.3	32.7 ± 3.0	46.0 ± 3.1	63.3 ± 1.2	53.1 ± 4.9
NABE 6	216.3 ± 40.9	35.0 ± 1.0	43.9 ± 2.1	56.0 ± 2.4	47.8 ± 4.0
Yellow Short	216.0 ± 32.2	29.0 ± 2.0	50.3 ± 2.7	64.0 ± 0.6	52.4 ± 0.7
NABE 13	211.7 ± 40.4	32.4 ± 1.6	44.3 ± 2.3	56.7 ± 2.4	45.3 ± 2.4
NABE 14	211.1 ± 26.0	32.0 ± 1.8	45.9 ± 2.9	56.9 ± 3.0	45.2 ± 2.4
NABE 12C	204.9 ± 28.2	34.6 ± 1.0	45.1 ± 2.3	57.7 ± 2.3	47.8 ± 3.2
K132	204.1 ± 26.2	31.9 ± 1.7	45.7 ± 2.5	56.3 ± 3.1	44.7 ± 2.1
Yellow Long	204.0 ± 50.8	29.0 ± 1.0	50.7 ± 3.3	63.7 ± 1.2	53.0 ± 3.7
NARBL 244 (Black 1)	203.3 ± 128.1	37.0 ± 1.0	46.7 ± 2.7	61.7 ± 1.5	58.5 ± 2.4
NABE 15	202.7 ± 62.5	30.0 ± 1.7	50.0 ± 2.1	64.3 ± 0.7	52.9 ± 1.7
NABE 7C	196.1 ± 19.7	33.3 ± 1.7	45.0 ± 2.1	56.1 ± 2.1	45.8 ± 1.9
NARBL 60	181.0 ± 27.7	27.7 ± 0.7	52.0 ± 0.0	64.0 ± 1.2	51.2 ± 0.6
Golden Beans Round	180.0 ± 32.9	27.7 ± 0.7	53.0 ± 0.6	63.0 ± 2.5	53.1 ± 1.5
NABE 11	173.9 ± 30.2	34.4 ± 0.8	46.1 ± 2.7	57.6 ± 2.8	48.0 ± 3.5
Ocuc	167.3 ± 69.7	29.7 ± 2.7	48.7 ± 2.7	64.0 ± 2.1	53.0 ± 4.9
Small Seeded Cream	158.3 ± 66.1	30.7 ± 3.7	50.7 ± 3.4	61.3 ± 2.3	53.7 ± 5.2
Black Big Size	155.7 ± 71.1	30.0 ± 2.1	52.3 ± 0.3	65.7 ± 1.8	54.2 ± 3.0
NARBL 220	154.3 ± 56.5	34.7 ± 2.7	52.7 ± 1.3	65.3 ± 0.3	59.4 ± 4.5
Golden Beans Oval	150.3 ± 84.3	31.7 ± 0.9	48.7 ± 2.9	59.7 ± 4.3	54.2 ± 2.3
Bam	127.7 ± 53.7	27.3 ± 0.3	49.3 ± 3.3	59.3 ± 4.3	49.1 ± 2.8
Mary Meda	122.3 ± 43.9	31.7 ± 4.7	50.3 ± 3.2	61.7 ± 3.5	55.4 ± 5.7
LSD (0.05)	115.8	4.3	5.7	6.3	7.1
F probability	0.586	0.004	0.194	0.044	0.024

*sorted in descending order by total adult weevils emerged

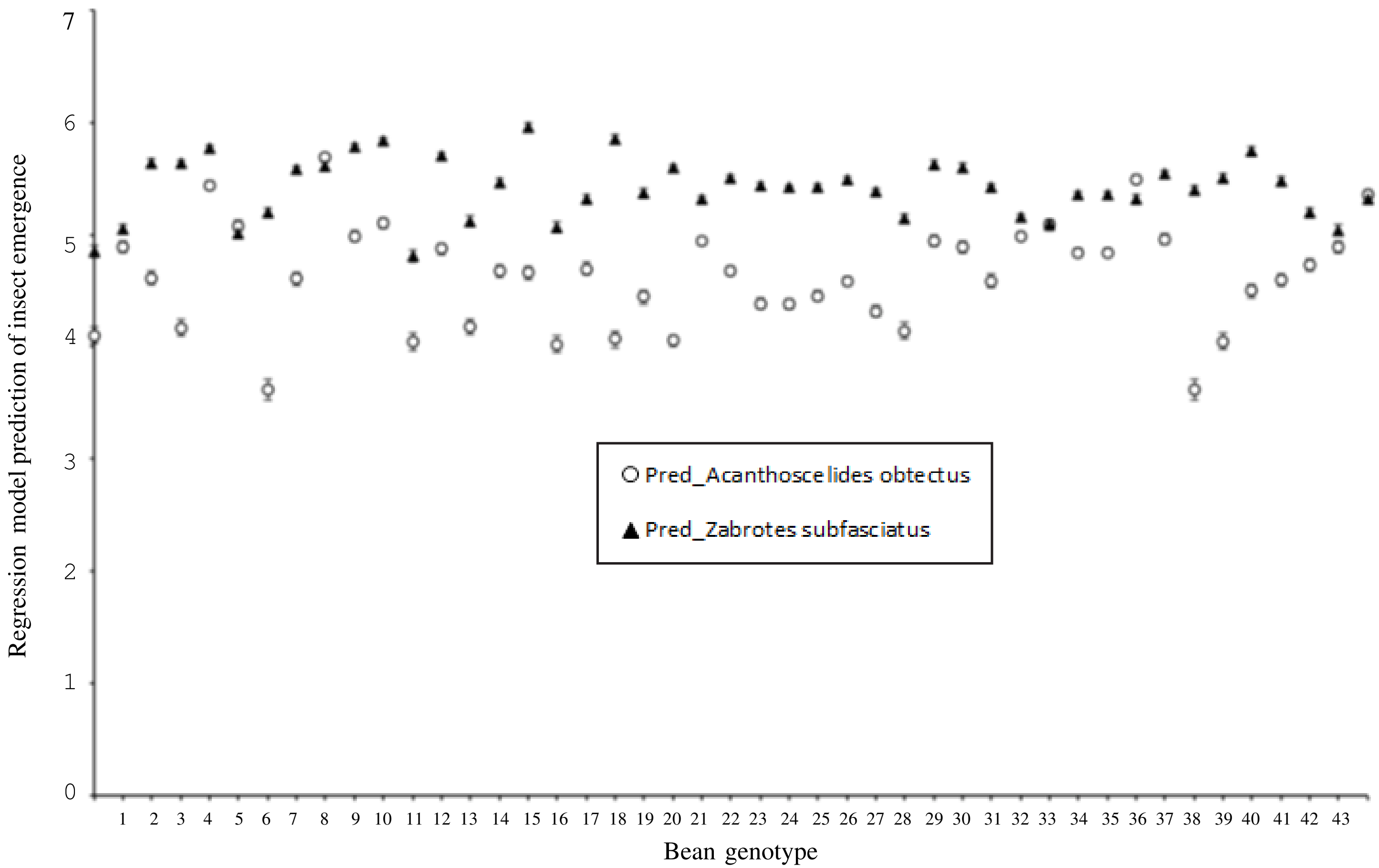

Figure 1. Scatter plot of total emerging F_1 progeny of *Acanthoscelides obtectus* and *Zabrotes subfasciatus* from 45 different genotypes as predicted from a generalized linear regression model using a Poisson distribution with logarithm link [Bean Genotypes: 1=Bam; 2="Black big size"; 3=Cheparron; 4="Dark greyish spotted"; 5=Gantagazose; 6="Golden beans oval"; 7="Golden beans round"; 8=Jewe; 9=Kanyewa; 10=Kaula; 11=Kigome; 12=Mary Meda; 13="Nambale short"; 14=Ocuc; 15="Pinkish stripe oval"; 16="Purple brown"; 17="Small seeded cream"; 18="Yellow long"; 19="Yellow round"; 20="Yellow short"; 21=K131; 22=K132; 23=NABE 1; 24=NABE 2; 25=NABE 3; 26=NABE 4; 27=NABE 5; 28=NABE 6; 29=NABE 7 C; 30=NABE 8 C; 31=NABE 9 C; 32=NABE 10 C; 33=NABE 11; 34=NABE 12 C; 35=NABE 13; 36=NABE 14; 37=NABE 15; 38=NABE 16; 39=NARBL 40-3BLACK – 2; 40=NARBL 50 – 1; 41=NARBL 53 – 1; 42=NARBL 53 – 3; 43=NARBL – 60; 44=NARBL – 220; 45=NARBL244-1BLACK-1].

TABLE 5. The susceptibility indices (Mean ± SEM) and host reaction classes of 45 different common Ugandan bean genotypes evaluated for resistance after infestation with *Acanthoscelides obtectus* and *Zabrotes subfasciatus* (Mean ± SEM) and incubating for d" 100 days*

Bean genotype	*Zabrotes subfasciatus*		*Acanthoscelides obtectus*	
	Susceptibility index	Resistance class	Susceptibility index	Resistance class
Kigome	13.0 ± 0.1	HS	12.7 ± 0.4	HS
K131	12.9 ± 0.5	HS	8.7 ± 0.8	S
NABE 1	12.7 ± 0.7	HS	10.1 ± 0.5	HS
NABE 8C	12.7 ± 0.4	HS	10.2 ± 0.9	HS
NABE 9C	12.7 ± 0.6	HS	10.7 ± 0.5	HS
Yellow Round	12.7 ± 0.3	HS	9.9 ± 0.8	S
NABE 2	12.5 ± 0.8	HS	9.9 ± 0.5	S
NABE 3	12.5 ± 0.5	HS	9.4 ± 0.7	S
NABE 4	12.4 ± 0.7	HS	10.1 ± 0.3	HS
NABE 5	12.4 ± 0.2	HS	10.9 ± 0.3	HS
Kaula	12.2 ± 1.3	HS	12.1 ± 0.4	HS
Cheparron	12.1 ± 1.0	HS	10.8 ± 0.8	HS
Kanyewa	12.1 ± 1.4	HS	14.1 ± 0.2	HS
NABE 10C	12.1 ± 0.6	HS	9.3 ± 0.7	S
NABE 13	12.1 ± 1.0	HS	10.9 ± 0.5	HS
NABE 6	12.0 ± 1.0	HS	9.6 ± 0.8	S
NARBL 53 - 1	12.0 ± 1.6	HS	10.6 ± 1.5	HS
Gantagazose	11.9 ± 1.2	HS	13.3 ± 1.8	HS
NABE 12C	11.9 ± 0.8	HS	7.9 ± 1.5	S
NABE 14	11.9 ± 1.0	HS	10.9 ± 0.8	HS
Purple Brown	11.9 ± 1.3	HS	10.7 ± 1.9	S
K132	11.8 ± 0.8	HS	11.2 ± 0.3	HS
NABE 7C	11.8 ± 0.6	HS	8.9 ± 0.9	S
NARBL 40-3 (Black 2)	11.8 ± 0.9	HS	7.8 ± 2.3	S
NARBL 53 - 3	11.6 ± 1.7	HS	10.4 ± 1.3	HS
Nambale Short	11.5 ± 1.2	HS	12.6 ± 1.0	HS
NABE 16	11.4 ± 0.7	HS	12.0 ± 0.3	HS
NABE 11	11.3 ± 1.0	HS	11.5 ± 0.7	HS
Jewe	11.2 ± 0.3	HS	10.4 ± 1.5	HS
Dark Greyish Spotted	11.0 ± 1.8	HS	10.5 ± 1.3	HS
NARBL 50 - 1	11.0 ± 0.8	HS	8.8 ± 2.4	S
Yellow Short	10.7 ± 0.3	HS	10.3 ± 1.9	HS
NARBL 244 (Black 1)	10.6 ± 1.5	HS	12.3 ± 1.2	HS
Pinkish Stripe Oval	10.6 ± 0.6	HS	9.2 ± 3.5	S
Yellow Long	10.5 ± 0.8	HS	10.8 ± 0.9	HS
NABE 15	10.4 ± 0.4	HS	13.1 ± 0.8	HS
Ocuc	10.2 ± 0.5	HS	10.2 ± 0.4	HS
NARBL 60	9.9 ± 0.3	S	10.2 ± 1.9	HS
Small Seeded Cream	9.9 ± 1.5	S	8.8 ± 1.9	S
Golden Beans Round	9.7 ± 0.3	S	9.0 ± 1.2	S
Golden Beans Oval	9.6 ± 0.6	S	10.3 ± 2.7	HS
Bam	9.5 ± 0.8	S	7.8 ± 1.4	S
Black Big Size	9.3 ± 0.8	S	12.9 ± 1.1	HS
NARBL 220	9.2 ± 1.1	S	10.6 ± 1.9	HS
Mary Meda	9.1 ± 0.4	S	9.7 ± 1.2	S
LSD (0.05)	2.0		2.4	
F probability	0.100		0.027	

Resistant classes: SI 0.0 – 2.5 = resistant (R); SI 2.6 – 5.0 = moderately resistant (MR); SI 5.1 – 7.5 = moderately susceptible (MS); SI 7.6 – 10.0 = susceptible (S) and SI > 10 = highly susceptible (HS); *sorted in descending order by susceptibility index of *Z. subfasciatus*

TABLE 6. Grain damage of 45 different common Ugandan bean genotypes by *Acanthoscelides obtectus* after incubation for d" 100 days (Mean ± SEM)*

Bean genotype	Seed damage (%)	Severity of seed damage estimated by the proportion (%) of seeds with a number of exit holes				Grain weight loss (%)
		1 hole	2 – 3 holes	4 – 5 holes	> 5 holes	
Kanyewa	95.3 ± 4.7	16.2 ± 8.7	24.6 ± 6.6	26.4 ± 3.8	32.7 ± 11.6	27.3 ± 6.4
NABE 15	90.7 ± 5.2	20.9 ± 16.6	23.2 ± 4.3	25.8 ± 13.1	30.2 ± 16.7	26.6 ± 10.4
Golden Beans Oval	79.3 ± 20.7	36.5 ± 26.9	16.8 ± 3.2	24.0 ± 12.2	22.7 ± 11.6	25.2 ± 9.4
NABE 11	83.3 ± 2.4	22.1 ± 12.7	19.4 ± 4.1	19.3 ± 3.1	39.1 ± 19.1	21.2 ± 11.4
NABE 6	82.7 ± 1.8	46.4 ± 10.6	26.0 ± 5.2	13.0 ± 2.3	14.7 ± 4.5	20.3 ± 5.5
Jewe	83.3 ± 7.0	61.2 ± 18.4	24.1 ± 11.0	9.7 ± 5.6	5.0 ± 3.7	19.9 ± 9.3
Kigome	93.3 ± 6.7	28.2 ± 18.1	25.8 ± 3.0	22.5 ± 9.8	23.5 ± 15.5	19.8 ± 6.1
Ocuc	86.0 ± 7.0	64.2 ± 6.2	26.8 ± 5.8	9.0 ± 8.0	0.0 ± 0.0	19.4 ± 5.7
Cheparron	72.7 ± 8.7	42.5 ± 12.2	33.7 ± 8.9	19.0 ± 7.8	4.7 ± 3.3	18.5 ± 2.8
NARBL 244 (Black 1)	90.7 ± 6.6	31.6 ± 18.4	31.2 ± 2.8	13.3 ± 5.6	23.9 ± 14.3	17.1 ± 6.4
Gantagazose	90.0 ± 6.4	24.5 ± 4.7	35.7 ± 14.1	14.9 ± 1.6	24.9 ± 17.5	16.9 ± 9.5
NABE 3	71.3 ± 15.7	52.0 ± 12.3	16.9 ± 8.9	20.7 ± 4.6	10.4 ± 5.2	16.6 ± 5.3
NABE 2	90.7 ± 4.8	47.1 ± 20.8	27.9 ± 7.1	19.4 ± 11.5	5.6 ± 2.3	14.9 ± 2.3
NABE 14	87.3 ± 7.0	27.0 ± 13.7	29.7 ± 14.1	17.3 ± 6.6	26.0 ± 21.0	13.5 ± 6.1
Bam	72.0 ± 12.7	65.2 ± 11.6	25.5 ± 7.8	8.0 ± 4.0	1.4 ± 1.4	12.9 ± 5.7
NARBL 53 - 3	78.7 ± 12.7	50.9 ± 18.6	35.1 ± 12.0	6.0 ± 3.1	8.0 ± 4.2	12.7 ± 1.4
Purple Brown	69.3 ± 19.2	56.7 ± 18.1	20.5 ± 4.8	9.2 ± 4.6	13.7 ± 10.9	12.5 ± 4.8
NABE 13	90.0 ± 5.8	26.2 ± 5.1	33.7 ± 9.6	17.3 ± 1.8	22.9 ± 4.2	12.0 ± 1.5
NABE 1	87.3 ± 2.4	45.6 ± 18.2	25.8 ± 2.6	16.2 ± 12.8	12.4 ± 5.6	11.3 ± 3.7
Nambale short	82.7 ± 11.9	47.0 ± 15.5	18.6 ± 9.1	13.9 ± 5.6	20.5 ± 6.8	10.9 ± 1.6
Black Big Size	83.3 ± 9.8	47.7 ± 13.3	23.2 ± 4.5	18.2 ± 11.2	11.0 ± 6.9	10.6 ± 3.8
Kaula	84.0 ± 8.0	35.8 ± 8.4	30.4 ± 4.7	22.8 ± 7.5	11.0 ± 4.2	10.5 ± 2.0
NARBL 220	66.7 ± 17.6	48.1 ± 21.3	27.9 ± 4.5	12.7 ± 12.7	11.3 ± 11.3	10.2 ± 5.9
NABE 12C	78.7 ± 0.7	38.4 ± 18.0	30.5 ± 2.7	14.4 ± 6.1	16.7 ± 13.1	9.9 ± 8.1
Yellow Long	63.3 ± 7.7	45.7 ± 15.5	30.0 ± 2.7	13.1 ± 6.7	11.2 ± 7.3	9.5 ± 2.1
K131	72.7 ± 7.3	52.2 ± 17.3	18.3 ± 9.3	22.2 ± 9.4	7.3 ± 4.3	9.4 ± 5.0
NARBL 60	73.3 ± 17.6	51.5 ± 27.0	20.3 ± 7.8	19.8 ± 16.2	8.3 ± 6.0	9.4 ± 5.6
Yellow Short	60.7 ± 10.4	54.5 ± 18.5	23.9 ± 7.6	15.9 ± 10.7	5.7 ± 5.7	9.4 ± 6.1
NABE 10C	90.0 ± 10.0	41.7 ± 10.4	33.6 ± 6.7	18.1 ± 7.2	6.6 ± 4.1	8.9 ± 1.8
K132	86.7 ± 6.7	24.5 ± 11.6	33.3 ± 9.8	23.3 ± 8.5	18.8 ± 3.4	8.6 ± 5.7
NABE 8C	83.3 ± 1.8	32.9 ± 1.4	28.5 ± 6.8	20.8 ± 1.3	17.9 ± 6.2	8.1 ± 2.5
Pinkish Stripe Oval	65.3 ± 10.7	52.6 ± 24.9	19.3 ± 9.8	14.9 ± 8.4	13.2 ± 8.5	8.0 ± 4.7
NABE 7C	68.7 ± 5.9	51.1 ± 25.6	26.1 ± 13.5	15.0 ± 8.7	7.8 ± 7.8	7.7 ± 7.0
NABE 5	76.0 ± 6.1	43.0 ± 6.2	34.5 ± 1.9	17.2 ± 5.1	5.3 ± 0.5	7.6 ± 3.4
NARBL 50 - 1	51.3 ± 13.5	74.1 ± 15.2	12.2 ± 6.5	3.7 ± 3.7	10.1 ± 5.6	6.7 ± 3.4
NARBL 53 - 1	66.7 ± 18.5	51.8 ± 21.6	29.1 ± 11.9	14.3 ± 7.3	4.8 ± 3.9	6.7 ± 3.3
Mary Meda	60.0 ± 2.3	62.4 ± 14.1	25.0 ± 8.0	10.3 ± 5.2	2.2 ± 2.2	6.2 ± 3.1
NABE 16	86.0 ± 5.0	30.7 ± 13.2	40.0 ± 5.9	17.4 ± 7.0	11.9 ± 5.0	6.2 ± 3.0
NABE 9C	86.7 ± 6.7	38.3 ± 11.2	34.0 ± 6.7	15.5 ± 1.0	12.2 ± 7.7	6.0 ± 3.4
Yellow Round	63.3 ± 7.7	61.2 ± 14.2	18.8 ± 5.3	10.7 ± 4.5	9.3 ± 5.6	6.0 ± 1.8
Small Seeded Cream	62.7 ± 15.3	70.1 ± 16.4	16.2 ± 8.4	12.0 ± 6.7	1.7 ± 1.7	5.8 ± 2.6
NABE 4	72.7 ± 8.5	57.0 ± 2.6	33.1 ± 5.2	7.4 ± 1.6	2.5 ± 1.5	3.7 ± 1.1
Golden Beans Round	57.3 ± 1.3	78.7 ± 7.6	20.2 ± 8.7	1.1 ± 1.1	0.0 ± 0.0	3.3 ± 2.3
Dark Greyish Spotted	57.3 ± 2.9	60.7 ± 14.2	26.0 ± 9.3	9.9 ± 8.0	3.4 ± 1.9	2.4 ± 1.3
LSD (0.05)	13.8	15.2	9.6	9.5	10.8	14.8
F probability	0.010	0.204	0.649	0.775	0.012	0.007

*sorted in descending order by Grain weight loss (%)

TABLE 7. Grain damage of 45 different common Ugandan bean genotypes by *Zabrotes subfasciatus* after incubation for d" 100 days (Mean ± SEM)

Bean genotype	Seed damage (%)	Severity of seed damage estimated by the proportion (%) of seeds with a number of exit holes				Grain weight loss (%)
		1 hole	2 – 3 holes	4 – 5 holes	> 5 holes	
K131	98.7 ± 1.3	0.0 ± 0.0	7.4 ± 4.1	48.9 ± 17.7	43.6 ± 15.0	37.2 ± 8.7
Yellow Round	99.3 ± 0.7	4.8 ± 4.8	5.4 ± 3.6	40.9 ± 3.1	48.9 ± 5.2	37.1 ± 14.9
Purple Brown	100.0 ± 0.0	0.7 ± 0.7	4.0 ± 4.0	36.0 ± 16.0	59.3 ± 20.7	33.8 ± 12.2
NABE 2	90.0 ± 10.0	13.3 ± 13.3	22.8 ± 16.0	26.6 ± 10.8	37.3 ± 18.7	33.0 ± 14.5
NABE 15	94.0 ± 3.1	5.2 ± 5.2	9.5 ± 4.6	42.9 ± 6.2	42.4 ± 9.9	32.9 ± 6.7
NABE 3	90.0 ± 7.2	10.2 ± 8.2	24.0 ± 12.5	32.3 ± 14.3	33.5 ± 29.4	32.1 ± 9.5
Jewe	88.0 ± 6.1	20.5 ± 11.6	23.3 ± 14.5	22.0 ± 6.8	34.2 ± 26.9	29.8 ± 12.0
Yellow Short	96.0 ± 4.0	8.8 ± 2.8	45.3 ± 14.7	29.3 ± 10.5	16.5 ± 6.6	29.8 ± 9.5
Golden Beans Round	88.0 ± 4.0	11.2 ± 4.5	35.1 ± 10.4	40.4 ± 11.3	13.3 ± 5.0	29.6 ± 10.1
Cheparron	94.7 ± 5.3	11.0 ± 10.0	15.8 ± 9.7	33.9 ± 7.6	39.3 ± 23.1	28.2 ± 7.7
Kigome	98.0 ± 2.0	2.8 ± 1.4	15.2 ± 5.3	37.5 ± 11.6	44.6 ± 15.7	28.1 ± 9.6
NARBL 53 - 3	84.7 ± 8.7	12.4 ± 8.5	25.6 ± 11.9	30.1 ± 7.2	32.0 ± 14.5	25.8 ± 12.3
Golden Beans Oval	87.3 ± 6.6	21.9 ± 9.0	28.6 ± 10.9	25.0 ± 7.7	24.5 ± 14.8	25.1 ± 3.5
NABE 5	100.0 ± 0.0	2.0 ± 2.0	18.0 ± 13.1	28.0 ± 7.6	52.0 ± 8.1	24.7 ± 5.9
NABE 6	93.3 ± 4.8	21.6 ± 15.8	30.9 ± 15.8	16.0 ± 4.7	31.5 ± 25.5	24.1 ± 11.9
Kaula	94.7 ± 5.3	7.4 ± 4.1	7.6 ± 3.2	51.3 ± 18.1	33.7 ± 23.7	23.1 ± 7.4
NARBL 53 - 1	99.3 ± 0.7	2.7 ± 1.3	18.8 ± 8.7	49.8 ± 9.3	28.8 ± 17.7	22.3 ± 13.3
Kanyewa	95.3 ± 4.7	3.1 ± 3.1	18.1 ± 13.1	26.2 ± 7.1	52.7 ± 20.2	21.9 ± 14.3
Ocuc	90.0 ± 5.0	19.8 ± 18.7	20.6 ± 5.5	48.1 ± 17.4	11.4 ± 5.7	21.9 ± 7.7
NABE 8C	96.7 ± 3.3	1.3 ± 0.7	8.2 ± 1.9	70.5 ± 3.4	19.9 ± 4.2	21.4 ± 9.6
NARBL 60	75.3 ± 13.1	45.5 ± 15.9	24.4 ± 8.8	25.5 ± 8.2	4.6 ± 2.3	19.6 ± 6.7
Dark Greyish Spotted	100.0 ± 0.0	1.3 ± 1.3	24.7 ± 19.0	28.7 ± 18.8	45.3 ± 27.6	17.9 ± 12.5
NARBL 50 - 1	95.3 ± 4.7	4.2 ± 2.3	10.7 ± 1.7	52.4 ± 12.2	32.8 ± 15.6	16.9 ± 1.0
NABE 7C	82.0 ± 3.5	22.7 ± 13.9	38.5 ± 17.3	25.3 ± 4.3	13.5 ± 4.1	16.8 ± 3.1
NABE 14	90.0 ± 5.0	21.2 ± 15.2	39.3 ± 6.4	24.1 ± 4.7	15.4 ± 9.3	15.8 ± 7.5
NABE 10C	95.3 ± 4.7	13.7 ± 11.8	23.8 ± 17.2	53.6 ± 10.7	8.9 ± 6.7	15.1 ± 8.0
Nambale short	100.0 ± 0.0	5.3 ± 3.5	20.7 ± 10.7	24.7 ± 3.7	49.3 ± 14.4	14.4 ± 3.2
NARBL 40-3 (Black 2)	92.0 ± 4.0	6.1 ± 3.0	23.8 ± 1.7	50.5 ± 11.2	19.6 ± 9.9	14.3 ± 2.8
Bam	93.3 ± 6.7	20.2 ± 6.2	36.3 ± 4.1	37.8 ± 7.3	5.7 ± 1.2	14.0 ± 7.6
Gantagazose	100.0 ± 0.0	0.0 ± 0.0	15.3 ± 7.0	56.0 ± 14.1	28.7 ± 15.8	13.4 ± 3.1
Pinkish Stripe Oval	98.0 ± 2.0	8.9 ± 3.5	19.4 ± 8.6	56.9 ± 7.1	14.8 ± 3.4	13.3 ± 5.8
NABE 16	90.0 ± 5.3	23.1 ± 14.1	25.3 ± 13.6	19.3 ± 7.3	32.3 ± 21.1	13.1 ± 7.3
NABE 4	92.7 ± 7.3	7.7 ± 7.7	25.3 ± 15.2	33.0 ± 5.0	34.0 ± 17.8	12.4 ± 6.2
NABE 9C	100.0 ± 0.0	3.3 ± 1.8	21.3 ± 15.4	32.7 ± 20.1	42.7 ± 23.7	11.9 ± 7.3
Small Seeded Cream	86.0 ± 0.0	31.0 ± 12.1	41.1 ± 13.5	8.5 ± 3.4	19.4 ± 19.4	11.7 ± 4.7
Mary Meda	85.3 ± 5.8	26.7 ± 11.9	45.3 ± 14.2	25.2 ± 15.8	2.8 ± 2.8	11.1 ± 4.9
K132	86.7 ± 6.8	13.3 ± 6.8	39.4 ± 15.7	21.6 ± 4.4	25.7 ± 18.2	11.0 ± 8.9
NABE 1	91.3 ± 4.4	7.6 ± 4.0	36.9 ± 12.6	32.6 ± 18.5	22.8 ± 10.8	11.0 ± 1.7
Yellow Long	96.7 ± 3.3	13.2 ± 11.2	29.9 ± 4.1	30.3 ± 10.8	26.7 ± 5.7	11.0 ± 3.2
NARBL 244 (Black 1)	89.3 ± 7.1	19.5 ± 10.7	39.6 ± 19.9	26.8 ± 20.7	14.1 ± 8.0	9.6 ± 7.5
NABE 13	94.0 ± 6.0	15.2 ± 9.2	33.1 ± 15.6	20.4 ± 1.6	31.3 ± 22.9	9.2 ± 6.8
NARBL 220	90.7 ± 1.8	17.1 ± 10.1	37.6 ± 18.3	28.6 ± 20.7	16.7 ± 8.4	6.8 ± 3.1
NABE 12C	90.7 ± 4.8	9.2 ± 5.3	46.1 ± 12.1	27.7 ± 9.1	16.9 ± 8.0	6.1 ± 2.6
Black Big Size	97.3 ± 2.7	12.8 ± 9.1	39.6 ± 10.7	36.1 ± 13.6	11.5 ±3.6	5.8 ± 2.2
NABE 11	90.0 ± 5.0	27.6 ± 17.5	30.0 ± 14.5	36.0 ± 20.4	6.4 ± 5.4	4.4 ± 2.1
LSD (0.05)	7.1	10.4	14.9	16.5	21.7	23.2
F probability	0.027	0.045	0.113	0.012	0.210	0.006

*sorted in descending order by Grain weight loss (%)

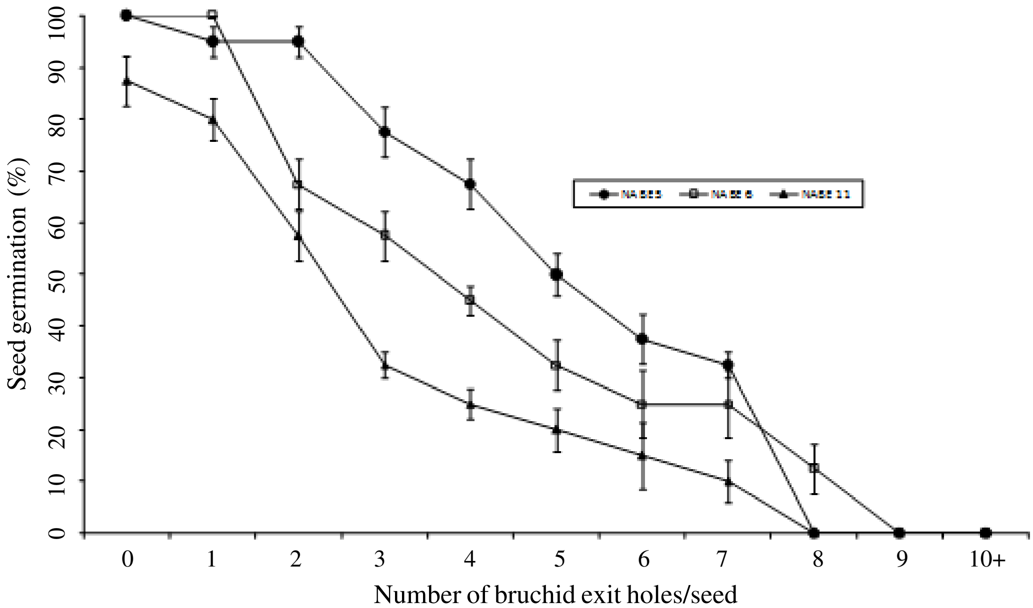

Figure 2. Effect of *Acanthoscelides obtectus* damage on seed germination of three bean varieties differing in seed size: NABE 5 (small), NABE 6 (medium) and NABE 11 (large).

DISCUSSION

The data presented clearly shows that all the 45 dry bean genotypes evaluated supported reproduction, growth and development of *A. obtectus* and *Z. subfasciatus* (Tables 3 and 4), thus providing evidence of susceptibility of all materials to the two-bruchid species. This indicates that the discovery of bruchid resistance in Mexico has not yet been tapped into Uganda's common bean germplasm. However, the genotypes were more susceptible to *Z. subfasciatus* than *A. obtectus,* and supported higher reproduction of *Z. subfasciatus* than *A. obtectus*. The warm temperatures in the laboratory in which the study was conducted (mean daily maximum temperature 27^{O}C and mean daily minmum temperature 17^{O} C) may have favoured *Z. subfasciatus,* which prefers low altitude warmer areas (Schoonhoven and Cardona, 1986; Cardona, 1989; Cardona and Karel, 1990). On the other hand, the higher rate of multiplication of *Z. subfasciatus* than *A. obtectus* may be explained by the differences in preferential mode of bruchid species infestation, and egg oviposition. *Zabrotes subfasciatus* infestation and damage only occurs in the storage, starting from pre-existing insect populations and gluing eggs to the seed (Cardona *et al*., 1989; 1990; Cardona and Kornegay, 1999). This gives it a better adaptation to storage conditions than *A. obtectus,* whose infestation may begin from the standing crop in the field, by females ovipositing eggs on growing pods; while in storage *A. obtectus* scatters eggs among seeds (Shade *et al*., 1987; Acosta *et al*., 1992). Similarly, *Z. subfasciatus* progeny generally took longer (34-44 days) to emerge and develop than *A. obtectus* (27-37 days).

The average developmental period (Tables 3 and 4) was similar to that reported by Dendy and Credland (1991) and Parsons and Credland (2003), but the wide range of development times for both bruchid species would indicate differences in geographically distinct bruchid populations used in the evaluation. This, moreover, highlights that caution should be taken to compare pest status of these two species under the same physical conditions (Credland, 1994), and in making predictions about the responses of the different populations to new bean cultivars for agricultural use. This is so because each species (and biotype) may differ in its ability to infest or attack the same variety under different environmental conditions (Singh and Schwartz, 2011).

Resistance to bruchids in the range of dry bean market class varieties, breeding lines and landraces in Uganda evaluated in this study is inadequate, and limits direct exploitation of this germplasm. This further highlights the limited success of breeding to transfer bruchid resistance to wider germplasms, despite the discovery of resistance in non cultivated bean accessions three decades ago (Schoonhoven *et al*., 1983) and the rarity of natural occurrence of resistance to most of the storage insect pests in cultivated species, and instead suggests continued screening of very large numbers of drybean landraces and/or wild races.

Grain weight loss observed in the current study (Tables 6 and 7) is within range of losses due to bruchids reported in Africa (Karel and Autrique, 1989), and confirms that *Z. subfasciatus* and *A. obtectus* cause large losses in stored beans directly through their consumption of the seed. Additional loss due to bruchid damage is experienced through reduction in seed germination when damaged bean seeds are planted and either rot before germination or germinate into abnormal seedlings. Bruchid effect on bean seed germination is possibly due to damage to the embryo (Baier and Webster, 1992) or loss of food reserves a result of bruchid consumption of cotyledons (Mariga *et al*., 1993).

Although a farmer may plant small-seeded bean varieties with 1 - 2 bruchid emergence holes and experience minimal reduction in germination (Fig. 2), there is a significant reduction in germination of large seeded varieties even with 1 - 2 bruchid emergence holes. However, any bean seed with more than 3 emergence holes is probably not worth planting out or should be planted at a higher seeding rate with the expectation of lower emergence.

CONCLUSION

Evidently, *Z. subfasciatus* and *A. obtectus* are responsible for large post-harvest losses to beans directly through their consumption of the seed and, indirectly through the qualitative deterioration of the beans (and subsequently market value) or the reduced seed viability. Their infestation therefore is a menace to utilisation, storage and sustainability of production of the beans. With the inadequacy of resistance within the existing germplasm in Uganda, and the inherent restrictions to the use of pesticides, alternative integrated pest management options for bruchid control should urgently be sought.

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