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Effect of Harvesting and Threshing Time and Grain Fumigation of Field Peas (*Pisum sativum* L.) on Pea Weevil (*Bruchus pisorum* (L.) (Coleoptera: Bruchidae) Development and Damage

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Abstract

Experiments were conducted in the field and in the laboratory to investigate the effects of harvesting and threshing times and grain fumigation on pea weevil, *Bruchus pisorum* (L.), development, the damages they cause and the associated grain yield on field peas in Ethiopia. Pre-harvest data indicated that significantly more eggs were found on flat and swollen pods than on other stages of the pod. Egg and larval density significantly varied with season. Grain yield was significantly higher on plots harvested early; seasons, fumigation and threshing times did not affect yield. Delay in harvesting caused more infected seeds and seeds with infected black spots. Fumigation and threshing time did not affect the number of infested seeds and seeds with infected black spots. When data were recorded after four months of storage, all factors, i.e., season (year), harvesting and threshing time and fumigation significantly affected the number of adult weevil emergence windows. Therefore, the number of windows was significantly higher in 2004/05 than 2006/07, in non-fumigated seeds compared to fumigated ones, and in late harvested and threshed seeds compared to others. Apart from reducing the physical damage and reduction of seed weight loss of seeds in store, early harvesting, threshing, and fumigation immediately after harvest contributed to the reduction in the inoculum of the beetle in the future. It can; therefore, be concluded that growers should practice early harvesting and threshing and fumigate immediately after threshing to minimize the damage in an infested seed pea crop and also to reduce future inoculums.

Keywords: pea weevil, harvesting and threshing time, fumigation, field peas

1. Introduction

Field pea is one of the so-called highland pulses, also called cool-season food legumes that are widely cultivated in the Amhara Region of Ethiopia. The region accounts for more than 46% of the area and 42% of the total pulse production in the country (Wuletaw and Getachew, 2002). Pulse crops play a vital role in maintaining sustainable agriculture by improving soil fertility, increasing food self sufficiency and by serving as a source of animal feed and cash.

In Africa, field pea is cultivated only in Ethiopia, the Democratic Republic of Congo and Burundi. The Ethiopian highlands still possess the largest reservoir of field pea genetic diversity. Field pea, being one of the most important pulse crops in the cool highlands of Ethiopia, forms an integral part of the daily diet along with other cereals and pulses and makes the major protein source for most rural households in Ethiopia.

The Amhara region of Ethiopia covers more than 47% of the total area allotted for field pea production in the country and 44% of the field pea production (Worku, 2002). In the year 2000, about 100 thousand ha of land was allotted to field pea production from which about 70 thousand tons of grain was produced (CSA, 2000/01). Until recently, the pea aphid (*Acyrthosiphon pisum* L.) (Harris) and

African bollworm (*Heliothis armigera*) (Hübner) were the most common pests of field peas. However, since 1992, field pea was reported to have suffered from a newly emerging pest, the pea weevil (*Bruchus pisorum*) (Worku, 2002). Farmers in one of the districts expressed their concern for the future of field pea in their area; they claimed that the crop was going to be extinct. The pea weevil is spreading to the nearby regions at an alarming rate pushing local landraces towards extinction. Farmers have reported that this pest is the deadliest that they have ever seen on field pea.

The pea weevil is cosmopolitan and it was known all over the world long before it invaded Ethiopia around 20 years ago. It is an important pest of peas in North and South America (Pesho *et al*., 1977), the Indian subcontinent (Basher *et al*., 1991), Australia (Horne and Bailey, 1991), Europe (Girsh *et al*., 1999) and lately Ethiopia (Adane *et al*., 2002; Birhane, 2002; Melaku *et al*., 2002; Worku, 2002).

Economic infestations occur when adult females lay eggs on the surface of developing green pea pods in the field and neonate larvae burrow through the pod walls and eventually into developing seeds where weevil development is completed (Clement, 1992). Infested pea crops can lose up to 20% of their weight from larval feeding, and are prone to shattering when harvested, so that the total yield of a heavily infested crop may be reduced by 5 to 10% (Baker, 1998). In Australia, an infestation level as high as 72% is reported (Horne and Bailey, 1991). In Ethiopia losses can rise as high as 85% (Worku, 2002). Various management options of pea weevil were suggested in different parts of the world (Horne and Bailey, 1991; McDonald, 1995). Resistant pea cultivars would help farmers to reduce losses and provide environmentally safer option than the use of contact insecticides for adult pea weevil management. Screening activities carried out in early 2000s in Ebinat area of Ethiopia revealed some degree of difference among accessions but none of them were immune to the pest (Melaku *et al*., 2002). In other countries, where pea weevils were well-known pests for a long time and where sufficient research has been done on their management, some cultural practices have been suggested to minimize the damages caused by the beetle. It is very important to destroy crop residues and infested seeds should not be planted unless they are fumigated. Careful harvesting prevents shattering, which otherwise allows weevils to disperse throughout fields and harvesting must be done as early as possible, i.e., when the seed moisture level falls to 12% (Baker, 1998). Volunteer plants should be destroyed. Early planting and harvesting is also desirable (Anonymous, 2007).

In Ethiopia, however, because this pest has appeared recently, there is little information on its biology and management. The present study elucidates the effect of harvesting and threshing times of field pea as they apply specifically to the Ethiopian condition and the fumigation of field pea grains in storage on pea weevil development, the damage they cause and grain yield.

2. Materials and Methods

This trial was conducted for two years (2004/05 and 2006/07) in the cool semi-arid area of Wag Hemra zone of the Amhara region, Ethiopia. Years were also termed season for clarity. The study had two components: a field work and a laboratory study.

2.1 Field work

The trial was laid out in a split-plot design with Randomized Complete Block Design, replicated three times. The plot size was 4 m × 5 m. The local field pea seeds that are commonly grown in the area were planted following farmers' practices.

Once pods started forming, the pod development stages were scored until maturity in one of the categories of flat, swollen, filled, green wrinkled and yellow wrinkled, and at the same time they were examined for the presence of eggs laid between successive sampling dates or censuses. The old and the new eggs on one pod between sampling dates were distinguished by the following parameters: the new eggs looked bright orange with no apparent structural differentiation, while the old ones looked dark brown because of the developing head capsule of the larvae.

Ten pea plants were randomly selected from each plot and one pod was randomly chosen from each selected plant and inspected for the presence of eggs and larvae. This was repeated at each developmental stage of the pods, i.e., flat, swollen, filled, green wrinkled and yellow wrinkled stages. The black dots or holes on the pods were counted to represent the number of larvae. The black dots on the pods represent the number of larvae that are hatched and entered the pod. On the other hand, days to flowering, heading and pod setting were recorded. At maturity, harvesting and threshing treatments were done as outlined in the treatments section.

Yield data per plot were recorded immediately after threshing. They were then stored in the laboratory for further follow up. Pea weevils inside seeds continued feeding in storage and reduced the weight of the grains. To determine the loss in grain weight as time advances in store, the grains per plot were weighed again at two and four months after threshing.

Treatments

Treatments were applied beginning from harvesting and threshing. The main plots were the fumigated and non-fumigated (applied on seeds in store after harvest), while the subplots were the interaction effects of harvesting and threshing times. Harvesting times were the number of weeks after maturity (i.e., one, two, three and four weeks). Threshing times were the length of time we waited after harvest to do the threshing (i.e., immediately after harvest, one week , two weeks and three weeks later). The number of main plots was two, replicated thrice made a total of six. The number of sub-plots was 16, which was a factorial combination of 4 harvesting and 4 threshing times, replicated thrice made a total of 48. The overall total number of plots was 96. This was equivalent to 2 plots × 4 harvesting times × 4 threshing times × 3 replications.

2.2. Laboratory study

Every time plants on each plot were harvested and threshed, i.e., according to treatment assignments, the seeds were taken to the laboratory for the fumigation. Half the plots were not fumigated as per the treatment protocol. One phostoxin tablet was applied as a fumigant in seeds contained in gas-proof plastic bags. After seven days of exposure, the container was opened and ventilated.

The following data were recorded at various times in the store by taking a random sample of 100 seeds per plot: number of seeds with windows, number of healthy and infected seeds, seeds with black spot infection, seeds blackened, 100-seed weight and adults that emerged. As pea weevils continued feeding, they invited microorganisms (particularly fungi) to take over and cause infections. The identity of the fungi was not determined.

Statistical analysis

An analysis of variance (ANOVA) was conducted using the general linear model (GLM) procedure (SAS, 1999-2000) to assess effects of harvesting time, threshing time and fumigation on pea weevil development, the damages caused and the grain yield and its components. Least square means were separated using the Student Newman-Keuls (SNK) test at $P = 0.05$. Differences between years and fumigation levels were analyzed using t-test. Other treatments were analyzed using F-test.

Data taken at intervals were analyzed using the repeated measures analysis to determine the differences in egg and larval count among pod setting stages. The weevil damage symptoms that were recorded at various intervals of time and the grain yield associated to each data collection date were also analyzed by the repeated measures procedure. The results of the data that showed significant effect with respect to particular treatment(s) and/ or other sources of variation were presented in tables and discussed. Those that were not significant were explained in the text without tabulation.

3. Results

Plant growth and development

The trial was planted on the 15th of July in 2004/05 and on the 7th of July in 2006/07. It flowered in 46 days; the first pods appeared in about two months after planting. The crop matured in 81-88 days. Harvesting dates varied from 85 to 106 days after planting.

Pre-harvest data (eggs and larvae)

At the yellow wrinkled stage of pods, egg density significantly varied between years ($T_{1,7}$=159.43, P<0.0001). In 2004/05, the density ranged between 2.4 to 5.0, with a mean of 3.6 eggs. In 2006/07, it ranged from 0 to 23 with a mean of 10.1. The density of eggs at the flat stage of pods also significantly varied between years ($T_{1,7}$=551.75, P<0.0001). In 2004/05, the density of eggs at the flat stage of the pods ranged between 0.3 to 8.0, with a mean of 2.1. In 2006/07, it ranged from 10 to 62 with a mean of 34.2 flat eggs. The same situation was observed with the density of eggs on swollen and filled pod stage. In contrast, the density of eggs on the green wrinkled pods did not vary with season ($T_{1,7}$=6.66, P=0.0712).

In 2004/05, the density of eggs on swollen pods ranged between 2.1 and 6.7, with a mean of 3.8. In 2006/07, on swollen pods, the density ranged from 1 to 10 with an average of 5.1 eggs. In 2004/05, eggs on filled pods ranged between 2.3 to 5.3 with a mean of 3.6, while in 2006/07, the density ranged from 1 to 12 with a mean of 6.6. In 2004/05, the eggs on green wrinkled pod stage ranged from 2.1 to 11.1 with a mean of 4.7, while in 2006/07, the range was between 0 and 18.0 and a mean of 5.9.

The repeated measures analysis of egg count at different pod stages showed significant difference among the pod stages (Table 1). Egg count varied from 0 on wrinkled pods to 62 on flat pods, with a mean of 4.4 on swollen pods to 18.1 on flat pods. In 2004/05, larvae were counted at the green and yellow wrinkled stage of the pods, which did vary with respect to any of the treatments. The repeated measures analysis of larval counts at the different pod stages showed no significant difference among the pod stages (Table 1). The number of larvae varied from 1 to 4, with a mean of 2.7.

Table 1. ANOVA table for the repeated measures analyses of egg and larval count at different pod stages.

Variables	Effect	Num DF*	Den DF*	F value	Pr>F
Eggs	Pod stage	4	428	37.75	<0.0001
Larvae	Pod stage	4	47	0.34	0.5621

* Num DF and Den DF stand for degrees of freedom for the numerator and denominator respectively. In the F-test, F stands for the F value and Pr>F stands for the level of significance.

Post-harvest data (grain yield and damage symptoms on seeds in store)

Grain yield

At threshing time, both grain yield and 100-grain weight were significantly affected by harvesting time only (Table 2). Other factors, i.e., years, fumigation, and threshing time did not affect yield. When the grain was weighed two months after harvest, again only harvesting time significantly affected grain yield. The highest yield was recorded for the earliest harvesting time (Table 2). None of the factors significantly affected both grain yield and 100-grain weight four months after harvest.

Table 2. Effect of harvesting time on grain yield and 100 grain weight of field pea in Sekota in 2004/05 and 2006/07.

Harvest time	At threshing time Grain yield (g/plot)*	100 grain weight (g)*	2-month after harvest Grain yield (g/plot)*
H_1	1533.7±31.2a	13.9±0.17a	1500.8a
H_2	1397.6±60.0b	13.3±0.18ab	1376.8b
H_3	1262.6±39.0b	13.1±0.16b	1254.8b
H_4	1334.8±41.5b	13.3±0.17b	1315.6b
F	6.78	3.53	5.66
P	0.0002	0.0160	0.0010

* These data were taken at threshing time; H_1 to H_4 stand for harvesting times; F and P stand for F value and P value; means within a column followed by the same letter are not significantly different at P<0.05 (SNK); H_1, H_2, etc. stand for harvesting dates; data are averages of the two years (2004/05 and 2006/07).

Infected seeds

There was significant interaction between year and harvesting time on infected seeds per 100 seed sample per plot both at threshing time and at 4-month in storage (Table 3). Fumigation and threshing time did not have significant influence on them. In 2004/05, delay in harvesting caused more infected seeds.

Table 3. Effect of harvesting time and season on the number of infected seeds of field pea in Sekota in 2004/05 and 2006/07.

Harvest time	At threshing				4-month after threshing			
	2004/05	2006/07	*T*	*P*	2004/05	2006/07	*T*	*P*
H_1	37.9bA	27.8aB	7.06	<0.0001	36.4bA	27.5aB	4.76	<0.0001
H_2	42.0abA	28.6aB	9.43	<0.0001	39.3bA	28.3aB	7.82	<0.0001
H_3	41.7abA	28.8aB	7.83	<0.0001	43.7aA	28.5aB	9.34	<0.0001
H_4	44.2aA	29.0aB	7.64	<0.0001	43.5aA	28.7aB	13.50	<0.0001
F	3.35	0.39			7.33	0.41		
P	0.0224	0.7630			0.0002	0.7463		

F and P of the F-test stand for F value and P value (or the significance level of the test); T and P of the t-test stand for T value and P value; the t-test compares the two years for each harvesting treatment; for each of the threshing time and 4-month after threshing, means within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at P<0.05 (SNK); H_1, H_2, etc. stand for harvesting dates.

Infected black spots on seeds

The number of infected black spots on seeds significantly varied between harvesting times in 2004/05 but not in 2006/07 (Table 4). The numbers were also significantly higher in 2004/05 than in 2006/07. Fumigation and threshing did not influence the number of infected black spots. In 2004/05, delay in harvesting increased seed numbers with infected black spots.

Table 4. Effect of harvesting time and season on the number of black spots infested seeds of field pea in Sekota in 2004/05 and 2006/07.

Harvest	At threshing				At 4-month after threshing			
	2004/05	2006/07	*T*	*P*	2004/05	2006/07	*T*	*P*
H_1	37.4bA	28.8aB	6.84	<0.0001	36.2bA	27.6aB	4.43	<0.0001
H_2	41.3abA	28.8aB	8.68	<0.0001	38.3abA	28.5aB	7.02	<0.0001
H_3	40.6abA	28.9aB	7.42	<0.0001	41.7aA	28.5aB	8.27	<0.0001
H_4	42.9aA	29.0aB	6.83	<0.0001	40.6aA	28.7aB	11.14	<0.0001
F	2.62	0.50			3.55	0.36		
P	0.0557	0.6850			0.0175	0.7828		

For each of the threshing time and 4-month after threshing, means within rows followed by the same upper case letter and within a column followed by the same lower case letter are not significantly different at P<0.05 (SNK); H_1, H_2, etc. stand for harvesting dates; F and P of the F-test stand for F value and P value (or the significance level of the test); T and P of the t-test stand for T value and P value; the t-test compares the two years for each harvesting treatment.

Number of windows

All factors, i.e., season or year, harvesting and threshing time, significantly affected the number of windows on seeds except fumigation (Table 5). All other combinations were not significant. Delay in harvesting time significantly increased the number of windows in both years. Number of windows was significantly higher in 2006/07 than in 2004/05 on the earliest harvested grains. There was no significant difference on late harvested ones (Table 5) .

Table 5. Effect of harvesting time and season on the number of weevil emergence windows on field pea in Sekota in 2004/05 and 2006/07.

	At threshing			
Harvest time	2004/05	2006/07	*T*	*P*
H_1	0.58bB	1.4bA	-2.5	0.0161
H_2	1.00bB	1.8bA	-3.2	0.0025
H_3	1.54bA	2.0bA	-1.2	0.2444
H_4	3.17aA	2.8aA	0.73	0.4666
F	15.47	4.62		
P	<0.0001	0.0047		

Means within rows followed by the same upper case letter and means within a column followed by the same lower case letter are not significantly different at P<0.05; H_1, H_2, etc. stand for harvesting dates; F and P of the F-test stand for F value and P value (or the significance level of the test); T and P of the t-test stand for T value and P value; the t-test compares the two years (2004/04 and 2006/07) for each harvesting treatment.

Four months later, fumigation also had contributed significantly to the number of windows; all factors significantly contributed to the number of windows and the interaction among the factors was highly significant (Tables 6 and 7).

The number of windows significantly increased with delay in harvesting (Tables 6 and 7). Non-fumigated grains had significantly more windows than the fumigated ones (Table 6). The interaction between harvesting and threshing time was more apparent on the two earliest harvested treatments than those harvested later (Table 7). On these early harvested seeds, late threshing, i.e., three weeks after harvest, resulted in significantly more windows than other threshing treatments (Table 7). This was true for early, i.e., first and second harvested plots. Late harvested ones, i.e., third and fourth, did not show significant difference (Table 7).

Effect of sampling date as time factor on weevil damage symptoms on seeds and grain yield

By analyzing damage caused by weevils across sampling dates, the repeated measures analyses showed that fumigation, harvesting time, threshing time, and data collection date consistently and significantly affected the number of adult emergence windows but not other damage symptoms and the associated grain yield (Table 8). Harvesting time also appeared to significantly affect the number of infected seeds, seeds with black spots infection (Table 8).

Table 6. Effect of season, harvesting time and fumigation on the number of weevil emergence windows on field pea in Sekota in 2004/05 and 2006/07.

	Fumigated	Non-fumigated	*T*	*P*
		2004/05		
H_1	0.3cB	3.1dA	-2.076	0.0498
H_2	2.5bB	6.8cA	-3.223	0.0039
H_3	4.3aB	12.8bA	-7.440	<0.0001
H_4	5.6aB	16.3aA	-9.541	<0.0001
F	17.54	28.53		
P	<0.0001	<0.0001		
		2006/07		
H_1	1.5bA	3.3dA	-1.817	0.0768
H_2	1.8bB	5.8cA	-4.042	0.0005
H_3	2.7bB	8.4b A	-5.759	<0.0001
H_4	5.6aB	13.7aA	-8.493	<0.0001
F	13.78	29.18		
P	<0.0001	<0.0001		

For each year, means within rows followed by the same upper case letter and means within a column followed by the same lower case letter are not significantly different at $P<0.05$ (SNK); H_1, H_2, etc. stand for harvesting dates; F and P of the F-test stand for F value and P value (or the significance level of the test); T and P of the t-test stand for T value and P value; the t-test compares the two years for each harvesting treatment.

Table 7. Effect of season, harvesting time and threshing time on the number of weevil emergence windows on field pea in Sekota in 2004/05 and 2006/07.

	TT0W	TT1W	TT2W	TT3W	*F*	*P*
			2004/05			
H_1	0.0bB	0.3bB	1.0bB	5.5bA	4.96	0.0098
H_2	0.8bB	4.5abAB	5.2abAB	8.2ab A	5.79	0.0051
H_3	7.2aA	7.0aA	7.7aA	12.3abA	1.63	0.2150
H_4	9.0aA	9.2aA	11.0aA	14.7aA	1.13	0.3607
F	10.50	4.59	6.46	3.26		
P	0.0002	0.0133	0.0031	0.0431		
			2006/07			
H_1	0.7bB	0.8bB	2.5bB	5.5bA	13.35	<0.0001
H_2	1.2bB	3.5abAB	4.0bAB	6.5bA	4.42	0.0153
H_3	2.8bA	5.8aA	6.7abA	6.8bA	1.55	0.2335
H_4	8.2aA	7.8aA	10.0aA	12.5aA	1.28	0.3081
F	13.89	5.26	5.45	3.71		
P	<0.0001	0.0077	0.0067	0.0285		

NB: TT0W stands for threshing conducted immediately after harvest, TT1W stands for threshing conducted one week after harvest, TT2W two weeks after harvest and TT3W three weeks after harvest; H_1 to H_4 stand for harvesting times; for each year, means within rows followed by the same upper case letter and means within a column followed by the same lower case letter are not significantly different at $P<0.05$ (SNK); F and P of the F-test stand for F value and P value (or the significance level of the test).

Table 8. ANOVA tables for the repeated measures analyses of different weevil damage symptoms and grain yield data taken at various times across the season.

Damage symptoms and grain yield	Effect	Num DF	Den DF	F value	Pr>F
Number of infected seeds per 100 seeds	Year	1	333	526.9	<.0001
	Fumigation	1	333	0.2	0.6585
	Harvesting time	3	41	6.4	0.0012
	Threshing time	3	41	0.7	0.5904
	Data collection date	2	333	0.9	0.3522
Black spots infected	Year	1	333	443.1	<.0001
	Fumigation	1	333	3.1	0.0773
	Harvesting time	3	41	3.9	0.0150
	Threshing time	3	41	0.7	0.5341
	Data collection date	1	333	2.4	0.1243
Number of weevil emergence windows	Year	1	333	1.6	0.2068
	Fumigation	1	333	99.5	<0.0001
	Harvesting time	3	41	185.5	<0.0001
	Threshing time	3	41	101.2	<0.0001
	Data collection date	1	333	204. 8	<0.0001
Grain yield	Year	1	523	3.3	0.0714
	Fumigation	1	523	0.5	0.4918
	Harvesting time	3	41	1.3	0.2801
	Threshing time	3	41	0.1	0.9835
	Data collection date	2	523	0.3	0.7383
100 grain weight	Year	1	333	3.4	0.0672
	Fumigation	1	333	0.1	0.6165
	Harvesting time	3	41	1.8	0.1688
	Threshing time	3	41	0.1	0.7095
	Data collection date	1	333	0. 8	0.5211

* Num DF and Den DF stand for degrees of freedom for the numerator and denominator respectively. In the F-test, F stands for the F value and Pr>F stands for the level of significance.

4. Discussion

This study was intended to determine if the particular treatments we applied could contribute for the reduction of the weevil inoculum and subsequent damage on an already harvested grain in the store. If properly practiced, such cultural control methods were believed to gradually decrease the carryover of the pest. All the treatments were designed to be applied starting from maturity of the crop in order to determine if this activity would reduce the subsequent development of the weevil already inside the grain at the prevailing conditions of the present area. We wanted to prove whether or not proper harvesting, threshing and fumigation practices would bring significant effect on weevil survival in this particular study area. The treatments were not meant to prevent infesting adult weevils and their oviposition on young developing pea pods. Egg density was significantly higher on flat and swollen pods. This corroborates the reports by Hardie and Clement (2001). In a field and laboratory experiment, Hardie and Clement

(2001) reported that flat and swollen *P. sativum* pods longer than 10-20 mm provide optimal or near optimal oviposition substrates. They used this technique successfully to screen pea accessions for resistance to the weevil. The female lays eggs on developing pods of any size; eggs are first laid on young pods at about the time the flowers begin to wither (McDonald, 1995).

The results also indicated that the earlier the harvesting time, the more the grain yield at threshing time and also two months after harvest. Early harvesting is one of the mechanisms to reduce future carryover. The application of these current treatments, i.e., the manipulation of time of harvesting and threshing and the practice of fumigation can contribute more for the reduction of the future inoculum than make direct impact on this particular trial. This is because the treatments are meant to reduce carryover but not prevent infestation of plants on this particular trial.

However, these particular treatments can contribute for the reduction of weevil attack of an already infested grain in the store. This was the objective it was meant to meet. While *Callosobruchus* spp. can re-infest dry legumes in storage, *Bruchus pisorum* is generally reported not to be able to attack dry pulses but it has the ability to successfully over-winter and leave the storage in order to infest the new crop in the field. This needs to be clarified from literature data and additional field studies. The development of *B. pisorum* starts only at the young pod stage; fresh attacks are never reported on harvested grains in the field or in the store (Baker, 1998). However, feeding continues even in store once the seed carries the weevil inside it. So, if practiced widely in the hot spot area of the pest, the weevil can gradually be reduced to a minor pest. Control of the pest and its damage on existing crop in the field can only be achieved by preventing adults from egg laying on young pods (McDonald, 1995). The treatment in the current experiment can; thus, contribute for the future weevil reduction as well as reducing the damage on seeds containing the weevil inside.

McDonald (1995) reported that when peas were harvested early, only 26% of the maximum possible damage, i.e., seed weight loss, occurred. The remainder of the weight loss occurred around or after harvest because pea weevil larvae continued feeding for two more months in store. Hence, about 74% of the seed weight loss could be prevented by early harvest and fumigation of the crop immediately following harvest, which in effect arrests the further development of the weevil to adulthood (McDonald, 1995). This may mean fumigating the invisible pest because feeding larvae are hard to see even when peas are cracked open. The sooner the fumigation is done, the more possible it is to minimize the loss. This was clearly shown in this study where the yield significantly increased when harvesting was done one week after maturity than doing it two, three or four weeks after. The longer the delay between harvest and fumigation, the better the chance to see developed weevils when peas are cracked open, but by then the insect has caused the maximum damage possible.

Most beetles emerge through exit holes in spring leaving behind a hollowed-out pea. Some may not emerge from the seed until the seed is disturbed. If harvesting has been delayed, the beetles may fly out of the crop and take shelter so that they will overwinter until the next cropping. Even if there are no beetles in the seed, they leave clean holes behind.

Shattering can be kept to a minimum by harvesting the crop as soon as it is ripe (McDonald, 1995). Sheep can be used to clean up crop residues immediately following harvest. Sheep eat infested peas and larvae and the remainder of the beetles becomes exposed to sunlight. Heavy grazing also reduces the likelihood of volunteer peas surviving as hosts for weevils in subsequent years (McDonald, 1995). Thus, timely harvesting and threshing are indispensable.

In the current experiment, fumigation significantly reduced the number of weevil emergence windows. However, the most advisable way to control pea weevil is spraying insecticides against the adults before they manage to lay eggs on developing pods (McDonald, 1995). This mechanism can be made effective if pea plants are sprayed when beetles first fly to the crop in the field. If this is not done and the seed appears to be infested, fumigation, early harvest and threshing are the last lines of defense.

In field trials in Australia, a single spray of cypermethrin applied to plots in a field pea crop at the rate of 40 g a.i./ha and endosulfan at the rate of 350 g a.i/ha reduced damage by pea weevil from 11% in the unsprayed plot to 4%; peas sprayed with methomyl (340 g a.i./ha) or fenvalerate (40 g a.i./ha) suffered 6% and 8% damage, respectively (Horne and Bailey, 1991). By conducting further bioassays in the laboratory and by extrapolation, they concluded that cypermethrin was the most effective as a knock-down effect pesticide against pea weevils (Horne and Bailey, 1991). This is a future research agenda in the present study area.

Because the current study has revealed that early harvesting and threshing and fumigation reduced the damage caused by pea weevils on already infested crop, mobilization of the affected community simultaneously will significantly reduce subsequent infestation in the area. If the fumigation and the cultural practices such as optimal harvesting and threshing are done in hotspot areas (districts) for a couple of years (in sort of a campaign), pea weevils will gradually disappear.

In conclusion, growers should practice integrated management practices including cultural practices such as early harvesting and threshing and also early fumigation to reduce damage on already infested and harvested grain and future inoculum. An additional option can be trying to stop egg laying on the developing pods by preventing adults from approaching pea fields for egg laying. This may be done by spraying effective insecticides targeted against adult weevils-an issue that can be taken as further research agenda.

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