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BIOLOGY AND DAMAGE ASSESSMENTS OF *LYGUS* SPP. INFESTING OILSEED *BRASSICAS* GROWN IN ALBERTA

A Thesis
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by

Richard A. Butts

In Partial Fulfilment of the
Requirements for the Degree
of
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RICHARD A. BUTTS

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In western Canada, lygus bugs are often present in oilseed *Brassica* crops, collectively referred to as oilseed rape. Studies were conducted to determine whether or not oilseed rape is an acceptable host for lygus bug and to assess the impact of lygus bug feeding on the oilseed rape plant.

Lygus bugs were sampled from 1982 to 1986 in fields of oilseed rape, *Brassica campestris* L., and *B. napus* L., and alfalfa, *Medicago sativa* L., in Alberta. Of the three species collected, *Lygus elisus* Van Duzee was the most abundant in rape in four of the years, and *L. lineolaris* (Palisot de Beauvois) was the most abundant in the fifth year. *L. borealis* (Kelton) was the most abundant in alfalfa. All three species reproduced and reached maturity in rape and alfalfa.

Lygus adults were first collected in rape when it reached the bud stage. Populations reached a peak in August when rape was in the early pod stage. A single generation of lygus bugs was completed in the three crop species. Seeding date influenced the abundance of lygus bugs in rape such that the highest densities were found in the crops which reached the bud stage earliest. Lygus bugs are potentially serious pests of oilseed rape because their phenology assures that the later-instar nymphs and adults are present in the crop when seeds are developing.

Lygus bugs were monitored in field plots of five cultivars of oilseed rape, B. napus and B. campestris, containing low or high levels of glucosinolates. At the early pod stage, the number of lygus bugs collected did not differ among cultivars of the same species. Nymphs reared on the five cultivars had the same survival and developmental rate regardless of the glucosinolate status of the cultivar. Survival, development, and growth were compared for nymphs reared in the laboratory on excised leaves of rape and alfalfa. Nymphs developed faster and had higher survival when reared on rape than when reared on alfalfa. However, the dry weights of adults collected from an alfalfa field were significantly higher than those reared on alfalfa in the laboratory indicating excised alfalfa may not be as good a source of food for laboratory tests as excised rape. The results demonstrate that oilseed Brassica crops with high or low levels of glucosinolates are both suitable hosts for the three species of lygus bugs.

Lygus bug injury to oilseed rape, B. napus and B. campestris was assessed both in plots and commercial fields from 1984 to 1986. The symptoms of injury by lygus bugs in oilseed rape were similar to those described in other crops. Reproductive organs which have been injured by lygus bugs may turn brown, shrivel up, and abscise. This type of injury is termed "blasting". Lygus bug injury resulted in significant increases in the number of "blasted" buds, flowers, and seeds. Bud loss was compensated for by the production of more pods in 1984 and 1985. However, in 1984, the pods on injured plants were significantly lighter in weight, resulting in a decline in seed production with increased injury. Compensation for flower loss also occurred, but seed production declined as injury increased in both years. Compensation for seed injury did not occur in either year. The results indicate that lygus bug injury does occur in oilseed rape and has the potential to result in economic losses in this crop.

The impact of lygus bug injury in oilseed rape was assessed in plots and commercial fields of *B. napus* L. and *B. campestris* L. When lygus bugs were controlled at the early pod stage of oilseed rape, yield increased by 11-35%. Lygus bug densities reached 52 lygus bugs per 10 sweeps at the early pod stage in 1985. Neither insecticide applications at bud stage nor flowering resulted in increased yields. The percentage of seeds injured increased, and the yield decreased, as lygus bug density increased. Also, yield declined as the percentage of seed injured by lygus bug increased. These relationships followed the same trends in a number of experiments conducted over two years, but many of the slopes defining the trends were not statistically significant and the predictive variables accounted for relatively small proportions of the variation. However, the relationships between lygus bug density, percentage of seed injured by lygus bug, and oilseed rape yield support the conclusion that lygus bug can cause agronomically important losses of oilseed rape under field conditions in Alberta.

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1 INTRODUCTION

1.1 The Problem

Many species of the genus Lygus (Heteroptera: Miridae), are economically important agricultural pests in a variety of crops (Tingey and Pillemer 1977). They injure their hosts directly by feeding on them (Strong 1970) and indirectly by inducing responses which are detrimental to plant growth (Hori 1976). Lygus bugs are polyphagous but show a distinct preference for the reproductive parts of their host plants (Strong 1970). Most of the injury due to lygus bug feeding occurs to the buds, flowers, and seeds of infested plants.

In western Canada, lygus bugs are often present in oilseed Brassica crops, collectively referred to as oilseed rape. The amount of oilseed rape grown in western Canada varies yearly, but in general, it is the third most abundant field crop after barley and wheat (Alberta Agriculture 1988). The pest status of lygus bugs in oilseed rape is unknown. There are no published reports of lygus bug infesting or injuring oilseed rape in Canada and very few reports of infestations in these crops from other parts of the world (Hori and Hanada 1970). Thus, there is no reliable information on which to base decisions regarding control of lygus bug in rape.

The species composition and seasonal occurrence of lygus bug in oilseed rape has not been documented in North America. In Japan, one species of lygus bug is known to complete a single generation on wild crucifers after it completes a generation in adjacent clover fields (Hori and Hanada 1970). However, in the short season available in western Canada, it is not known whether lygus bug can successfully complete a generation in commercial oilseed rape crops.

The common cultivars of oilseed rape produce seed with low levels of glucosinolates and erucic acid, and are known as Canola. The transformation to low glucosinolate cultivars occurred in the late 1970's. Glucosinolates are important to insect herbivores because they are believed to be feeding deterrents for generalists and attractants for crucifer specialists (Feeny 1977). Glucosinolates have been identified as feeding deterrents for one species of lygus bug (Hatfield *et al*. 1982). The impact of the reduced level of glucosinolates in Canola on the abundance of lygus bug in the crop has not been investigated.

Many insect pests attack Canola crops (Lamb 1989). However, Canola is often able to compensate for insect injury (Williams and Free 1979). In western Canada, the flea beetle, *Phyllotreta* spp. and the Bertha armyworm, *Mamestra configurata* Wlk. are the two major pests which commonly necessitate control in this crop (Lamb and Turnock 1982, Bracken 1987). Lygus bugs have been noted in Canola grown in Alberta (M. Dolinski, Alberta Agriculture, pers. comm.). However, the symptoms of injury caused by lygus bugs infesting Canola have not been described.

1.2 Objectives

The overall objective of the research described in this thesis was to determine the pest status of lygus bugs in Canola. The study was conducted with the following specific objectives:

1. To describe the species composition of lygus bugs in Canola, and the changes in lygus bug densities in relation to crop phenology.
2. To evaluate the impact of the glucosinolate status of the crop on the ability of lygus bugs to exploit oilseed rape as a host.

3. To describe and assess the types of injury caused to oilseed rape plants by lygus bug feeding.
4. To determine the impact of injury by lygus bug, especially as regards yield reductions in Canola.

Knowledge of the species composition and seasonal abundance of lygus bug in relation to crop phenology is a basic prerequisite for understanding the impact of lygus bug on the crop and for planning control programs if control is necessary. Knowledge of the suitability of various cultivars as hosts may help us understand when lygus bug began exploiting oilseed rape as a host and whether cultivars might be chosen that are less suitable as hosts. Identification of injury will aid in the separation of lygus bug injury from injury due to other causes. Knowledge of the types and timing of the injury and its consequences for seed production will aid in deciding whether control is necessary and on the timing of control measures. Finally, knowledge concerning the impact of lygus bug feeding on the yield of oilseed rape is essential for deciding whether control of lygus bug is necessary, and for developing economic thresholds in the future.

1.3 Thesis Organization

The thesis is divided into four major sections: Introduction, Literature Review, Research, and General Discussion. The Literature Review introduces background information on the feeding biology of lygus bugs and the responses of oilseed rape to insect injury. The Research section describes the new research that was conducted on lygus bugs in oilseed rape for this thesis. This section is organized around the four specific objectives listed above. Each of these is addressed in a separate section written in the style of a scientific paper. The General Discussion relates the important observations and conclusions from the four research papers and provides general conclusions on the pest status of lygus bugs in oilseed rape.

2. LITERATURE REVIEW

2.1 Lygus Bug Classification, Distribution, and Economic Importance

The genus *Lygus* Hahn was first described in 1833 and for many years included a diverse group of species under several subgenera (Kelton 1975). After many revisions, the genus is now said to contain 43 known species worldwide, of which 34 occur in North America, 7 in Europe, and 2 in Asia (Kelton 1975). Twenty-two species have been collected on the Canadian Prairies (Kelton 1980). The *Lygus* genus contains many economically important species collectively referred to as "lygus bugs" or "lygus" in the scientific literature.

Lygus bugs are distributed throughout North America on a wide variety of host plants. *Lygus hesperus* (Knight) is reported on more than 100 plant species in 24 families (Scott 1977). *L. lineolaris* (Palisot de Beauvois) is reported on 328 host plant species (Young 1986). *L. elisus* (Van Duzee) and *L. desertinus* (Knight) are found on many weed species (Fye 1980, 1982b)

Several lygus bug species are recognized as pests of cultivated crops, usually injuring seeds or fruit (Kelton 1975). In western Canada lygus bugs are serious pests of alfalfa, *Medicago sativa* L., grown for seed (Craig 1983). Lygus bugs accounted for a 45% loss of apples on unsprayed trees, in Quebec, in 1979. Over a three year study a minimum of 20% of the apples were deemed unmarketable (Boivin and Stewart 1982). Lentils are downgraded if lygus bug injury is found on more than 3% of the seed (Summerfield *et al*., 1982). Lygus bug can be a serious pest of many different crops. Therefore, the factors that allow lygus bug to utilize such a variety of hosts are important.

2.2 Host Plant Interaction

2.2.1 Feeding Biology

Nutritional requirements strongly influence periods of activity, numbers, and distribution of lygus bugs in the field. Lygus bugs require a reliable source of water to maintain their water balance (Cohen 1982). Daily water loss is equivalent of 50 to 100% of their body weight. When observed for 15 minutes per day for 20 days *L. hesperus* spent more time actively feeding than in non-locomotion, locomotion, tapping or probing plants (Hatfield *et al*. 1983). On rare occasions, lygus bugs have been seen phloem feeding, presumably to obtain water rather than food (Miles 1972). Lygus bugs are active at times at which humidity is normally high and rest in locations where water loss is reduced. *Lygus* spp. collected in alfalfa and safflower have peak periods of flight activity at 5 a.m. and 8 p.m. (Butler 1972, Mueller and Stern 1973). *L. hesperus* remains on average five to seven nodes down from the terminal part of the cotton plant. Seventy-five percent of those resting on leaves remain on the bottom surface (Wilson *et al*. 1984). At this location, temperatures are approximately 2°C less than air temperatures (Fye and Bonham 1971) and wind speed is reduced by two-thirds (Edwards and Wratten 1980); these contribute to a lower rate of evaporation.

The quantity of food present also influences lygus bug distribution in the field. Lygus bug numbers are positively correlated with plant density (Leigh *et al*. 1974) and negatively correlated with plant size (Fye 1982a). Lygus bug distribution within the plant canopy is correlated with the distribution of fruiting structures (Wilson *et al*.

1984). In cotton, 85% of the green bolls and 97% of the squares are located in the top two feet of the crop canopy. When cotton is in the green boll and square stages, 70-100% of all insect species are located in the top two feet of the canopy (Fye 1972).

Lygus bugs feed preferentially on meristematic tissue of actively growing plants, i.e., growing tips, buds, flowers, and seeds (Strong 1970, Hori 1971b). These areas are high in chloride ions, nitrate ions and glutamine (Hori 1974a). Upon ingestion, these products are transferred to the gut in sufficient amounts to activate the gut amylases (Hori 1971c). As a result the amylase, which is normally active under acidic conditions, is also strongly activated on the alkaline side of the optimum pH (Hori 1969). This promotes the digestion of higher molecular weight polysaccharides, which are otherwise difficult to utilize (Hori 1971a). As a result, the insects are able to digest low and high molecular weight polysaccharides (sugar and starch) to an equal degree (Hori 1974a) and therefore, may be able to utilize starches as well as sugars for their carbohydrate source in nature.

Because lygus bugs show a preference for feeding on meristematic tissue (Strong 1968), their behavior is closely linked with the growth stage of the host. To feed continually on the fruiting stages they must do one of three things: 1) feed on a host that continually flowers (Scott 1983), 2) utilize a series of hosts (Cleveland 1982), or 3) feed on a host that will produce more fruit if injured (Strong 1968).

Carrots flower indeterminately and so provide food for <u>L. hesperus</u> all season long (Scott 1983). Alfalfa is also a long season crop which maintains lygus bug populations throughout the growing season while other crops grown in the same area do not (Khattat and Stewart 1980).

Many Lygus species utilize a series of hosts during the season (Khattat and Stewart 1980; Cleveland 1982; Fye 1980). They are first found on each of the crops during the bud and bloom stage (Khattat and Stewart 1980). Egg laying occurs on most of the hosts visited, however, nymphal survival is not always high (Cleveland 1982). Nevertheless, nymphal survival is high enough overall that substantial overwintering populations result (Fye 1980).

Alfalfa is one of the preferred hosts of several species of lygus bugs (Cave and Gutierrez 1983; Khattat and Stewart 1980). Alfalfa compensates for bud loss by producing more buds (Strong 1968). In one experiment, three groups of 10 stems were maintained with 10, 20, and 30 seed pods per stem. All of the buds were removed from each stem. In 5 weeks, the stems with 10 pods produced 17.8 buds/stem, those with 20 pods yielded 8.1 buds and those with 30 pods yielded 6.1 buds. This response has been demonstrated in other crops. Cotton, confined with lygus bugs, continues to form buds for as long as the buds are injured. However, if the lygus bugs are removed several fruits develop and bud production declines (McKinlay and Geering 1957). By feeding on hosts that are able to compensate for injury, lygus bugs have a food supply that is renewable and available for extended periods of time.

2.2.2 HOST SELECTION

Patterns of host attraction and acceptance for *L. lineolaris* (Hatfield *et al*. 1983) follow the same general pattern as all phytophagous insects (Miles 1972). Initial orientation is achieved through visual and olfactory stimuli (Prokopy *et al*. 1979, Ave *et al*. 1978). Adults of the species *L. lineolaris* make significantly more visits to rectangles painted certain colors (e.g., white, yellow) than to those painted other colors (e.g. black, red, green, blue, and orange). However, clear plexiglass rectangles captured as many adults as rectangles approximating the same spectral reflectance patterns as part of their host plant, i.e., apple buds, blossoms foliage, or bark (Prokopy *et al*. 1979). This is true even when the tested colors are applied to surfaces approximating the size of the plant parts normally visited by the adults (Prokopy and Owens 1978). Therefore, although visual stimuli may play a role in the responses of lygus bug adults visiting a host plant, the precise nature of this role is yet to be determined.

Olfactory cues may also be important. Removal of the rostral tip sensilla or antennae of adults abolishes a feeding preference for frego bract over normal cotton squares (Ave *et al*. 1978). This demonstrates that hosts may be recognized, at least from a short distance, through olfactory cues from chemosensilla present on the rostrum and antennae.

Once *L. lineolaris* arrives on a plant, locomotion occurs, with simultaneous rostral and antennal tapping. Both chemosensillae and mechanosensillae (Ave *et al*. 1978) on the rostrum provide sensory input at this point.

When locomotion ceases and stylet probing begins, salivation and reingestion of salivated material occurs (Miles 1972). The lygus bug tests the food source using epipharnygeal chemosensillae and allows for modification of ingestion by stimulants and deterrents (Hatfield *et al*. 1982). Sugar stimulates feeding by *L. lineolaris*. The degree of stimulation depends on the type of sugar present (Hatfield *et al*. 1982). Certain tannins, quinones, phenolics, glucosides and alkaloids deter feeding (Hatfield *et al*. 1982). Cotton tannin is one of the most effective feeding deterrents. Leucine, an amino acid, also deters feeding. Gossypol is a feeding deterrent which is present in epidermal pigment glands of plants of the genus *Gossypium* (Eagle *et al*. 1948). Cotton plants which are devoid of these glands are more susceptible to lygus bugs than glandular cotton with glands (Tingey *et al*. 1975).

Factors which influence termination of feeding have not been determined. Sensory adaption, central programming, or input from gut stretch receptors may be involved (Hatfield *et al*. 1983). Before feeding is terminated, severe injury to the plant host may be induced by both mechanical destruction of plant tissue and physiological reactions of the plant.

2.3 Feeding and injury

2.3.1 Feeding Mechanisms

The mouthparts of lygus bugs are of the piercing-sucking type. They form a slender segmented beak that arises from the front part of the head and extends back along the ventral side of the body sometimes as far as the base of the hind legs. The segmented portion of the beak is the labium which serves as a sheath for the four piercing stylet bristles (two mandibles and two maxillae). The maxillae fit together in the beak to form two channels, a food channel and a salivary channel. The labrum is a short lobe at the base of the beak on the anterior side (Borror _et al_. 1976).

Lygus bugs feed using a lacerate and flush method without secretion of a stylet sheath (Miles 1972). A small amount of saliva is extruded from the rostrum to the feeding site. This deposition is repeated several times and occasionally the bug will suck the juice up presumably "tasting" the host (Miles 1972). Assuming the "taste" is satisfactory the stylet is inserted, withdrawn partially and reinserted several times. During the penetration and withdrawal process copious amounts of fluid emerge from the stylet. This saliva contains several substances which aid in the feeding process (Miles 1972). Once the laceration is completed the fluid is ingested. Laceration, salivary secretion and ingestion can take up to 10 minutes for _L. hesperus_. The obliterated area is conical and has a maximum width of about 1 mm (Strong 1970).

In the process of ingesting the saliva, considerable amounts of liquified plant material are also ingested. _L. disponsi_ Linnavuori withdraws an average of 82.5 mg plant juice per bug over five instar stages, while the adult withdraws 7 - 13 mg of plant juice/day (Hori 1971a). _L. hesperus_ can ingest the liquified contents of an alfalfa bud in only 23 seconds (Strong 1970).

The composition of the saliva has been investigated by a number of researchers (Miles 1967, Strong and Kruitwagen 1968, Hori 1974b, 1975). Polygalacturonase (pectinase) solubolizes the middle lamella (layer between cells) of plants, thus aiding penetration and maceration of the plant tissue. Other enzymatic components of saliva such as amylases and proteases appear to aid external digestion of insoluble organic nutrients (Tingey and Pillemer 1977). Some non-enzymatic components may originate in the food source after transport from the gut to the salivary glands following ingestion. For example, dietary amino acids have been detected in the saliva of many mirids (Nuorteva and Laurema 1961, Miles and Lloyd 1967).

A growth promoting factor can be isolated from the salivary gland of *L. disponsi* (Hori 1974b). This factor inhibits indole-3-acetic acid (IAA) activity to promote IAA activity. Therefore, if it is injected into the feeding site it will result in symptoms similar to those of IAA itself (Hori 1976). IAA may be synthesized in the salivary glands of some Heteroptera (Miles and Lloyd 1967). However, there is no evidence of IAA in the salivary glands of *L. rugulipennis* Popp., *L. hesperus* or *L. disponsi* (Nuorteva 1956, Strong 1970, Hori 1974b). An injection of 0.5% IAA into the food source inhibits feeding by *L. disponsi* whereas an injection of 0.1 to 0.05% stimulates feeding (Hori 1980). If IAA is ingested by *L. disponsi*, it is converted to a substance with a high molecular weight and then is excreted since it can be toxic to the insects if it enters the haemolymph (Hori 1979).

2.3.2 Description of Injury by Lygus

Injury by lygus bugs can be categorized into five generalized types (Tingey and Pillemer 1977): localized wilting and tissue necrosis; morphological deformation of fruit and seed; abscission of fruiting forms; altered vegetative growth; and tissue malformation. Symptoms of each category of injury are found in a wide variety of crops (Table 1). Tissue necrosis often occurs in the immediate vicinity of the wound. This type of injury rarely influences plant growth unless it is extreme. When young leaves of cotton are injured, large holes may become evident as the leaves mature, termed "leaf ragging" (Taylor 1945). This may influence the production of fruiting structures through the reduction of photosynthates.

Morphological deformities of fruit and seed have also been documented for several plants. "Catfacing" is a term used to describe the deformed growth that results when the area around a feeding puncture in large fruit stops growing and the rest of the fruit continues to increase in size. This symptom is common in peaches (Rice 1938) and apples (Boivin and Stewart 1982) injured by lygus bugs. Shrivelled or deformed seeds are also common symptoms of lygus bug injury. "Chalky spot" is found in lentils and other legume crops injured by lygus bugs (Summerfield _et_ _al_. 1982). In this case, seeds are often discolored, partially deformed, and exhibit a profusion of white material around the sight of the wound.

Reproductive organs which have been injured by lygus bug may turn brown, shrivel up, and abscise. This type of injury is termed "blasting" and may or may not affect plant growth. Alfalfa plants often overcompensate for blasted buds (Strong 1968). Tomato plants injured by _L. lineolaris_ produce 42% more blossoms than control plants (Davis _et_ _al_. 1963). Development of new reproductive organs by injured plants varies with the stage of plant development (Strong 1968).

Table 1: Crop damage and symptoms associated with feeding injury caused by various species of Miridae.

Damage category	Symptoms	Crop	Reference
Localized tissue necrosis	Brown, discolored tissue; sunken lesions; shrunken anthers	Cotton	Pack and Tugwell 1976
		Cashew	Hill 1983
	Leaf ragging	Cotton	Pearson and Maxwell-Darling 1958
		Tea	Calnaido 1959
	Blackened buds and flowers	Coffee	Hill 1983
	Black spotting on pods	Cocoa	Hill 1983
	"Bleached" areas on leaves	Grasses	Haws 1978
Morphological deformations of fruit and seed	Apical seediness	Strawberry	Allen and Goede 1963
	Cat facing	Peach	Rice 1938
		Apple	Boivin and Stewart 1982 Jensen 1972
	Misshapen fruit	Cotton	Pack and Tugwell 1976
		Apple	Boivin and Stewart 1982
	Shrivelled seed	Alfalfa	Sorenson 1936
		Carrot	Flemion and Olson 1950
		Green bean	Khattat and Stewart 1975
		Lima bean	Elmore 1955
		Lentil	Summerfield *et al*. 1982
Abscission of fruiting forms	Premature drop of buds, flower, fruit	Cotton	McKinlay and Geering 1957
		Tomato	Davis *et al*. 1963
		Snap bean	Fisher *et al*. 1946
		Alfalfa	Sorenson 1936
		Tea	Calnaido 1959
		Apple	Prokopy and Hubbell 1981
		Cabbage	Getzin 1983
		Green bean	Khattat and Stewart 1975
		Soybean	Broersma and Luckman 1970
	Silvertop (white) heads with some aborted seeds)	Grasses	Arnott and Bergis 1967 Haws 1978
Altered patterns of vegetative and fruiting growth	Increased number of vegetative branches	Alfalfa	Jeppson and MacLeod 1946
		Guayule	Addicott and Romney 1950
		Cotton	Hill 1983
	Multiple crowns	Sugarbeet	Varis 1972
	Bunched terminal growth	Cashew	Hill 1983

Table 1: Crop damage and symptoms associated with feeding injury caused by various species of Miridae. (continued)

Damage category	Symptoms	Crop	Reference
Altered patterns of vegetative and fruiting growth (contd)	Decreased biomass	Alfalfa	Shull *et al*. 1934
		Sugarbeet	Varis 1972
	Elongation of internodes	Cotton	Dale and Coaker 1958
	Elongation of stylets	Coffee	Hill 1983
	Increased plant height	Carrot	Scott 1969
		Cotton	Tugwell *et al*. 1976
	Stunted plants	Cotton	Hill 1983
	Decreased seed weight	Soybean	Broersma and Luckman 1970
		Lentil	Summerfield *et al*. 1982
	Increased root weight	Carrot	Scott 1969
	Decreased root weight	Sugarbeet	Varis 1972
	Increased number of fruit	Cotton	Tingey *et al*. 1975
	Tip die back	Asparagus	Grafius and Morrow 1982
Tissue malformation	Split stem lesions	Cotton	King and Cook 1932
		Poplar	Sapio *et al*. 1982
	Swollen nodes	Cotton	Dale and Coaker 1958
	Leaf crinkling	Sugarbeet	Hori 1967
	Leaf roll	Cotton	Hill 1983

Adopted and expanded from Tingey and Pillemer (1977)

Alteration of the patterns of vegetative and fruiting growth is a broad category of injury which includes any abnormality that is not obviously insect injury, i.e., increased root growth, increased number of tillers, stunted plants. Carrots grown from seed subjected to lygus bug injury produce roots which weigh 30 to 40% more than the roots grown from protected seed (Scott 1970). Lygus bug feeding may delay regrowth of alfalfa hay without producing visible signs of injury. In one study, the heights of alfalfa plants were 10.8, 4.4, and 7.1 cm, in cages containing no insects, cages containing *Adelphocorus lineolatus* (Goeze), and cages containing *L. lineolaris*, respectively (Newton and Hill 1970).

Tissue malformations result from lygus bug punctures in vegetative areas of the plant. Leaves become stunted in areas injured by the feeding puncture and often swell and fold in areas surrounding the injured area. In sugar beets swollen nodes, leaf crinkling, and leaf roll reduce plant vigour by reducing the flow of photosynthates (Hori, 1967). These injured areas create a point of entry for disease organisms. Split stem lesions on seedling poplar allow fungi, which cause canker disease, to enter and sometimes kill the young sapling. Even if the tree lives it lacks vigour and bears an unsightly scar which increases in size with the growth of the tree (Sapio *et al*., 1982). This type of injury as well as those listed above may be explained by a series of mechanical and physiological factors.

2.3.3 Physiological Explanation for Injury

Destruction of meristematic tissue, through the combined action of salivary pectinase and repeated probing, has been proposed as an explanation for plant bug injury (Strong 1970, Strong and Kruitwagen 1968). Meristematic tissue is the site of auxin production. Injury to this tissue could lead to a hormonal imbalance and result in most of the types of injury attributed to lygus bug (Strong 1970). For example, the destruction of meristematic tissue in the terminal bud could lead to the altered vegetative growth seen in sugar beets (Varis 1972). *L. rugulipennis* feeding reduces stem growth of sugar beets and the loss of apical dominance may result in increased growth of the lateral buds and the production of multiple crowns (Rubinstein and Nagao 1976). Morphological deformation of apples and strawberries (Boivin and Stewart 1982, Allen and Goede 1963) might also be explained by the destruction of meristematic tissues within fruit or seeds. Injury to auxin-producing tissue on one side of a fruit is known to produce localized inhibition of growth and abnormal fruit shape (Nitsch 1950). Finally, abscission of fruit following the feeding of lygus bug on alfalfa, tomatoes and green beans (Sorensen 1936, Khattat and Stewart 1975, Davis *et al*. 1963) can be explained by the destruction of auxin-producing tissue in these organs, because auxins play a major role in the prevention of abscission (Thimann 1972).

Evidence supporting the hypothesis that mechanical and enzymatic destruction is responsible for lygus bug injury was obtained in a study of *L. rugulipennis* in sugar beets (Varis 1972). Repeated probing with a needle did not lead to typical symptoms of feeding by *L. rugulipennis*, i.e., multiple crowns and decreased root weight. However, when probing was combined with the removal of plant juices and injection of pectinase most of the symptoms associated with lygus bug feeding were observed.

Mechanical and enzymatic destruction of tissue, however, does not explain all the symptoms of lygus bug injury. Increased growth, hypertrophy of cells, and distorted leaf growth have all been seen at or near feeding sites (Carter 1962, Scott 1970, Hori 1971b). Non-enzymatic factors may also be playing a role. Amino acids, oxidative enzymes, and phenolic compounds are more abundant in leaf tissue exposed to feeding (Hori 1976). Also, several amino acids and growth promoting factors are found in the salivary gland and can be injected into the host tissue (Miles and Lloyd 1967, Hori 1975). It has been suggested that the salivary amino acids change the amino acid pattern of a normal leaf and this may be related to the increase in oxidative enzymes (Hori 1976). The plants produce phenolic compounds as a result of the attack by the insect. The attacked cells release these compounds; this accelerates necrosis and destroys neighboring cells, thus preventing further invasion. Necrosis is the result of phenolics being oxidized and forming quinones which are toxic to the invader and the host tissue (Levin 1971). Thus it is possible that the tissue surrounding the injured area suffers the toxic effect of the quinones produced by the plant itself. Abnormal growth follows because quinones inactivate amino acids, IAA and various enzymes (Hori 1976). At the same time, the growth-promoting factors in the saliva spread to the surrounding tissue promoting IAA activity and result in the unbalanced growth between injured parts and surrounding tissue (Hori 1976).

In summary, the causes of injury and malformation caused by mirid feeding are as follows; sites of meristematic tissue are attacked; growing tissue is mechanically destroyed by the insect stylets;

neighboring cells are destroyed by pectinase and other enzymes; growth in the injured area is inhibited by quinones; and growth in surrounding tissue is promoted by plant growth promoting factors from the saliva.

The above factors are modified according to how sensitive the plant is to feeding injury. For example, sugar beets are much more sensitive to lygus bug feeding than is chinese cabbage (Hori and Atalay 1980).

2.4 Insect Injury in Relation to Growth of Oilseed Rape.

Insects may cause injury to roots, stems, buds, flowers, and seeds of oilseed *Brassica* crops such as rape (Lamb 1989). Lygus bugs are not likely to feed on roots, however, they have been noted injuring all the other plant parts in other crops (Tingey and Pillemer 1977). Lygus bugs have been noted in commercial crucifer crops (Hori and Hanada 1970, Scott 1977, Getzin 1983). However, the economic impact of lygus bug injury in oilseed rape has not been assessed.

Oilseed rape is able to compensate for injury to various plant parts (Tatchell 1983; and Williams and Free 1979). The impact of insect injury on oilseed rape varies with the crop stage of the plant at the time of attack, and depends on how that crop stage influences seed yield. The seed yield of an individual plant is determined by the number of pods, seeds per pod, and the weight of individual seeds (McGregor 1981). Crucifer seedlings are susceptible to lygus bug feeding. Fye (1982c) found that severe injury occurred to crucifer seedlings when *L. elisus* adults were confined on the seedlings for 48 h; in many cases the seedlings were killed. However, in the field, a change in density of seedlings in the crop may not lead to a change in yield. Plants grown at lower densities produce more pods and leaves and have larger stems and roots (Rood and Major 1984). A reduction from 200 to 40 seedlings per square meter leads to a 20% or less loss in yield (McGregor 1987). However, regardless of the crop's ability to compensate for seedling injury, the phenology of lygus bug suggests that this insect may not enter the crop until the bud and flower stage has been reached (Khattat and Stewart 1980). Therefore, seedling injury by lygus bug may not occur in the field.

Buds and flowers are shed naturally by oilseed rape plants. Up to 60% of the buds may abscise without a noticeable reduction in yield (Williams and Free 1979). Abscission mostly occurs towards the end of flowering or later, and is most prevalent in later developing inflorescences indicating a potential for recovery from early injury by retention of buds that would otherwise abscise (McGregor 1981). Meligethes spp., beetles which feed on buds and flowers, cause little or no reduction in yield at low levels of infestation and may even cause slight increases in yield (Nilsson 1987). Yield reductions do, however, occur at high levels of infestation indicating that there is a limit to how much the plant can compensate (Nilsson 1987; Sylen and Svenson 1976).

Seed injury could be compensated for by a reduction in natural abortion of seeds (Pechan and Morgan 1985), however, this has not been documented. Attack by the seed pod weevil, Ceutorhynchus assimilis Payk., sometimes results in an increase in 1000 seed weight (Tatchell 1983), and an increase in the number of pods developing on auxiliary racemes (Tulisalo et al. 1976; Tatchell 1983). However, these effects are not consistent. Studies of seed injury are complicated by differences in seed weight, seed number, and number of aborted seed, depending on the position of pods on a plant (Pechan and Morgan 1985; Diepenbrock and Geisler 1979; Inanaga *et al*., 1986). There is as yet little convincing evidence that canola can compensate for seed injury.

3 SEASONAL ABUNDANCE OF THREE LYGUS SPECIES (HETEROPTERA: MIRIDAE) IN OILSEED RAPE AND ALFALFA IN ALBERTA.

3.1 Abstract

Lygus bugs were sampled from 1982 to 1986 in fields of oilseed rape, Brassica campestris L. and B. napus L., and alfalfa, Medicago sativa L., in Alberta. Of the three species collected, Lygus elisus Van Duzee was the most abundant in rape in four of the years, and L. lineolaris (Palisot de Beauvois) was the most abundant in the fifth year. Lygus borealis (Kelton) was the most abundant in alfalfa. All three species reproduced and reached maturity in rape and alfalfa.

Lygus bug adults first entered rape when it reached the bud stage. Populations reached a peak in August when rape was in the early pod stage. A single generation of lygus bug was completed in the three crop species. Seeding date influenced the abundance of lygus bug in rape such that the highest densities were found in the crops which reached the bud stage earliest. Lygus bugs are potentially serious pests of oilseed rape because their phenology assures that the later-instar nymphs and adults are present in the crop when seeds are developing.

3.2 Introduction

Lygus bugs occur in oilseed rape, Brassica campestris L. and B. napus L., but they have not been reported to be a pest of the crop in Canada. Lygus elisus Van Duzee is known to injure cabbage, B. oleracea L., (Getzin 1983) and attack B. campestris grown for seed in the U.S.A (Scott 1977). This study describes the species composition and seasonal abundance of lygus bugs in Canola cultivars of oilseed rape in Alberta as the first step in determining their status as pests. Canola cultivars have low levels of erucic acid and glucosinolates in their seeds and are the only cultivars grown in Canada for human and animal consumption (Thomas 1984). Both species of oilseed rape were examined and the results compared to those from alfalfa for which the pest status of lygus bugs is well known (Craig 1983).

3.3 Materials and Methods

The species composition and seasonal abundance of lygus bugs were determined by sampling one commercial field each of _B_. _campestris_, _B_. _napus_, and _Medicago sativa_ L. near Fairview, Alberta from 1982-1985, and near Vegreville, Alberta in 1986. Lygus bug populations were also sampled in experimental plots of Canola at the same two locations in 1985 and 1986, to confirm that the timing of the invasion of the crop is related to its stage of development.

Sampling Commercial Fields. In each field, three widely-spaced transects were selected. Along each transect 1 to 3 sample sites were selected to ensure that each site was at least 30 m from any other site and 20 m from the edge of the field. The sites were marked with flags so that approximately the same area would be sampled on each sampling date. Samples were taken from 5 sites per field in 1982 and 1983 and from 10 sites per field in 1984-1986. At each site, a net 38 cm in diameter was swept through the crop 10 times; each sweep was through an arc of 180°. The 10 sweeps at each site constituted one sample. The net was everted into a plastic bag and captured insects were taken to the laboratory where nymphs were categorized by instar, and adults were identified to species based on the key of Kelton (1975). Nymphs could not be identified to species. At each site, five plants, 1 m apart, were selected and the growth stage for each was recorded (Harper and Berkenkamp 1975). The fields were sampled twice weekly during the growing season, or until the crop was harvested (16 to 18 sampling days per year for Canola and 24 to 28 in alfalfa). In Canola, sampling commenced when the crop began to form the first true leaves. In alfalfa, sampling began in the first week of May (Appendices 1 and 2).

To determine whether or not sweep samples accurately reflect the relative frequency of species present in Canola, sweep samples were compared to destructive samples of defined areas in the crop. To sample the lygus bugs in a defined area, the bottom was removed from a metal garbage can, 63.2 cm high with a diameter of 42.5 cm at the top and 37.5 cm at the bottom, giving a sample area of 0.11 m^2. The can was thrust vertically into the crop and twisted until the lower rim was approximately 2 cm below the soil surface. Plant material was clipped off at ground level, shaken firmly, and removed from the can. Plants were then beaten on a white cotton sheet and any remaining lygus bugs were collected. The ground within the can was searched, and after the can was removed, the soil in the sampled area was turned and searched. On 2 August 1985 when plants were in the early pod stage (5.1), a sample consisting of 10 sweeps and five samples of 0.11 m^2 were taken in each of five plots of B. napus cv. Andor. On 21 August 1986 when plants were also in the early pod stage (5.1-5.2), the sampling was repeated in 15 plots of B. napus cv. Westar.

To determine the species composition of immature lygus bug in the crops, first to third instar nymphs were collected on 25-29 July 1985 in M. sativa and B. napus fields by clipping plants at ground level and shaking nymphs onto a white sheet. The nymphs were reared to adulthood in the laboratory on their host plants in a rearing room held at 22°C and 75% RH, with a photoperiod of 16 h light and 8 h dark. Resulting adults were collected and identified to species.

The seasonal patterns of abundance were determined in the field populations. For the adults, two groups were readily identified by the disjunct, bimodal seasonal distribution (Appendix 1). These two groups corresponded to the overwintering adults that invaded the fields, termed spring adults, and the adults of the next generation which developed in the fields, termed the summer adults. The dates of separation between spring and summer generations of all three Lygus species were the same. Peak densities for the spring and summer generations were compared using a two way analysis of variance on data transformed by calculating the square root of x + 1. When significant differences were detected mean separations were determined using Duncan's new multiple range test (Steel and Torrie 1980).

Seeding Date and Seasonal Abundance. Samples from the commercial fields suggested that the timing of the invasion of the crop was related to its stage of growth. To test this hypothesis, an experiment was conducted with B. campestris cv. Tobin and B. napus cv. Westar seeded on three dates. Species were placed in separate experiments with identical treatments placed side-by-side. The plots were 6 by 30 m, seeded at a rate of 7 kg/ha for Westar and 5 kg/ha for Tobin, and separated with 2 m pathways. Rows were 20 cm apart, giving 30 rows per plot. The plots, with seeding dates as treatments, were arranged in a randomized complete block design with five replicates. The seeding dates were 21 May, 10 June, and 24 June 1985 at Fairview, and the experiment was repeated in 1986 at Vegreville with seeding dates of 12 May, 22 May, and 5 June. The second and third seedings were planted as soon as the plants of the preceding seeding began to form true leaves. In 1985, seeding was delayed and _B. napus_ plots were abandoned when they did not emerge because of drought.

The plots were sampled by taking 10 sweeps (as described above) in each at twice weekly intervals. Sampling commenced when the plants produced the first true leaves and continued until the pods were ripe and beginning to shatter. Nymphs in the samples were categorized by instar and counted; adults were identified to species and counted. On each sampling occasion, the growth stages of five plants near the center of each plot were recorded.

To confirm the apparent differences in lygus bug numbers among plots at different growth stages, all plots were intensively sampled on 26 June 1986 in _B. campestris_, and on 30 June 86 in _B. napus_ when the first-seeded plots were in flower, the second-seeded plots were in bud, and the last-seeded plots were in the vegetative stage. Intensive sampling consisted of 30 sweep samples and 30 suction samples per plot. The suction samples were obtained using a backpack D-Vac (Dietrick 1961) by placing the orifice of the flexible collecting tube (diameter of 33 cm) over the plants and thrusting it down through the crop canopy until it touched the ground. The collecting tube was withdrawn and the lygus bugs were removed from the net collecting bag.

3.4 Results

Species Composition in Commercial Fields. Three species of lygus bug collected during the study were _L. borealis_ (Kelton), _L. elisus_, and _L. lineolaris_ (Palisot de Beauvois). Voucher specimens of these species have been deposited in the Canadian National Collection, Ottawa. _L. borealis_ was the predominant species in alfalfa each year, and made up 62-82% of the catch of summer adults (Table 2 and Appendix 1). _L. elisus_ and _L. lineolaris_ made up, on average 14.2% and 9.2% of the catch, respectively. In both species of Canola at Fairview, _L. elisus_ predominated from 1982-1985 making up 49% of the summer adults in _B. napus_ and 60% in _B. campestris_, but the other two species were also always present (Table 2). G-tests (Sokal and Rohlf 1981), conducted by pooling the numbers collected from 1982-1985, indicated that the relative frequency of lygus bug differed among crops. The relative frequency of _L. borealis_ was significantly higher in alfalfa than in Canola ($G = 1244.4$; $df = 1$; $P < 0.01$) but did not differ between Canola species ($G = 0.01$; $df = 1$; $P > 0.05$). The relative frequency of _L. lineolaris_ was significantly higher in _B. napus_ than in either alfalfa ($G = 134.9$; $df = 1$; $P < 0.01$) or _B. campestris_ ($G = 35.0$; $df = 1$; $P < 0.01$). The relative frequency of _L. elisus_ was significantly higher in _B. campestris_ than in _B. napus_ ($G = 16.3$; $df = 1$; $P < 0.01$)and higher in _B. napus_ than in alfalfa ($G = 768.3$; $df = 1$; $P < 0.01$). At Vegreville in 1986, the species composition in Canola differed markedly from that observed in preceeding years at Fairview: _L. lineolaris_ predominated, _L. elisus_ was absent, and only one _L. borealis_ was found in the two Canola fields.

Table 2: Number of adult lygus bugs of the summer generation collected in three crop species from 1982 to 1985 in Fairview, Alberta, and in 1986 in Vegreville, Alberta.

		No. Samples[1]		Lygus species		
Crop	Year	days[2]	sites	*L. borealis*	*L. elisus*	*L. lineolaris*
B. campestris	1982	6	5	11	40	4
	1983	7	5	34	24	3
	1984	7	10	35	58	14
	1985	6	10	71	174	19
	1986	7	10	0	0	7
B. napus	1982	7	5	248	413	106
	1983	8	5	18	11	5
	1984	7	10	157	220	60
	1985	9	10	372	671	304
	1986	7	10	1	0	110
M. sativa	1982	14	5	152	10	23
	1983	--	--	--	--	--
	1984	6	10	210	70	14
	1985	14	10	1406	238	127
	1986	13	10	147	20	70

[1] Ten sweeps per site on each sampling day.

[2] Days refers to the number of days of sampling during which the summer generation was present.

Sweep samples accurately reflected the species composition of adult lygus bugs in *B. napus*. Fifty sweeps on 2 August 1985 yielded 17 adults: 6 *L. borealis*, 11 *L. elisus*, and 0 *L. lineolaris*. Twenty-five samples of 0.11 m^2 yielded 19 adults: 5 *L. borealis*, 11 *L. elisus*, and 2 *L. lineolaris*. On 21 August 1986, 150 sweeps yielded 34 adults: 0 *L. borealis*, 12 *L. elisus*, and 22 *L. lineolaris*. Seventy-five samples of 0.11 m^2 yielded 39 adults: 2 *L. borealis*, 9 *L. elisus*, and 28 *L. lineolaris*. G-tests showed that the frequency of *L. elisus* was independent of sampling method in 1985 ($G = 0.04$; $df = 1$; $P > 0.05$) and in 1986 ($G = 1.32$; $df = 1$; $P > 0.05$) and that the frequency of *L. lineolaris* was independent of sampling method in 1986 ($G = 0.41$; $df = 1$; $P > 0.05$) (Sokal and Rohlf 1981).

The species composition of nymphs collected in the commercial fields was similar to those of new adults collected 3 weeks later. On 25 July 1985, 486 nymphs collected from alfalfa produced 438 adults: 86% *L. borealis*, 10.3% *L. elisus*, and 3.7% *L. lineolaris*. Sweep samples on August 21 of 155 adults in the same field contained: 77.4% *L. borealis*, 19.4% *L. elisus*, and 3.2% *L. lineolaris*. On 29 July 1985, 275 nymphs collected from *B. napus* produced 238 adults: 26% *L. borealis*, 35.3% *L. elisus*, and 38.6% *L. lineolaris* compared to sweep samples on August 23 of 213 adults which contained: 35.6%, 45.5%, and 18.8% of the same species, respectively. G-tests showed that the frequency of all three species in alfalfa was independent of the stage of lygus bug collected ($G = 3.56$; $df = 2$; $P > 0.05$). The relative frequency of *L. lineolaris* nymphs in Canola was higher than that of the *L. lineolaris* adults ($G = 21.95$; $df = 1$; $P < 0.01$), whereas the frequency of the other two species did not change between the samples of nymphs and adults.

Seasonal Abundance in Commercial Fields. Very few lygus bugs were found in Canola until it reached the bud stage (stages 3.1-3.3 of Harper and Berkenkamp 1975) (Fig. 1 and Table 3). From 1982 to 1986, only three lygus bug adults were found on a single sampling date, in *B. napus* in 1985, before buds were detected in the crop, although fields were sampled 1-2 times before buds appeared. Adults were found in alfalfa during the vegetative stage. However, numbers were low until the bud stage was reached. Initially only adults were collected. Within 2 weeks, 1st-instar nymphs appeared and adults became scarce. The five nymphal instars appeared in succession (Fig. 2) and then adults reappeared in the samples. The same pattern was observed in all three crop species and in all years, although the timing varied with crop and year (Figs. 1 and 2). No differences were noted in the synchrony of the adult peaks for the three lygus bug species, but the sample sizes of the less abundant species were too low to detect minor differences in phenology. The timing of the initial peak of adults coincided with the early flowering stage of Canola (4.1 to 4.2 of Harper and Berkenkamp 1975) (Table 3). In Canola, the highest number of lygus bugs were observed between 12-21 August in 1982-1986, when most lygus bugs were in the 4th and 5th instars or adult stage and the crop was in the early pod stage (5.1 and 5.2 of Harper and Berkenkamp 1975) (Fig. 2). In the commercial fields, the peak densities of lygus bug were significantly higher in the spring generation in *M. sativa* than in *B. napus* and *B. campestris* ($F = 9.59$; $df = 2,10$; $P < 0.01$) (Table 4) based on Duncan's new multiple range test (Steel and Torrie 1980). Peak densities in the summer generation showed the same trend, although differences were not significant.

Figure 1. Seasonal abundance of adults (———) and nymphs (- - - - -) of lygus bugs infesting Brassica species and Medicago sativa, near Fairview, Alberta, in 1984 and 1985. Arrows indicate the initiation of bud development in each crop.

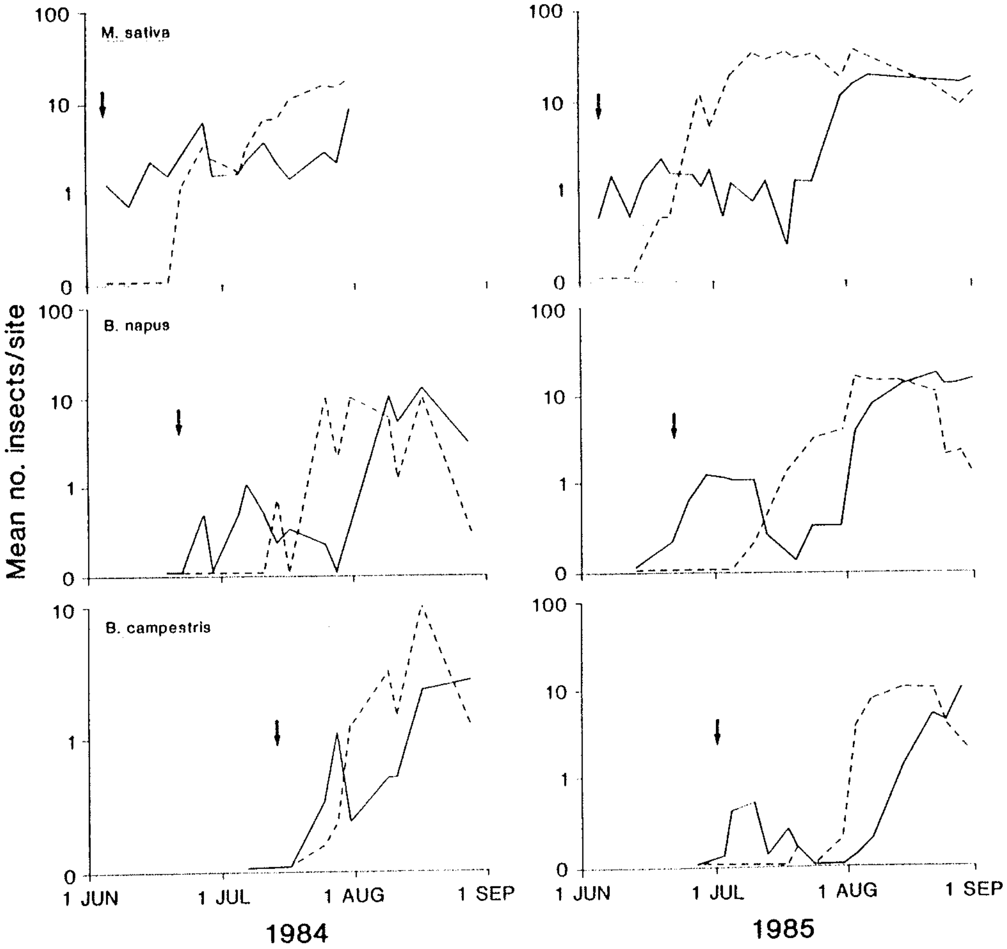
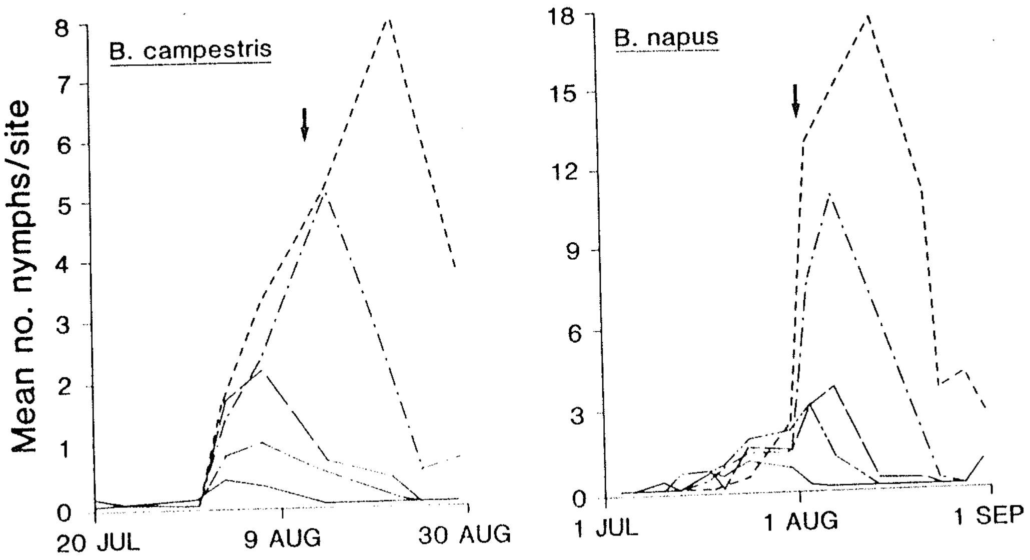

Mean no. insects/site
M. sativa
B. napus
B. campestris
100
10
1
0
1 JUN
1 JUL
1 AUG
1 SEP
1984
1985

Table 3: Crop growth stages and dates at which lygus adults first appeared and the population of spring adults peaked in commercial fields of two _Brassica_ species in Alberta, from 1982-1986.

Crop[1]	First adults		First peak	
	Stage	Date	Stage	Date
B. campestris	3.1-3.3	June 27-July 15	4.1-4.2	July 2-July 23
B. napus	2.6-3.3	June 17-25	3.3-4.2	June 27-July 5

[1] One field of each species was sampled by taking 50 sweeps (1982-1983) or 100 sweeps (1984-1986) for each crop twice weekly.

Figure 2. Seasonal abundance of the first (———), second (—··—), third (— — —), fourth (—·—·), and fifth (------) instar nymphs of lygus bug in 2 *Brassica* species near Fairview, Alberta in 1985. Arrows indicate the initiation of pod development in each crop.


Mean no. nymphs/site
B. campestris
8
7
6
5
4
3
2
1
0
20 JUL
9 AUG
30 AUG
B. napus
18
15
12
9
6
3
0
1 JUL
1 AUG
1 SEP

Influence of Seeding Date and Crop Stage. The appearance of adult lygus bugs in plots seeded on three different dates was closely related to when the plots reached the bud stage. Lygus bugs were present in only one of 84 samples taken during the seedling stage (Table 5). Once the crop was in bud, lygus bug adults were present in most plots regardless of when the plots were seeded. On 26 June 1986 in *B. campestris* and 30 June 1986 in *B. napus*, intensive sampling by sweeping and D-vac sampling confirmed that no lygus bugs could be detected in plots which were in the seedling stage. Both sampling methods detected adult lygus bugs in plots which were in bud or flower.

In 1985, the number of lygus bugs in the plots, measured by the peak density, were significantly lower in later seeded plots in both the spring ($F = 30.72$; df = 2,12; $P < 0.01$) and summer generations ($F = 9.14$; df = 2,12; $P < 0.01$) (Table 6). In 1986, the same trend was evident in both crop species, although differences were not significant. However, the peak density of the summer generation in the *B. campestris* plots was significantly greater than the peak in the *B. napus* plots seeded the same day, in the second ($t = 5.71$; df = 4; $P < 0.01$) and third seedings ($t = 3.94$; df = 4; $P < 0.05$). The first seeding showed the same trend but the difference was not significant ($t = 1.94$; df = 4; $P > 0.05$). The peak density occurring in the plots during the summer was significantly correlated with that occurring during the spring ($r = .8098$; $P < 0.001$; $n = 45$) when both cultivars and both years were included in the analysis.

Table 4: Peak densities of lygus bugs in commercial fields of three crop species in Alberta from 1984-1986.

		Crop					
		B. campestris		*B. napus*		*M. sativa*	
Location	Year	PK1[1]	PK2	PK1	PK2	PK1	PK2
Fairview	1982	3.0	27.6	9.6	135.6	7.8	15.2
Fairview	1983	1.0	8.2	1.0	9.6	--	--
Fairview	1984	0.6	13.8	0.7	31.4	13.5	43.0
Fairview	1985	0.7	18.0	1.8	44.4	15.6	80.0
Vegreville	1986	0.1	1.0	1.2	9.1	4.6	7.3
Mean		1.1	13.7	2.9	46.0	10.4	36.4

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[1] PK1 is the peak density of the spring generation and PK2 is the peak density of the summer generation. Peaks are the means for 5 sites per field in 1982 and 1983, and 10 sites per field from 1984 to 1986. Ten 180° sweeps were taken per site.

Table 5: Mean number of lygus bug adults collected by sweeping 4 crop stages of oilseed rape cvs. Tobin and Westar, seeded on 3 dates in 1985 at Fairview, and in 1986 at Vegreville, Alberta.

	Crop stage							
Seeding	Seedling	n	Bud	n	Flower	n	Pod	n
Tobin 1985								
1[1]	0	5	3.0 (1.01)[2]	10	7.2 (1.86)	15	12.4 (3.27)	25
2	0	15	1.3 (0.36)	15	1.8 (0.50)	15	7.3 (0.99)	20
3	0	15	1.1 (0.48)	6	2.3 (0.35)	15	5.2 (0.99)	20
Tobin 1986								
1	0	10	--	--	2.0 (0.59)	14	1.5 (0.41)	22
2	0	5	1.6 (0.38)	13	1.0 (0.32)	13	6.5 (2.26)	17
3	0	10	0.8 (0.33)	10	1.0 (0.27)	20	8.4 (3.15)	14
Westar 1986								
1	0	5	1.7 (0.50)	9	0.2 (0.12)	13	2.1 (0.61)	16
2	0.3 (0.33)	9	1.0 (0.42)	8	0.7 (0.29)	13	4.0 (1.09)	12
3	0	10	0.3 (0.15)	10	2.4 (0.25)	14	3.6 (0.90)	10

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[1] Seedings 1, 2 and 3 were seeded on May 21, June 10, June 24 in 1985 and on May 12, May 26 and June 5 in 1986.

[2] Mean (SE) are based on 10, 180° sweeps per plot for n plots.

Table 6: Mean peak densities of lygus collected in field plots seeded on 3 successive dates in 1985 at Fairview, and in 1986 at Vegreville, Alberta.

Seeding	n	Spring generation	Summer generation
Tobin 1985			
1[1]	5	14.0(2.39)[2]	61.8(9.96)
2	5	2.6(0.74)	30.6(4.33)
3	5	1.0(0.32)	22.6(4.96)
Tobin 1986			
1	5	2.2(0.58)	12.4(2.31)
2	5	1.2(0.58)	11.4(1.94)
3	5	1.2(0.58)	11.6(3.50)
Westar 1986			
1	5	1.4(0.68)	4.2(1.46)
2	5	1.2(0.37)	3.8(1.46)
3	5	0.4(0.24)	3.2(0.58)

[1] Seedings 1, 2, and 3 were seeded on May 21, June 10, June 24 in 1985 and on May 12, May 26 and June 5 in 1986.

[2] Mean (SE) are based on 10, 180° sweeps per plot for n plots.

3.5 Discussion

Three species of lygus bug adults occur in all three species of crop. The successful rearing of nymphs collected from alfalfa and Canola demonstrates that all three species oviposit and develop in alfalfa and Canola. The species compositions of the nymphal populations are similar to those of adults. However, the relative abundance of the species varies between Canola and alfalfa with *L. borealis* making up about 70% of the lygus bugs in alfalfa, whereas *L. elisus* or *L. lineolaris* predominate in Canola, together making up about 70% of the populations. Fye (1982b) obtained similar results in Washington where *L. elisus* made up 81-100% of the lygus bugs on crucifers, but only 17% on alfalfa. Therefore, it is likely that some adult lygus bugs are migrating into Canola from nearby alfalfa, as is the case with the cotton-alfalfa complex (Stern *et al.* 1964), but alfalfa is probably not the main source of lygus bugs for Canola because alfalfa harbors primarily *L. borealis*. Cruciferous weeds are abundant in Alberta (B. Blackshaw, Agriculture Canada, personal communication) and could provide a large source of *L. elisus* or *L. lineolaris* for infesting Canola.

When both species are common, *L. elisus* occurs at a relatively higher frequency in *B. campestris* than *L. lineolaris*, and *L. lineolaris* occurs at a relatively higher frequency in *B. napus*. The differences in occurrence of the lygus bug species in the three crops may be due to differences in their feeding and oviposition or differences in their phenologies in relation to the different phenologies of the crops. The predominance of *L. lineoaris* in Vegreville in 1986 resulted in a species composition markedly different from that observed in previous years.

However, the species composition in 1986 near Fairview differed similarly from that observed in the same area in previous years. Sweep samples in seven Canola fields showed that L. elisus comprised 22% of the population, less than half the frequency observed in the four previous seasons, and L. lineolaris, which had been the least abundant, was the most numerous species (M. Okuda, Alberta Agriculture, personal communication).

At Vegreville and Fairview, Alberta, all three species of lygus bug complete a single generation per year, in both alfalfa and Canola. Univoltism is demonstrated by the disjunct, bimodal peak in the seasonal distribution for adults, and the single, successive peaks for the five nymphal instars. In contrast, at Saskatoon, Saskatchewan, lygus bugs complete two generations in alfalfa (Craig 1983). Saskatoon (52° 8' N, 106° 38' W) is 4° south of Fairview (56° 4' N, 118° 23' W), but only 1° south of Vegreville (53° 29' N, 112° 3' W). The similarity in voltinism at Fairview and Vegreville and the difference in voltinism between these locations and Saskatoon is probably explained by the heat units available to lygus bugs at the three locations. The 30 year average for degree-days accumulated above 10°C (Champlain and Butler 1967) is 874, 599, and 576 at Saskatoon, Vegreville, and Fairview, respectively (Environment Canada 1982). This difference in voltinism and the number of heat units available in different parts of western Canada indicates that the synchrony between lygus bugs and Canola may vary among regions.

In the northern part of the agricultural area of Alberta, lygus bugs are synchronized to the phenology of the crop. The last two instars and newly moulted adults occur in the crop when it is in the early pod stage.

The later developmental stages of lygus bug are known to cause the most injury (Gutierrez et al. 1977), and injury to pods and developing seeds is most likely to be the source of economic losses in Canola. This synchrony is maintained in spite of differences in seeding dates among fields by the fact that the overwintered adults do not invade Canola until the crop produces buds, regardless of when the buds appear in the crop. Thus, populations of lygus bugs develop on Canola during its reproductive phase. Synchrony identical to this is found in lygus populations infesting green beans (Khattat and Stewart 1980).

Seeding date does affect the abundance of lygus bugs in the crop. The fields which are seeded earliest, and produce buds first, accumulate the largest numbers of lygus. Apparent differences observed in lygus bug abundance between the two Canola species may reflect differences in the time they come into bud rather than differences in their suitability as hosts for lygus bug. In commercial fields, *B. napus* accumulates larger numbers of lygus bug than *B. campestris*, but it is normally seeded and comes into bud earlier than *B. campestris*. In experimental plots where the two species are seeded simultaneously, *B. campestris* reaches the bud stage earlier and accumulates more lygus bug than plots of *B. napus*. Alfalfa comes into bud earlier than either Canola species and accumulates more lygus bug , but the differences in lygus bug species composition between alfalfa and Canola may also contribute to this difference in lygus bug abundance. To determine the relative importance of host plant and crop phenology to lygus bug abundance, experiments will have to be designed to assure that crops reach the bud stage at the same time. The relationship and seeding date may vary with location since later seedings of green beans in Quebec apparently accumulate more lygus bug (Khattat and Stewart 1980).

Three species of lygus bugs annually invade, reproduce in, and develop in Alberta Canola. Their injuring stages are synchronized with susceptible stages of the crop. It remains to be determined whether or not their feeding activity has an economic impact on Canola production.

4. COMPARISON OF OILSEED BRASSICA CROPS WITH HIGH AND LOW LEVELS OF GLUCOSINOLATES AND ALFALFA AS HOSTS FOR THREE SPECIES OF LYGUS (HETEROPTERA:MIRIDAE).

4.1 Abstract

Lygus bugs were monitored in field plots of five cultivars of oilseed rape, *Brassica napus* L. and *Brassica campestris* L., containing low and high levels of glucosinolates. At the early pod stage, the number of lygus bugs collected did not differ among cultivars of the same species. Nymphs reared on the five cultivars had the same survival and developmental rate regardless of the glucosinolate status of the cultivar. Survival, development, and growth were compared for nymphs reared on excised stem tips of rape and alfalfa, *Medicago sativa* L., that had flower buds or flowers. Nymphs developed faster and had higher survival when reared on rape than when reared on alfalfa. However, the dry weights of adults collected from an alfalfa field were significantly higher than those reared on alfalfa in the laboratory indicating excised alfalfa may not be as good a source of food for laboratory tests as excised rape. The results demonstrate that oilseed *Brassica* crops with high or low levels of glucosinolates are both suitable hosts for the three species of lygus bug.

4.2 Introduction

Oilseed rape, *Brassica napus* L. and *B. campestris* L., has become an important crop in Canada, both as a source of edible oil and a protein meal for animal consumption. The success of the rape crop in Canada is largely due to the development of high yielding cultivars of rape called

Canola that have less than 5% erucic acid as a proportion of total fatty acids in the oil, and less than 30 umol/g of glucosinolates in the oil-free meal (Downey 1983; Daun 1983).

Glucosinolates are feeding deterrents and toxins for many polyphagous insects, but are attractants or feeding stimulants for oligophagous insects which use members of the Cruciferae as hosts (Blau *et al*. 1978). Concern has been expressed that the reduction in glucosinolates in Canola cultivars may lead to an increase in infestation of the crop by polyphagous insects. On the other hand, the changes in glucosinolate composition of the plants might reduce the attractiveness of the crop to crucifer specialists. Among polyphagous feeders, the evidence is equivocal. Davis *et al*. (1981) demonstrated that larvae of *Tenebrio molitor* L. fed seed of Canola cultivars reach much higher weights than those fed other rape cultivars. However, Loschiavo and Lamb (1985) concluded that seeds of Canola cultivars are no more suitable as food for *Oryzaephilus mercator* (Fauvel), *Oryzaephilus surinamensis* (L.), *Cryptolestes ferrugineus* (Stephens) and *Tribolium castaneum* (Herbst) than are seeds of other cultivars. Weber *et al*. (1986) found that the polyphagous aphid *Mysus persicae* (Sulz.) develops equally well on rape and Canola cultivars. Similarly, the crucifer specialists so far studied have not been affected by the transition from rape to Canola cultivars (Gerber and Obadofin 1981, Ahman 1982, Larsen *et al*. 1985, Weber *et al*. 1986, Lamb 1989).

Lygus borealis (Kelton), *L. elisus* Van Duzee, and *L. lineolaris* (Palisot de Beauvois) have recently been cited as potential pests of oilseed rape (Section 3). These lygus bugs are polyphagous (Fye 1982b, Snodgrass *et al*. 1984). Glucosinolates are reported to be a feeding deterrent for *L. lineolaris* (Palisot de Beauvois) (Hatfield *et al*. 1982). It is possible that these potential pests of Canola were only recognized recently because they successfully invaded Canola, but were unable to effectively exploit the older high glucosinolate rapes as a host.

This study was undertaken to determine whether or not cultivars of Canola containing low levels of glucosinolates are more susceptible to infestation by lygus bug than the older cultivars of rape with high levels of glucosinolates. Also, the suitability of oilseed *Brassica* crops as hosts for lygus bug was compared to that of alfalfa, *Medicago sativa* L., because this crop is known to support large populations of lygus bug (Craig 1983).

4.3 Materials and Methods

The five cultivars used in the study were: *B. napus* cvs. Westar and Andor, and *B. campestris* cv. Tobin, which are low glucosinolate oilseed rapes; *B. napus* cv. Midas and *B. campestris* cv. Torch, which are high glucosinolate oilseed rapes (Thomas 1984). To determine whether differences among cultivars influence the abundance of lygus bugs in these crops, populations of lygus bug were sampled in experimental plots of the five cultivars at Fairview in 1985, and at Vegreville, Alberta, in 1986. Lygus bug development and survival on the five cultivars, and on *M. sativa* cv. Beaver, were also studied in the laboratory.

Relative abundance in field plots. The five cultivars of rape were seeded in plots, 10 x 4 m, with rows 20 cm apart, giving 20 rows per plot. Cultivars, as treatments, were arranged in a randomized complete block design with five replicates. The seeding date was 21 May in 1985 and in 1986. In 1985, plots were sampled four times between flowering and maturity. In 1986, plots were sampled once weekly from emergence to the time of harvest. On each sampling date, plots were swept 10 times each, through an arc of 180°, with a net that was 38 cm in diameter. The net was everted into a plastic bag and captured insects were returned to the laboratory where adults were identified to species, based on the key of Kelton (1975). Nymphs could not be identified until they reached adulthood. In each plot, five plants were selected at intervals of 1 m and the growth stage of each was recorded (Harper and Berkenkamp 1975). Orthogonal contrasts were used to compare the number of insects collected in high and low glucosinolate cultivars (Steel and Torrie 1980). In 1986, the number of insect days accumulated through the season was calculated for each plot using the method described by Ruppel (1983).

Development in the laboratory. *L. elisus* was used in this study because it was the most abundant species in rape at the time. In July 1986, adults were placed in 6 oviposition cages containing potted plants of *B. napus*. Plants were examined daily until 124 first instar nymphs were collected and placed individually in petri dishes, 100 x 15 mm, containing bud clusters of one of the cultivars on moist filter paper. Petri dishes were held in a room maintained at 22° ± 0.5°C and 70-80% RH, with 18 h light and 6 h dark. Bud clusters were changed daily, at which time the instar and condition of the nymphs were recorded. When nymphs reached adulthood, pairs (a female and a male) were placed in petri dishes containing bud clusters of the same cultivar upon which they had been reared. Bud clusters were replaced daily and examined for eggs.

Oilseed rape versus alfalfa. Developmental times and survival of lygus bugs reared on oilseed rape, *B. napus* cv. Andor, and alfalfa, *M. sativa* cv. Beaver, were compared to determine whether or not lygus bugs develop on oilseed rape as successfully as on alfalfa. Sixty nymphs in the first instar were collected from fields of alfalfa and 48 from rape, *B. napus*, on 3 July 1985 and 18 July 1985, respectively. They were placed individually in petri dishes, 100 x 15mm, containing a bud cluster of rape or alfalfa. The bud clusters were replaced daily. At the same time, the instar and condition of each nymph was recorded. When nymphs reached adulthood, they were allowed to feed for one day, after which time they were placed in a freezer at -20°C for 24 h. Later they were dried in an oven at 35°C for 24 h, and weighed again (termed dry weight). Comparisons were made by analysis of variance, using a completely randomized design, between hosts (crops where nymphs were collected), foods (plants nymphs fed on in the laboratory), and host by food interaction. When significant differences were detected mean separations were determined used Duncan's new multiple range test (Steel and Torrie 1980).

To compare growth in the laboratory with growth in the field, adults were collected from a field of rape and a field of alfalfa in August 1985. They were frozen, dried, and weighed, as described above. Mean weights of field-collected and laboratory-reared adults were compared using unpaired t-tests.

4.4 Results

Relative abundance in field plots. In 1985, collections made in field plots during the early pod stage when populations peaked showed that there was no significant difference in the number of nymphs present between the cultivars high and low levels of glucosinolates (F = 0.02; df = 1,16; $P > 0.05$). There were also no differences between the cultivars of *B. campestris* (F = 0.17; df = 1,16; $P > 0.05$) (Table 7). For *B. napus*, Midas had fewer lygus bugs than the other two cultivars, but the numbers did not differ significantly (F = 0.39; df = 1,16; $P > 0.05$). Midas development was slightly slower than Andor and Westar (on 28 July 1985, Midas was in the mid-flowering stage (4.3) while Andor and Westar had completed flowering (4.4)). The number of lygus bugs was significantly higher in the *B. campestris* plots than in the *B. napus* plots (F = 26.71; df = 1,16; $P < 0.001$). In 1986, lygus bug densities were much lower in all plots. There were no significant differences between high and low glucosinolate cultivars (F = 0.02; df = 1,16; $P > 0.05$). There was no significant difference among cultivars within *B. campestris* (F = 1.15 df = 1,16; $P > 0.05$), or *B. napus* (F = 0.55; df = 1,16; $P > 0.05$). There was a significant difference between *B. campestris* and *B. napus* (F = 12.97; df = 1,16; $P < 0.01$). Analyses conducted on the counts, and on counts transformed by adding 1.0 and taking the square root, gave similar results (Snedecor and Cochran 1980).

In 1986, insect days accumulated over the growing season in *B. campestris* were 158 and 111.5 for Torch and Tobin, respectively. In *B. napus*, the insect days accumulated were 121.9, 159.2, and 1 11.7 for

Table 7: Density of Lygus nymphs during the early pod stage in 5 cultivars of oilseed Brassica in 1985 near Fairview, and in 1986 near Vegreville, Alberta.

			Density (nymphs/plot)	
Plant species	Cultivar	n	1985	1986
B. napus	Westar	5	6.6[1]	0.6
	Andor	5	7.8	0.6
	Midas	5	3.6	0.2
B. campestris	Tobin	5	29.8	1.8
	Torch	5	27.0	2.6
	S.E.[2]		4.41	0.50

[1] Means (S.E.) are based on 5 plots, sampled once using 10, 180° sweeps per plot. Sampling was done in the early pod stage (5.1 in Harper and Berkenkamp 1975) on August 8 in 1985, and on August 6 in 1986.

[2] S.E. was calculated from the error mean square of the analysis of variance. Analysis of variance was performed on untransformed counts.

Westar, Andor, and Midas, respectively. There were no significant differences among the insect days accumulated in the five cultivars (F = 1.54; df = 4,16; P > 0.05).

Development in the laboratory. The percentage of *L. elisus* nymphs surviving was independent of the cultivar on which they were reared χ^2 = 4.92; df = 4; P > 0.05). The developmental times were not significantly different among the five varieties tested (F = 0.64; df = 4,102 P > 0.05) (Table 8). The number of eggs laid per female was highly variable, and there was no significant difference in oviposition rate among cultivars (F = 0.85, df = 4,35; P = 0.5036) (Table 8). Plants of the cultivar Tobin were in poor condition due to the constant pruning necessary to ensure an adequate supply of bud clusters. The other cultivars were better able to tolerate pruning and did not show symptoms of stress.

Oilseed rape vs. alfalfa. The survival of nymphs fed rape was significantly higher than the survival of those fed alfalfa regardless of the host from which they were collected (Table 9). Developmental times were significantly shorter for the lygus bugs fed rape than for those fed alfalfa (F = 22.41; df = 1.38; P < 0.001) regardless of host (F = 4.46 df = 1,38; P > 0.05) (Table 10). The dry weights of adults were significantly higher for lygus bugs reared on rape than those reared on alfalfa (F = 105.42; df = 1,35; P < 0.001), regardless of host (F = 3.87; df = 1,35; P > 0.05) (Table 10). Externally, alfalfa and canola buds appeared to be in comparable condition after twenty-four hours. However, lygus bug adults collected in an alfalfa field were significantly heavier than those reared on alfalfa in the laboratory (t = 4.86; df = 23;

Table 8: Survival, developmental time, and oviposition of *Lygus elisus* on 5 cultivars of *Brassica*.

Food plant				Developmental		Eggs/female	
Species	Cultivar	n	Survival (%)	time (days)	Females ovipositing	$\bar{x}$ (SE)	Range
B. napus	Westar	25	92	15.7(0.18)	8	36(11.2)[1]	4-102
	Andor	25	84	15.8(0.18)	8	27(12.7)	9-109
	Midas	26	84.5	15.5(0.18)	7	38(16.1)	7-121
B. campestris	Tobin	25	72.0	15.8(0.20)	7	13(7.6)	1-58
	Torch	23	91.0	15.5(0.19)	10	38(8.4)	9-99

[1] Means (SE) are based on the numbers of eggs collected over the trial.

Table 9: Survival of lygus bugs collected from either *Brassica napus* or *Medicago sativa* (host), and reared on bud clusters of these two plants (food plant).

Host	Food plant	n	Survival (%)	χ^2, test of independence
M. sativa	*B. napus*	30	67	4.28, $P <. 05$
	M. sativa	30	40	
B. napus	*B. napus*	24	88	7.85, $P < .01$
	M. sativa	24	50	

Table 10: Developmental time, fresh weight, and dry weight of lygus bugs collected from *Brassica napus* and *Medicago sativa* and reared on the two plants.

	Laboratory reared from 1st instar				Field-collected adults	
Host	Food	n	Days to maturity	Dry wt. mg	n	Dry wt. mg
L. borealis						
B. napus	*B. napus*	8	9.6(0.38) a	4.5(0.23) a	6	3.8(0.56)a
	M. sativa	4	12.5(0.50) b	2.1(0.42) b	-	-
M. sativa	*B. napus*	19	10.7(0.27) a	4.7(0.19) a	-	-
	M. sativa	11	12.1(0.37) b	1.6(0.22) b	20	4.5(0.35)a
L. elisus						
B. napus	*B. napus*	8	9.8(0.23) a	3.8(0.34) a	12	3.8(0.59)a
	M. sativa	5	11.8(0.58) b	1.9(0.35) b	-	-
L. lineolaris						
B. napus	*B. napus*	5	9.2(0.58) a	3.8 (0.49) a	2	3.7(0.75)a
	M. sativa	3	11.7(0.67) b	1.5 (0.29) b	-	-

Means (SE) in each column within each group followed by the same letter are not significantly different (P=0.05, Duncan's [1950, in Steel and Torrie 1980] multiple range test). S.E. was based on the variance and n of each mean.

$P < 0.001$) and not significantly different from the weights of those collected in rape ($t = 0.97$; $df = 14$, $P > 0.05$), or reared on rape in the laboratory ($t = 0.34$; $df = 35$; $P > 0.05$) (Table 10). Field collected adults were assumed to be part the local residents and not migrants since the species proportion of collected adults was similar to that of collected and reared nymphs (Section 3).

4.5 Discussion

Lygus bugs occurred in similar numbers at early pod stage in cultivars with high and low levels of glucosinolates. Neither Midas nor Torch, the high glucosinolate cultivars of rape, accumulated insect days in a different way from the Canola cultivars in the same species. In 1985, however, there were differences in the numbers of lygus bugs present in the two rape species, *B. campestris* and *B. napus*. All five cultivars were seeded on the same date, in both years. When seeded at the same time *B. campestris* accumulates more lygus bugs than *B. napus* because it comes into bud more quickly (Section 3). Therefore, the differences in lygus bug numbers between species were likely due to the timing of crop development and not due to a difference among cultivars or an inherent difference in the suitability of the two species for lygus bug. Among the cultivars of *B. napus*, Midas flowered last, which probably accounts for the lower numbers of lygus bugs captured in Midas plots.

Cultivars of oilseed rape containing high levels of glucosinolates in their seed are no less suitable as a food source than cultivars with low levels of glucosinolates. There were no significant differences in the survival, developmental times or oviposition rates of lygus bug reared on the five cultivars. Lygus bug nymphs survive better and develop at a significantly higher rate when reared on excised rape than they do on excised alfalfa. These results are similar to those obtained by Hori and Kuramochi (1984) for *Lygus disponsi* Linnavuori. However, the weights of adults collected in an alfalfa field, were as high as those from rape. This indicates that lygus bugs reared on excised alfalfa in the laboratory are not comparable to those reared on growing alfalfa. Therefore, laboratory rearing procedures must be improved before conclusions can be made about the relative suitability of the two crops as hosts for lygus bugs.

Based on the occurrence of nymphs and adults of lygus bugs in field plots of oilseed *Brassicas* and the successful rearing of lygus bugs on five cultivars of rape, rape is an adequate host for the three lygus bug species. The glucosinolate status of the five cultivars had no effect on the suitability of the five cultivars for lygus bugs. Therefore, it is unlikely that the transformation from rape to Canola cultivars had any impact on the pest status of lygus bugs in the oilseed *Brassica* crops.

5 INJURY TO OILSEED RAPE CAUSED BY LYGUS (HETEROPTERA: MIRIDAE) AND ITS EFFECT ON SEED PRODUCTION.

5.1 Abstract

Lygus bug injury to oilseed rape, Brassica napus L. and Brassica campestris L. was assessed both in plots and commercial fields from 1984 to 1986. The symptoms of injury by lygus bugs in oilseed rape are similar to those described in other crops. Lygus bug injury resulted in significant increases in the number of "blasted" buds, flowers, and seeds. Bud loss was compensated for by the production of more pods in 1984 and 1985. However, in 1984, because the pods on injured plants were significantly lighter, there was a decline in yield weight with increased injury. Compensation for flower loss also occurred, but yield declined as injury increased in both years. Compensation for seed injury did not occur in either year. The results indicate that lygus bug injury does occur in oilseed rape and has the potential to result in economic losses in this crop.

5.2 Introduction

Lygus bugs cause damage of economic importance to more than 20 crop species (Tingey and Pillemer 1977). Lygus bug feeding causes buds and flowers to be shed, and destroys seed and apical meristem (Strong 1970, Tingey and Pillemer 1977). When buds or flowers are shed or seed collapses because of lygus bug feeding, the injury is called 'blasting'.

Oilseed rape, Brassica napus L. was first cited as a host of lygus bug in Japan (Hori and Hanada 1970). Lygus bugs also attack the other species of oilseed rape, Brassica campestris L., in the U.S.A. (Scott

1977). Whereas oilseed rape is a minor crop in Japan and U.S.A., the oilseed rape crop, called Canola, is one of the most important field crops in western Canada (Adolphe 1979, Alberta Agriculture 1988). The name Canola was adopted for oilseed rape cultivars with very low levels of erucic acid and glucosinolates in the seed. Determination of the status of Canola pests such as lygus bug is important to the agricultural industry in the region.

Lygus elisus Van Duzee, *L. lineolaris* (Palisot de Beauvois), and *L. borealis* (Kelton) infest and feed in Canola (Section 3 and 4), but the impact of their feeding on seed production is unknown. Oilseed rape plants compensate for injury to buds, flowers and pods, either by artificial injury or injury caused by the blossom beetle, *Meligethes aeneus* F. (Williams and Free 1979, Tatchell 1983), although compensation may not be complete (Nilsson 1987). Lygus bugs injure some of the same tissues as *M. aeneus*, although the two pests have different modes of feeding (*M. aeneus* chews plant tissue). Canola plants may also compensate for lygus bug injury. This study describes lygus bug injury occurring in Canola, the impact of this injury on seed production by Canola plants, and the ability of the plants to compensate for lygus bug injury.

5.3 Materials and Methods

5.3.1 Identifying lygus bug injury

The injury to Canola from feeding by lygus bug was observed: 1. on excised plant parts in petri dishes containing lygus bug nymphs or adults, 2. in field plots where lygus bugs were caged on plant parts at various growth stages, and 3. in commercial fields with natural infestations of lygus bugs. Examination of plant parts exposed to lygus bugs in petri dishes revealed the types of feeding scars made by lygus bugs. Confining lygus bugs to plant parts in sleeve cages on field grown plants permitted injury to be studied under semi-controlled conditions, so that its short and long term effects were evident. The observations in Canola with natural infestations confirmed that the injury observed in petri dishes and field cages occurred in commercial fields.

Seed injury was observed by dissecting pods and extracting seeds. Seed surfaces were examined under a dissecting microscope by rolling the seeds down a groove in a plexiglass plate so that the entire surface of each seed was visible. Injured and uninjured seeds were also compared using a scanning electron microscope.

To determine if disease organisms were associated with injury attributed to lygus bug, 100 partially collapsed seeds and 100 healthy seeds were selected from seed samples collected from plants confined with lygus bug during the pod stage. For each category, ten seeds were placed in each of 10 petri plates containing potato dextrose agar. Plates were held at room temperature for one week, at which time they were examined for disease organisms.

The viability of partially collapsed seeds with evidence of lygus bug injury was assessed by placing 100 injured and 100 healthy seeds in petri plates (10 seeds per plate) containing water agar. Dishes were held at 25°C for one week, at which time the germinated seeds were counted.

5.3.2 Distribution of injury on the plants

The distribution of healthy and lygus bug-injured buds, pods and seeds on Canola plants was determined by collecting plants in fields or plots of Brassica napus L., cv. Westar and B. campestris L., cv. Tobin. Each field was entered from the roadside and surveyed by walking a track with an inverted V pattern. Upon entering the field, the surveyor took a minimum of 50 steps into the field and then searched for the nearest suitable plant. Only plants with one primary raceme and four auxiliary racemes were selected, since on plants with more than five racemes, the later developing racemes were poorly developed and rarely contained pods. Subsequent plants were chosen by walking a random number of steps, random numbers were generated by computer to be between 50 and 100, and again selecting the nearest suitable plant. Similar methods, but on a smaller scale were used to select plants randomly in field plots.

The distribution of pods on racemes was determined for 20 plants collected from one commercial field of each species, near Fairview on August 15, 1985. The racemes on each plant were labelled basipetally and the numbers of pods per raceme were recorded on site. The distribution of healthy seeds and seed weight was determined for 10 plants for each species taken from plots at Fairview on August 22 for B. campestris, and August 29 for B. napus. The racemes were labelled basipetally, as described above, and then divided into thirds, based on the number of seed bearing pods on each raceme. A single pod was removed from the top, middle, and bottom third of each raceme. The contents of each pod were weighed and the total number of seeds per pod was recorded. The numbers of healthy and collapsed seeds in each pod were determined. Aborted seeds were noted but not recorded.

Analyses of variance based on a randomized complete block design were used to reveal differences among racemes or locations on racemes. Prior to the analyses, counts were transformed by adding one to the count and taking the square root (Snedecor and Cochran 1980). Where significant differences were found, mean separations were done using Duncan's new multiple range test (Steel and Torrie 1980).

5.3.3 Lygus Bug Injury and Seed Production

The effect of feeding injury by lygus bug on the production of seed by Canola plants was assessed in two ways: 1. Lygus bugs were confined in sleeve cages enclosing parts of plants. The resulting injury to buds, flowers, and pods was related to seed production. 2. Individual plants were sampled in commercial fields and plots. Seed production was related to the level of naturally-occurring lygus bug injury.

Injury by confined lygus. *B. napus* and *B. campestris* were seeded in 10 x 10 m plots, at a seeding rate of 7 kg/ha and 5 kg/ha, respectively. Rows were spaced 20 cm apart, giving 50 rows per plot. The two species were arranged in a randomized complete block design with four replicates. Seeding dates were May 28, May 21, and May 12 in 1984, 1985, and 1986, respectively. *B. campestris* cv. Tobin was seeded in all three years, whereas for *B. napus*, cv. Andor was seeded in 1984, and cv. Westar was seeded in 1985 and 1986.

To assure an adequate level of lygus bug injury, buds, flowers and pods were confined with lygus bugs in sleeve cages. The cages were made of nylon tulle supported by two plastic-covered rings, each 8 cm in diameter, and joined by a 16 cm length of wire. When buds were confined, all racemes on a plant in the bud stage were inserted in the sleeves. When flowers and pods were caged a single raceme was inserted into a sleeve, except in 1984 for _B_. _campestris_ where two racemes were inserted in a sleeve. So that racemes at the pod stage would fit in the cage, all but 10 pods were removed from the caged racemes. After inserting a raceme, the sleeve was tied loosely around the plant stem and a single adult of _L_. _elisus_ was placed in the sleeve containing plants to be infested. Control plants were treated in the same manner without the inclusion of an insect. Then, the other end of the sleeve was tied, and the cage was supported on a spike inserted into a wooden stake. Cages were left on the plants for 2 days in 1984 and for 7 days in 1985 and 1986.

Upon removal of the cage, each confined raceme was flagged for later identification. Five replicate cages per plot were used for each growth stage. An equal number of racemes was confined without lygus bugs, so that a total of 40 plants had caged racemes, 20 with an insect and 20 without for each plant growth stage caged. Racemes at the bud and flower stages (stages 3.1 and 4.1, respectively, based on Harper and Berkenkamp 1975) were caged in 1984 and 1985. Racemes at the pod stage (stage 5.1) were caged in all three years. In 1984, bud confinement experiments were conducted twice for _B_. _napus_ and flower confinement experiments were conducted twice for _B_. _campestris_. Otherwise, each stage was caged once.

The plants with caged racemes were harvested upon maturity. For racemes caged at the bud and flower stages, the number of aborted buds, blasted buds, blasted flowers, and healthy seed pods were recorded. The seeds from the confined racemes were collected and weighed. In 1984, in one experiment, racemes that had been caged in the bud stage were examined 10 days after the cages were removed to determine the number of flowers, blasted buds, healthy buds, and young pods. These plants were then allowed to develop to maturity, at which time they were harvested and measured as described above.

For racemes caged in the pod stage, pods were examined individually. The location of each pod on the raceme was recorded. Each pod was dissected and the numbers of healthy, injured, and aborted seeds were recorded. Injured seeds were divided into three categories: 1. punctured, seeds with a feeding puncture but no obvious collapse of the seed contents; 2. partially collapsed, seeds that had collapsed only in the area immediately surrounding the feeding puncture; and 3. collapsed, seeds that had collapsed to the extent that little more than the seed coat remained. The seeds in each category were counted and weighed separately.

The ability of Canola plants to compensate for lygus bug injury was assessed by measuring the deviations in seed production from that expected due to the direct, countable losses of seeds. For example, lygus bug feeding which causes seeds to collapse might reduce the number of healthy seeds by an amount equivalent to the number of collapsed seeds. In the simplest case, the total number of seeds produced by a plant, S, is equal to the number of healthy seeds, H, plus the number of seeds destroyed by lygus bug injury, D. Thus $S = H + D$ (1), or $H = S-D$ (2). If the plant is unable to compensate its seed production for the loss of individual seeds to lygus bug, then equation 2 describes the relationship between healthy and injured seeds. However, there may be plant compensation for seed loss, or indirect injury from lygus bugs that results in reduced seed production, injury other than that due to the loss of collapsed seeds. If so, the equation could be rewritten as: $H = S-bD$ (3), where b is a coefficient describing the change in seed production resulting from compensation or indirect injury. If the plant compensates for direct seed loss and indirect damage, then $b < 1$. If there is uncompensated, indirect injury correlated with the direct seed loss, then $b > 1$. Linear regression analyses where H is the dependent variable, and D is the independent variable can be used to estimate, a, the intercept or potential seed number, an estimate of S, and the slope parameter, b. Scattergrams of each relationship were examined and all relationships were determined to be linear. Therefore, this regression approach was used to determine the level of indirect injury to seed production and compensation for lygus bug injury.

The same approach was used to estimate the impact of bud and flower destruction on the production of pods. Linear regression analyses also were used to associate the different types of injury and seed production.

Lygus bug injury in commercial fields. Ten plants were collected from single fields of *B. napus* and *B. campestris* near Vegreville, Alberta on August 29, 1986 using the survey methods described above. All of the pods were hand harvested and dissected. For each plant the numbers of healthy and injured seeds were recorded and the seed was weighed.

5.4 Results

5.4.1 Description of Injury to Canola Caused by Lygus

Feeding lesions were often evident on stems and pods where lygus bugs had fed. These were characterized by brown raised areas which often coalesced to form large brown lesions in the feeding areas. When located on the pod, these lesions were not necessarily associated with injured seed.

Buds that had been fed upon by lygus bugs turned white within twenty-four hours. These buds often were shed soon afterwards. The remaining petiole was stunted throughout the life of the plant and it was possible to separate this injury from that which occurred in the flower stage. Injured flowers were characterized by an elongated petiole and an undeveloped portion of the pod which remained attached to the plant once the injured flower was shed. These symptoms were observed on foliage fed on by lygus bugs in petri dishes, on racemes exposed to lygus bugs in sleeve cages and also in commercial fields of Canola. Shedding of buds and flowers caused by lygus bugs in nature was difficult to separate from that which occurred naturally or from other types of injury.

Interpretation of lygus bug injury to seeds was based on observations of pods fed upon by lygus bugs in sleeve cages and commercial Canola infested naturally by lygus bugs. Some seeds were punctured by lygus bugs, leaving a small rupture in the seed coat but no other apparent effect. In such cases, there was no obvious discoloration of the punctured seeds and no significant difference in the weight of punctured and uninjured seeds. Dissection of 10 punctured seeds revealed no necrosis of the endosperm, indicating that the insect had injected little or no salivary fluids into the seed. Germination of these seeds was not significantly different from that of uninjured seeds collected from the same pod. Quality analyses were not conducted because insufficient quantities of this seed could be collected.

Some seeds injured by lygus bugs were partially collapsed. These seeds were usually smaller than healthy seeds and often misshapen. A puncture wound was usually evident in the vicinity of the collapsed area. The endosperm immediately below the wounded area was often necrotic. Some seeds were observed to have a profusion of white material immediately around the puncture in the seed coat. This symptom has been termed "chalky spot" in crops such as lentils (Summerfield et al. 1982). Scanning electron micrograph pictures of this area revealed large irregular-shaped granules with empty interstices. Pictures of healthy endosperm revealed that the granules were usually embedded in a matrix of material which was missing in the injured seed. The "chalky spot" symptom was not evident in all partially collapsed seeds. Seeds which were partially collapsed showed reduced germination and a slightly increased incidence of fungal infection. Germination was significantly lower (46%) for partially collapsed seeds than for for healthy seeds (97%) ($F = 45.59$; df = 1,18; $P < 0.001$). When seeds were incubated on dextrose agar, 12% of the partially collapsed seeds and 6.9% of the healthy seeds were contaminated with Alternaria spp., pathogens that have been associated with leaf spot in Canola (A. Tekaus, Agriculture Canada, pers. comm.). However, this difference was not significant ($F = 0.63$; df = 1,18: $P > 0.05$)

Some seeds injured by lygus bugs collapsed completely. These seeds consisted of little more than a seed coat. A feeding puncture was usually evident and the "chalky spot" symptom was often present in the area of the puncture. At harvest time, these seeds had coats which were similar in color to those of normal seeds except for the areas affected by the "chalky spot" symptom. The collapsed seeds had a flattened or concave shape and were often quite wrinkled. The diameter of these seeds was often similar to, or only slightly smaller than, that of a normal seed.

The percentages of injured seeds placed in each of the above categories followed the same trend in each year with the lowest number of seeds being placed in category one (punctured), slightly more in category two (partially collapsed) and the most in category three (collapsed). In 1984, for B. campestris, 21.0, 22.0, and 56.9% of the injured seeds ($n = 675$) were placed in categories one, two, and three respectively. In 1986, the proportions were 11.1, 13.8, and 75.0% for the same categories ($n = 390$). The shift between years was significant $\chi^2 = 36.3$; df = 2; $P < 0.01$). For B. napus, the proportions of injured seed placed in categories one, two and three were 10.5, 14.0, and 74.5 ($n = 919$) in 1984 and 1.2, 6.7, and 90.6 ($n = 366$) in 1986. Again, the shift was significant $\chi^2 = 37.5$; df = 2; $P < 0.01$).

Some seeds showed abnormalities which were not attributed to lygus bug feeding. Aborted seeds were often found at either end of a pod but also individual aborted seeds were found in the center of pods. These seeds were usually quite small and consisted of an undeveloped portion of the seed coat. Usually, they were white or light brown with a necrotic area at the point where the seed attached to the pod. In nearly all cases, aborted seeds were easily differentiated from seeds injured by lygus bugs by their light colour, small size, and lack of a feeding puncture. There was a weak negative correlation between the number of aborted seeds and injured seeds found per pod in 1984 ($r = -.222$; $n = 371$; $P < 0.001$), and 1986 ($r = -.108$; $n = 661$; $P < 0.001$).

Pigmented spots on the seed coat of some seeds might be confused with lygus bug feeding punctures. The pigmented areas were usually brown and quite evident especially on the yellow seeds of B. campestris. Scanning electron micrographs revealed no punctures in the seed coat at the pigmented sites. Therefore, these symptoms were assumed to be caused by factors other than lygus bug injury.

Early frosts in 1985 resulted in the loss of experiments in which lygus bugs were caged on racemes at the pod stage. Seeds exposed to the frost often collapsed and resembled seeds injured by lygus bugs. However, the seed coats of frosted seeds had a mottled appearance compared with a uniform yellow or dark brown for the lygus bug-injured seed (except for areas affected by the "chalky spot" symptom). The endosperm of frosted seed was often a dark green color versus the yellow color with a necrosis at the puncture for the lygus bug-injured seed. Drought stricken seeds, common in 1984, also collapsed and so resembled lygus bug injury to seeds. However, in cases of collapse due to drought the seeds showed no surface punctures, internal necrosis or the "chalky spot" symptom. In drought-affected pods, often all the seeds in an individual pod were collapsed, whereas lygus bug-injured seeds were mixed with healthy seeds along a pod.

5.4.2 Distribution of Lygus Bug-Injured Seed on Canola Plants

For both species of Canola, the number of pods was highest on Raceme 1, the first raceme to form, and lower on the other four racemes (Table 11). The number of seeds per pod was significantly higher in pods on the lower two thirds, or earliest formed pods on each raceme, in both B.

Table 11: Distribution of seed production on plants of *B. campestris* cv. Tobin and *B. napus* cv. Westar.

Plant trait	Location[1] on Raceme	Raceme[2] 1	2	3	4	5	SD	N
B. campestris								
No. pods		28.4a	21.7b	19.1b	22.9ab	19.4b	9.16	20
Seeds/pod	T	19.4	14.5	19.4	16.9	15.2	6.90	10
	M	21.4	17.2	20.8	24.9	22.4	6.76	10
	B	20.3	20.9	22.0	20.9	21.9	7.02	10
Seed weight,mg	T	2.05	1.88	1.69	1.57	1.97	0.40	10
	M	2.22	1.95	2.13	1.74	1.97	0.36	10
	B	2.35	2.26	2.17	2.14	2.21	0.40	10
B. napus								
No. pods		27.7a	15.6b	14.4b	13.6b	13.3b	7.24	20
Seeds/pod	T	20.9	21.0	24.1	24.1	18.7	6.22	10
	M	31.2	27.4	28.3	26.4	25.3	5.68	10
	B	28.6	30.7	28.6	29.5	30.8	5.78	10
Seed weight,mg	T	3.15	2.93	2.93	2.28	1.87	0.64	10
	M	3.72	3.24	2.98	2.60	2.84	0.46	10
	B	4.41	3.57	3.46	3.21	2.81	0.59	10

Means in rows representing no. pods followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955; in Steel and Torrie 1980] Multiple Range Test).

[1] Locations on raceme are T = top, M = middle, and B = bottom.

[2] Raceme 1 is at the top of the main stem, racemes 2-5 are formed sequentially as side branches.

napus ($F = 22.28$; df = 2,130; $P < 0.001$), and in *B. campestris* ($F = 11.27$; df = 2;127; $P < 0.001$) , but did not vary significantly among racemes for either *B. napus* ($F = 0.64$; df = 4,130; $P > 0.05$) or *B. campestris* ($F = 1.35$; df = 4,127; $P > 0.05$). Individual seeds were heaviest at the bottom of Raceme 1 and decreased in weight toward the top of the raceme and with raceme number. The last seeds to form at the top of Raceme 4 and 5 were the lightest. There were significant differences based on analysis of variance in the weight of seeds among racemes in *B. napus* ($F = 17.29$; df = 4,79; $P < 0.001$) and *B. campestris* ($F = 2.80$; df = 4,78; $P < 0.05$), and among parts of racemes for both *B. napus* ($F = 28.17$; df = 2,79; $P < 0.001$) and *B. campestris* ($F = 7.94$; df = 2,78; $P < 0.001$).

The percentage of seeds blasted by lygus bugs was higher at the top of each raceme in both *B. napus* ($F = 13.98$; df = 2,116; $P < 0.001$) and *B. campestris* ($F = 4.44$; df = 2,127; $P < 0.05$). For *B. campestris*, the percentage of seed blasted by lygus bugs tended to be lower on Raceme 1 compared to other racemes, although an analysis of variance revealed no significant differences ($F = 2.25$; df = 4,127; $P > 0.05$) (Table 12). In *B. napus*, the percentage of seeds blasted by lygus bugs were significantly lower ($F = 9.50$; df = 4,116; $P < 0.001$) on Raceme 1 than on Raceme 5.

5.4.3 Lygus Bug Injury and Seed Production

Bud injury. When lygus bug injury to buds was augmented by caging a lygus bug on racemes in the bud stage, the percentage of blasted buds on the racemes was higher than on racemes which were caged without lygus

Table 12: Distribution of seed blasted by lygus bug as a percentage of total seed on pods from 10 plants of _B_. _campestris_ cv. Tobin and _B_. _napus_ cv. Westar.

Location[1] on Raceme	Raceme[2]						
	1	2	3	4	5	SD	n
_B_. _campestris_							
T	10.7	18.4	22.7	29.1	24.5	25.2	10
M	14.1	14.6	13.5	21.6	25.9	23.4	10
B	10.6	9.4	7.2	13.8	14.9	18.2	10
_B_. _napus_							
T	17.3	60.4	32.0	28.4	52.2	26.9	10
M	12.8	23.4	16.5	21.7	39.0	19.4	10
B	3.7	20.6	11.6	20.7	27.2	16.8	10

[1] Locations on raceme are T = top, M = middle, and B = bottom.

[2] Raceme 1 is at the top of the main stem, racemes 2-5 are formed sequentially as side branches.

Table 13: Number of buds and pods produced per raceme and percentage of buds blasted on racemes of Canola caged with and without a lygus bug during the bud stage.

Year	Treatment	No. plants	Buds/ raceme	Pods/ raceme	% blasted
B. campestris					
1984	lygus[1]	18	21.4 a[2]	17.0 a	19.2 a
	no lygus	18	19.9 a	18.0 a	7.7 b
1985	lygus	20	41.5 a	28.6 a	27.2 a
	no lygus	18	28.0 b	22.7 a	15.6 b
B. napus					
1984	lygus	39	14.7 a	13.0 a	10.2 a
	no lygus	37	14.9 a	14.5 a	1.9 b
1985	lygus	16	24.0 a	20.6 a	12.8 a
	no lygus	20	18.4 b	16.0 b	11.5 a

Means for each year and species in a column followed by the same letter are not significantly different ($P < 0.05$; LSD test [Steel and Torrie 1980]).

Analysis of variance was conducted using data transformed using $(x + 1)^{0.5}$ for counts and arcsine for percentages.

[1] Insects were confined on the plants for 2 days in 1984 and 7 days in 1985.

[2] Means for counts and percentages are back-transformed from the transformed means.

bugs (Table 13). The increase in the percentage of blasted buds was significant in 1984 ($F = 4.87$; df = 1,31; $P < 0.05$) and in 1985 ($F = 7.08$; df = 1,36; $P < 0.05$) for *B. campestris*, and in 1984 for *B. napus* ($F = 17.21$; df = 1,66; $P < 0.001$). Some blasting of buds, flowers or young pods also occurred on the control racemes, probably due to natural infestation of the racemes by lygus bug before and after caging. The level of blasting was higher on *B. campestris* than on *B. napus*, and higher in 1985 than in 1984. In 1984, blasting ranged from 10-19%, but no reduction in the average number of pods produced by the raceme was observed although the level of blasting reached 19% (Table 13). In 1985, in *B. napus* significantly more buds were produced on plants caged with a lygus bug ($F = 5.81$; df = 1,35; $P < 0.05$). In *B. napus*, there were significantly more pods produced on plants caged with a lygus bug ($F = 6.17$; df = 1,35; $P < 0.05$) indicating that the plants overcompensated for bud injury. This same trend was evident in *B. campestris* where there was a significant difference in the numbers of buds produced ($F = 4.66$; df = 1,38; $P < 0.05$), but no difference in the number of pods produced ($F = 1.83$; df = 1,38; $P > 0.05$).

In both years, seed production by the racemes was negatively related to the percentage of buds blasted by lygus bug, however, these relationships were significant only in 1984 (Table 14). No compensation occurred on the raceme as a result of an increase in seed size or seed number. This was confirmed by the negative, although usually non-significant, relationship between seed production per pod and percentage of buds blasted. The regression relationships all had low r-square values, ranging from 0.07 to 0.27 for those which were

Table 14: Relationship between seed production by weight and the percentage of buds or flowers blasted by lygus bug when racemes were caged during the bud and flowers stages.

Year	Seed parameter, mg	Bud stage					Flower stage				
		n	Intercept	Slope	r^2	P	n	Intercept	Slope	r^2	P
B. campestris											
1984	Seeds/raceme	53	744.7	- 7.4	0.07	0.05	73	918.74	-20.71	.16	.00
	Seeds/pod	53	32.2	- 0.1	0.01	0.45	73	34.99	- 0.25	.04	.08
1985	Seeds/raceme	33	897.2	- 9.5	0.05	0.23	76	1343.80	-27.75	.29	.00
	Seeds/pod	33	34.7	- 0.5	0.22	0.01	76	52.23	- 0.85	.18	.00
B. napus											
1984	Seeds/raceme	64	1043.7	-18.2	0.27	0.00	38	1149.26	-4.27	.01	.62
	Seeds/pod	64	56.7	- 0.3	0.05	0.09	38	60.82	-0.27	.01	.45
1985	Seeds/raceme	34	1745.0	-25.7	0.07	0.12	31	2001.10	-48.27	.38	.00
	Seeds/pod	34	88.2	- 1.0	0.06	0.18	31	89.94	- 1.70	.45	.00

significant at $P < 0.05$. The lygus bug injury accounted for a relatively small proportion of the variation in the weight of seeds per raceme.

When B. campestris plants were examined 10 days after the cages were removed in 1984, there were significantly more flowers present on the racemes caged with an adult lygus bug ($\bar{x} = 26.7$ SD = 12.4 n = 20) compared to those caged without ($\bar{x} = 16.3$ SD = 12.0 n = 20). However, there were significantly fewer healthy buds on the infested racemes ($\bar{x} = 7.8$ SD = 10.6 n = 20) compared to the uninfested racemes ($\bar{x} = 14.9$ SD = 14.1 n = 20). B. napus racemes showed the same trend when caged with a lygus bug, that is, they had more flowers and fewer healthy buds, although the differences were not significant. Racemes receiving injury to buds initiated flowering of the remaining buds earlier, but no net change in the number of buds occurred. This is in contrast to 1985 when there was a net increase in the number of buds not just an acceleration in the rate of development of buds (Table 13).

Flower injury. When lygus bug injury to flowers was augmented by caging a lygus bug on a raceme in the flower stage, the percentage of blasted flowers on the racemes was higher than on racemes which were caged without lygus bugs (Table 15). A significant increase in the percentage of blasted flowers was observed in 1984 for both B. napus ($F = 22.01$; df = 1,34; $P < 0.001$) and B. campestris ($F = 7.81$; df = 1,96; $P < 0.01$). Some lygus bug injury occurred due to natural infestation before and after caging. A significant increase in the number of buds produced by lygus bug-injured racemes was evident only for B. campestris in 1985 ($F = 4.21$; df = 1,39; $P < 0.05$). In all cases, there was no significant difference in the number of pods produced on plants caged with or without a lygus bug (Table 15) indicating that some compensation occurred.

Table 15. Number of buds and pods produced per raceme and percentage of flowers blasted on racemes of Canola caged with and without a lygus bug during the flower stage.

Year	Treatment[1]	No. plants	Buds/ raceme	Pods/ raceme	% blasted
B. campestris					
1984	lygus	51	23.7a[2]	20.9a	9.3a
	no lygus	49	21.7a	20.7a	4.8b
1985	lygus	19	37.4a	29.7a	15.4a
	no lygus	20	26.3b	22.8a	12.4a
B. napus					
1984	lygus	19	19.8a	17.9a	9.5a
	no lygus	20	18.4a	17.7a	1.9b
1985	lygus	19	25.5a	21.6a	14.1a
	no lygus	17	20.2a	17.4a	13.6a

Means for each year and species in a column followed by the same letter are not significantly different ($P > 0.05$; LSD test [Steel and Torrie 1980]).

Analysis of variance was conducted using data transformed using $(x + 1)^{0.5}$ for counts and arcsine for percentages.

[1] Insects were confined on the plants for 2 days in 1984 and 7 days in 1985.

[2] Means for counts and percentages are back-transformed from the transformed means.

The weight of seeds produced per pod was negatively related to the percentage of flowers blasted, and therefore the plant did not compensate for flower loss by increasing the number or size of seeds produced in surviving pods (Table 14). The net result of lygus bug injury at flowering was a negative relationship between seed production per raceme and the percentage of flowers blasted for both species in both years. The slope of the relationship was significant for *B. campestris* in both years and for *B. napus* in 1985. As was observed in tests on the bud stage, the regression relationships accounted for a small amount of the variation in pod or seed production with r-squares from 0.11 to 0.45 for those relationships that were significant at $P < 0.05$. The lygus bug injury to flowers accounted for a relatively small proportion of the variation in number of pods per raceme or seed production.

Seed injury. When lygus bug injury to seed was augmented by caging lygus bug on a raceme with 10 pods, the percentage of seeds injured per pod was higher for caged racemes with an adult lygus bug than for those without lygus bugs (Table 16). The increase in injury was significant for *B. napus* in 1984 ($F = 33.91$; $df = 1,39$; $P < 0.001$) and 1986 ($F = 23.82$; $df = 1,39$; $P < 0.01$) and *B. campestris* in 1984 ($F = 9.32$; $df = 1,39$; $P < 0.01$). (The data from tests conducted in 1985 could not be analyzed because the pods were affected by an early frost.) Lygus bugs were present naturally in the plots after the cages were removed, and so there was injury to seeds from the control racemes. The pods which were caged with lygus bugs and suffered a higher seed loss did not produce a significantly different number of seeds than pods with low levels of injury (Table 16). They apparently did not respond to the

Table 16: Seed production and percentage seeds blasted for Canola racemes caged with and without lygus.

Year	Treatment[1]	No. pods	Seeds/pod	Seed weight, mg	% blasted
B. campestris					
1984	lygus	139	16.9a[2]	1.83a	22.4a
	no lygus	174	15.9a	1.87a	12.6b
1986	lygus	184	18.2a	2.48a	6.9a
	no lygus	170	18.2a	2.60a	5.2a
B. napus					
1984	lygus	116	19.4a	2.33a	38.7a
	no lygus	98	17.1a	2.53b	8.4b
1986	lygus	158	22.1a	3.04a	8.8a
	no lygus	147	23.1a	3.31b	1.8b

Means for each year and species in a column followed by the same letter are not significantly different ($P > 0.05$; LSD test [Steel and Torrie 1980]).

Analysis of variance was conducted on data transformed using $(x + 1)^{0.5}$ for counts and arcsine for percentages.

[1] Insects were confined on the plants for 2 days in 1984 and 7 days in 1986.

[2] Means for counts and percentages are back-transformed from the transformed means.

injury by producing more seed. In 1986, the lack of this form of compensation was confirmed by the relationships between the number of healthy (y) and blasted seeds (x), which had slopes that were not significantly different from 1 ($p > 0.05$) (Sokal and Rohlf 1981). The relationships were, for B. napus, $y = 24.4-0.96x$ $r^2 = 0.15$ $n = 115$, and for B. campestris $y = 19.3-0.93x$ $r^2 = 0.18$ $n = 174$, indicating a reduction of one healthy seed for each seed blasted in the pod. However, in 1984, the relationships were, for B. napus, $y = 16.6-0.50x$ $r^2 = 0.09$ $n = 156$, and for B. campestris, $y = 15.22-0.55x$ $r^2 = 0.13$ $n = 185$. In this case, the slopes were significantly lower than 1 approximating a reduction of 1 healthy seed for every 2 seeds blasted per pod. This indicates the plants did partially compensate for injury by producing more healthy seeds.

The total weight of seeds produced per pod was negatively related to the percentage of seeds blasted by lygus bugs for both species of Canola and in both years (Table 17). When lygus bugs blasted 10% of the seed, the loss in weight of seed produced per pod was about 11% (range 6-14% in the 4 tests) showing that pods had little or no ability to compensate the weight of seeds for the loss of seeds. This was confirmed by the fact that pods with injured seeds did not increase the size of remaining healthy seeds. The relationship between the weight of individual healthy seeds and the percentage of lygus bug injured seeds had small, non-significant slopes (Table 17). In B. napus in 1984 and 1986, the weight of individual seeds was significantly lower for racemes caged with a lygus bug than for those caged without (Table 16). In 1986, injury to the surface of the pods from lygus feeding was common in cages with a

Table 17: Relationship between seed production by weight and the percentage of seeds blasted by lygus when racemes were caged during the pod stage.

Year	Seed production, mg	n	Intercept	Slope	r^2	P
B. campestris						
1984	Seeds/pod	326	33.1	-0.21	0.09	0.00
	Seed weight	326	1.7	0.00	0.00	0.32
	Seeds/raceme	26	243.7	-1.65	0.18	0.03
1986	Seeds/pod	340	54.0	-0.75	0.14	0.00
	Seed weight	340	2.6	0.00	0.00	0.48
	Seeds/raceme	33	456.4	-5.80	0.05	0.21
B. napus						
1984	Seeds/pod	166	55.6	-0.58	0.40	0.00
	Seed weight	166	2.5	0.00	0.02	0.05
	Seeds/raceme	17	352.5	-3.42	0.49	0.00
1986	Seeds/pod	306	77.0	-1.07	0.29	0.00
	Seed weight	306	3.3	-0.03	0.12	0.00
	Seeds/raceme	32	624.2	-8.04	0.08	0.11

lygus, suggesting that the injury to pod surfaces may have caused a reduction in seed production through a reduction in seed size caused by injury to pod surfaces. Both B. napus (F = 11.43; df = 1,299; $P < 0.001$) and B. campestris (F = 4.38; df = 1,333; $P < 0.05$) pods produced a significantly lower weight of seeds when racemes were caged with a lygus (60.1 mg and 41.8 mg respectively) compared to those without a lygus (71.7 mg and 46.8 mg, respectively). For both species, the loss in weight of seeds produced per pod was greater than expected based on the percentages of blasted seed per pod (Table 16).

When seed production was considered on the basis of racemes, a similar pattern was observed to that revealed by analysis of seed production for individual pods. For both crop species and in both years the relationship between seed production per raceme was negatively related to the percentage of seed blasted per raceme, although the slopes of the relationships were significant only in 1984 (Table 17). When 10% of the seeds were blasted an average of 10.2% (range 6.8-12.9%) of the seed production by weight was lost.

As was observed in the bud and flower tests, the r-squared values for the relationships between seed production and the percentage of seed blasted were low, between 0.09 and 0.49 when $P < 0.05$, indicating that injury to the seed by lygus bugs accounted for only a small proportion of the variation in seed production among pods or racemes.

Lygus bug injury in commercial fields. The two commercial fields sampled in 1986 suffered a low level of lygus bug injury, with 2.4 ± 0.7% of the seed blasted in B. napus and 1.7 ± 1.4% blasted in B. campestris. For pods from the fields, the slopes of the relationships between number of healthy seeds per pod (y) and number of blasted seeds per pod (x) were significantly less than -1 for both B. napus ($t = 2.08$; $y = 27.26-1.17x$; $r^2 = .58$; $n = 140$; $P < 0.01$) and B. campestris ($t = 2.51$; $y = 24.5-1.29x$; $r^2 = .57$; $n = 96$; $P < 0.05$) indicating that, more than one healthy seed was lost for each seed blasted by lygus bugs. Seed production per plant was negatively related to the percentage of blasted seed for both species, but only significantly so for B. napus (Table 18). Using the percentage of blasted seed estimated in each field the relationship suggests that 1.2% of the seed production of B. campestris was lost whereas 4% of the seed production of B. napus was lost. There was no relationship between the weight of individual seeds and the percentage of seeds blasted as shown by the small, non-significant slopes of the relationships. Although the level of lygus bug-injury was low in these fields, the relationships between injury and losses in seed production were similar to those observed in cage tests.

5.5 Discussion

When presented with Canola in petri dishes or in field cages, lygus bugs feed actively on various plant parts and cause characteristic, visible injury. This injury is evident as lesions on the stems, buds, flowers, pods, and seeds of the plants. The same symptoms are evident in commercial Canola fields. No other insect pests or disease organisms have been identified in Canola which could account for these symptoms. The pathogen Alternaria spp., a potential pathogen of Canola, is present in only a small proportion of the lesions and could not be the main cause of the symptoms.

Table 18: Relationship between seed production by weight and the percentage of seeds blasted by lygus for plants collected in two fields of Canola near Vegreville, Alberta 1986.

Seed production, mg	n	Intercept	Slope	r^2	P
<u>B</u>. <u>campestris</u>					
Seeds/plant	10	6301.6	-43.3	0.06	0.49
Seed weight	10	1.5	0.0	0.22	0.17
<u>B</u>. <u>napus</u>					
Seeds/plant	10	8840.5	-147.5	0.55	0.01
Seed weight	10	3.3	0.0	0.32	0.09

The feeding activity of lygus bugs causes the shedding of buds and flowers of Canola. This injury is similar to symptoms of lygus bug injury in many other crops (Strong 1970, Tingey and Pillemer 1977). For instance, premature drop of buds, flowers and fruit has been noted in tomatoes (Davis et al. 1963), apples (Prokopy and Hubbel 1981), and cabbages (Getzin 1983). Alfalfa buds are destroyed quickly by lygus bugs. Lygus hesperus Knight can dissolve the contents of a 0.25 mm bud in 23 sec (Strong 1970). In cotton, small buds are shed within 4 days of being injured by lygus bugs (Strong 1970). The likelihood that these organs will be shed when injured by lygus bugs depends on their size. For example, 50% of buds 5 mm or less in diameter were shed when lygus bugs were confined on cotton, whereas none of the buds 8 mm or greater were shed (Strong 1970). In this study, shedding of buds was less evident for B. napus than for B. campestris, probably because of the larger size of the buds in the former species.

Natural shedding of buds and flowers is common in Canola and can be attributed to a variety of stresses other than lygus bugs. However, when natural shedding occurs, usually all buds or flowers produced during the period of stress, i.e. during a hot dry spell, are shed. An inadequate supply of nutrients (Allen and Morgan 1975, Mendham et al. 1981), sudden drops in temperature (Scott et al. 1973), and inadequate pollination (Williams 1978) all can result in podless stalks. When a plant has reached its capacity for seed production, a reduction in the availability of assimilates may result in the shedding of the remainder of the undeveloped buds (Keiller and Morgan 1988a). Usually buds are shed at the top of the raceme which is the last area to develop. Thus, although there are differences in the pattern of shedding of buds and flowers due to lygus bug feeding and other stresses, and often lesions are evident on the remnants of lygus bug blasted buds and flowers, it is not always easy to distinguish the shedding caused by lygus bugs from that caused by other stresses, especially under field conditions.

Lygus bug injury to seeds in Canola is also similar to that observed in other crops, such as lentils, where "chalky spot" and seed collapse are indicative of lygus bug feeding (Summerfield _et_ _al_. 1982). Shrivelled seeds are common in alfalfa fields infested with lygus bugs (Sorenson 1936). Injury to peach fruits can be placed in similar categories to those found in Canola: young fruits die when injured; larger fruits develop deformities consisting of depressions; and some fruits show scarring and dimpling but no deformities (Rings 1958).

Seed injury in Canola can be distinguished from other types of injury. Diseased, frozen and aborted seeds differ morphologically from seeds injured by lygus bugs. Drought-stricken seeds are similar in appearance to lygus bug-injured seed, but usually most or all seeds in a pod or part of a raceme are drought affected. Drought-stressed seeds do not exhibit lesions characteristic of lygus bug feeding. The symptoms of lygus bug injury to seeds are more distinct than those for buds because the evidence of the puncture is preserved in the seed coat. For this reason, the percentage of seeds which had collapsed or partially collapsed from lygus feeding were used as a measure of the feeding rate of lygus bugs on Canola plants. This measure underestimates the actual number of seeds affected by lygus bug feeding because it excludes seeds that were punctured but not collapsed.

The percentage of seeds blasted by lygus bugs is also a useful direct measure of the loss in seed production due to lygus bug feeding. But this measure of lygus bug injury to seed production assumes that: 1. seed weight and lygus bug injury are uniform over the plant, 2. there are no indirect effects of lygus bug feeding on seed production, and 3. the plant is unable to compensate for indirect injury or seed blasting. The latter two possibilities are addressed in subsequent paragraphs. Because the heaviest seeds on Canola plants are produced near the bottom of the primary raceme and a larger proportion of the lygus bug-blasted seeds occur on the top of other racemes, estimates of lost seed production based on the percentage of seeds blasted may overestimate the loss in seed production. In field collected plants of _B. napus_ significantly less injury occurs on the primary raceme. Therefore, the actual yield loss by weight (20%) is less than the yield loss estimated by percent injury (22%). In _B. campestris_ 12.8% of the seeds produced per plant were lost due to lygus bug feeding. However, if this number is adjusted according to the average number of seeds per pod, and the average weight per seeds produced on each raceme the percentage of yield lost is actually 15.7%. Therefore the location and extent of injury should be considered with any yield loss estimate.

The Canola plant is able to compensate for both bud and flower blast under certain conditions. In the greenhouse, potted plants compensate for injury to buds and flowers (Williams and Free 1979, Tatchell 1983). However, in the field compensation does not always occur (Nilsson 1987) probably due to competition between closely associated plants which tend to be smaller than plants grown individually (Rood and Major 1984). In

1984, plants compensated for bud injury, and produced as many or more pods than racemes with fewer blasted buds. However, as indicated by the decline in seed weight per pod these new pods were lighter, resulting in a net loss in seed production. Plants overcompensated for bud loss, in 1985, by producing significantly more pods on injured racemes. Therefore, even though seed weight per pod declined with increased bud injury, full compensation occurred. The differences between years may also be related to differences in the level of competition between plants for limited resources. In 1984, the rainfall for May and June was 246 mm which was more than twice the 30 year average for the Fairview area (99.3 mm), whereas in 1985, only 70.4 mm of rain fell, in the same period. Plots in 1984 were lush and dense compared to plots established in 1985. Therefore, intense competition between plants may have occurred in 1984, reducing the individual plant's ability to compensate for losses in seed production.

The impact of injury to the flowers will depend on when the injury occurs. Injury at anthesis can be compensated for by the development of a larger number of smaller pods and the level of compensation declines as the days from anthesis increase (Keiller and Morgan 1988b). Where flowers were injured, an increase in the number of pods produced as injury increased was not evident in this study, in either year. In 1984, the plants may not have been able to respond to injury because of weather conditions. However, in 1985, the lack of compensation may have been due to the length of the confinement. In this season, plants were injured over a week long period. Most other experiments have examined the impact of injury inflicted at one point in time (Tatchell 1983, Keiller and Morgan 1988b). Compensation is not as evident when injury occurs over a longer period of time (Williams and Free 1979).

Little is known about compensation for injury to seeds. Seed injury by _Ceutorhynchus assimilis_ (Payk.), which occurs early in pod development, may be compensated for in some years (Tatchell 1983). However, the proportion of pods infested is positively correlated to plant size (Williams and Free 1979) and this may have confounded the results of the above study. The current study shows that the Canola plant does not compensate for lygus bug injury to seeds by increasing the seed weight or number of healthy seeds in the same pod. Compensation may be achieved by allocating resources to other areas of the same plant, although no evidence for such compensation was found. The inability of Canola to compensate for seed loss may be a result of the late stage at which such injury occurs.

The level of compensation for direct injury by lygus bug to buds, flowers, pods and seed is difficult to measure precisely because measures of compensation are confounded by the indirect injury lygus bug also causes. The indirect injury, which results in lesions to the surfaces of stems and pods, probably results in a drain on the resources the plant might have marshalled to compensate for direct losses of buds or seeds to lygus bug feeding. Significant reductions in the weight of seed produced per pod occur as a result of indirect lygus bug injury. This effect shows that the indirect injury may more than balance the ability of the plant to compensate for lygus bug injury. Similarly, injury to the pod coat by _Dasineura brassicae_ (Winn.) leads to reductions in seed production (Tatchell 1983).

The level of compensation for direct and indirect injury by lygus bugs varies from year to year and between locations. More research work is needed to clarify how environmental factors and lygus bug injury interact to influence seed production in Canola. Lygus bugs must be considered a significant pest of Canola because significant injury does occur under field conditions and the Canola plant is not able to compensate for blasted seeds.

6 LYGUS (HETEROPTERA: MIRIDAE) INJURY AND YIELD LOSS IN OILSEED BRASSICA CROPS IN ALBERTA

6.1 Abstract

The impact of lygus bug injury in oilseed rape was assessed in plots and commercial fields of oilseed rape Brassica napus L. and Brassica campestris L. When lygus bugs were controlled at the early pod stage of oilseed rape, yield increased by 11-35%. Lygus bug densities reached 52 lygus bugs per 10 sweeps at the early pod stage in 1985. Neither bud nor flower sprays resulted in increased yields. The percentage of seeds injured increased and the yield decreased as lygus bug density increased. Also, yield declined as the percentage of seed injured by lygus bugs increased. These relationships followed the same trends in a number of experiments conducted over two years, but many of the slopes defining the trends were not statistically significant and the predictive variables accounted for relatively small proportions of the variation. However, the relationships between lygus bug density, percentage of seed injured by lygus bugs, and Canola yield support the conclusion that lygus bugs can cause agronomically important losses of Canola under field conditions in Alberta.

6.2 Introduction

Lygus bugs have been found in oilseed rape (i.e., Canola), Brassica napus L. and Brassica campestris L., grown in Canada for many years. Three species of lygus bugs infest Canola in Alberta (Section 3). Both species of Canola and all cultivars tested are infested (Section 4).

Until recently, no attempts have been made to determine whether or not lygus bug populations in Canola cause crop injury that might warrant control (Section 5). Control programs have been reported for lygus bugs infesting other crops, e.g. beans (Stewart and Khattat 1980), and cotton (Cave and Gutierrez 1983). The first step in developing control guidelines for lygus bug in Canola is to assess their pest status in the crop.

The objectives of this study were to determine: 1) if insecticidal control of lygus bug increases the yield of Canola; 2) if yield loss and the level of crop injury are related to lygus bug density; 3) how widespread and severe the losses of Canola due to lygus bug are in Alberta.

6.3 Methods and Materials

Insecticidal control and yield loss. Two types of experiments were conducted using an insecticide to control natural infestations of lygus bug in field plots. The purpose of the experiments was to determine if reducing the densities of lygus bugs during the pod stage, when lygus bug injury is important (Section 5), would increase the yield of the sprayed plots in relation to that of the control plots. The first was a randomized complete block (RCB) design with insecticide applied at three crop growth stages. The second was a split plot (SP) design with insecticide applied at a single crop growth stage.

The RCB experiments were seeded in plots (4 x 10 m) suitable for the cultivation of Canola at Fairview, Alberta and at Vegreville, Alberta on 4 June 1985 and 12 May 1986, respectively. *B. campestris* cv. Tobin was seeded in 1985 and 1986, and in 1986 *B. napus* cv. Westar was included in the same trial. Seed was sown at a depth of 2.5 cm, in rows spaced at 20 cm, and at a seeding rate of 5 kg/ha for *B. campestris* and 7 kg/ha for *B. napus*. In 1985, *B. campestris* was seeded in 4 plots, replicated 4 times. In 1986, the two cultivars were seeded in 4 plots each per block, totalling eight plots per block and each block was replicated 4 times. The treatments consisted of a single application of an insecticide at one of three plant growth stages and a control, as follows: at the early bud stage, when at least 75% of the plants had visible buds (3.1, growth stages defined by Harper and Berkenkamp (1975)); at the flower stage, when at least 75% of the plants had open flowers (4.1) and all the plants had bolted; at the early pod stage, when at least 75% of the plants had started forming pods (5.1); and the control plots, which were sprayed with water during the early pod stage. Deltamethrin was applied at a rate of 12 g AI/ha with a self propelled boom-sprayer using flat fan nozzles calibrated to deliver 100 l/ha at a pressure of 275 kpa and a speed of 6 km/hour.

Lygus bug densities in each plot were monitored immediately prior to an insecticide application and 48 h after spraying in 1985 (6 times), and weekly in 1986. Samples consisted of 10, 180° sweeps per plot using a 37.5 cm diameter sweep net.

The percentage of seed injured by lygus bug in each plot was estimated by picking pods from the top, middle and bottom of plants in each plot. Sampled plants were located by walking two paces into the plot and choosing every fifth plant along the length of each row. A subsample of 50 pods per plot were later examined in the laboratory by dissecting out the seeds and assigning them to injury categories. The number of healthy, lygus bug-injured, and aborted seeds per pod were recorded. Seeds were assigned to the 'lygus bug-injured' category if they had collapsed and a feeding puncture or the symptoms of enzymatic destruction of the seed contents were evident (Section 5). Any injured seeds determined not to be injured by lygus bug were recorded separately, but pooled with the healthy seeds to calculate percentages of seeds injured by lygus bug. Aborted seeds were not included in the count of total seeds. In 1985, because of an early frost, seed samples were collected green and then frozen. Seed samples deteriorated by the time they were examined and the percent injury could not be estimated accurately. Yields per plot were estimated by hand harvesting two, 1 m^2 areas in each plot, and in 1986, 1000-seed-weights were determined from each yield sample by weighing three subsamples of 1000 healthy seeds and calculating the mean weight. Two-way analysis of variance (SAS Institute 1985) was conducted for each parameter apportioning variance to spray timing and block effects. Separate analyses were performed for each year and cultivar. When significant differences were detected mean separations were determined used Duncan's new multiple range test (Steel and Torrie 1980).

The split-plot experiment was seeded in plots (6 x 30 m) on three dates 21 May, 10 June, and 24 June in 1985. Five replicate plots of _B. campestris_ cv. Tobin were sown on each date. A 5 x 6m area of each plot was sprayed with deltamethrin, as described above, during the early pod stage. Plots were monitored for lygus bug twice weekly using 10, 180° sweeps per plot in the sprayed and unsprayed areas of each plot. Yields from sprayed and unsprayed areas were determined by harvesting a one metre square area of each plot. They were compared using a paired t-test.

Lygus bug density, seed injury, and yield. To determine the relationships between lygus bug density and seed injury, the data from the experiments described above were analyzed by linear regression. Scattergrams were examined and all relationships appeared to be linear. Also, the same analyses were applied to estimates of seed injury and yield from seeding date and cultivar trials, and to samples taken from commercial Canola fields. These experiments are described below.

In 1985 and 1986, *B. campestris* cv. Tobin and *B. napus* cv. Westar were seeded on three dates (will be referred to as the 'seeding date trial') (Section 3). The two cultivars were sown in adjacent areas of a field in plots, 6 X 30 m, at a seeding rate of 7 kg/ha for Westar and 5 kg/ha for Tobin. Rows were 20 cm apart, giving 30 rows per plot. Five replicate plots were sown for each seeding date and crop species. The seeding dates were 21 May, 10 June, and 24 June 1985 at Fairview, and 12 May, 22 May, and 5 June 1986 at Vegreville. In 1985, seeding was delayed and *B. napus* plots were abandoned when they did not emerge because of drought.

Also in 1985 and 1986, five cultivars of oilseed rape were seeded (will be referred to as the 'cultivar trial') in plots, 10 x 4m, with rows 20 cm apart, giving 20 rows per plot (Section 4). The five cultivars used were: *B. napus* cvs. Westar, Andor, and Midas, and *B. campestris* cvs. Tobin and Torch. Five replicate plots were sown for each cultivar. The seeding date was 21 May in 1985, and in 1986. For both experiments, each plot was sampled for lygus bug during the early pod stage, and for pods late in the pod stage (as described above). The pods were dissected and the proportion of seed injured by lygus bug was determined. In the seeding date experiment, yields were estimated by harvesting two, 1 metre square areas of each plot and taking a mean weight.

To compare plot results to those for Canola growing under normal farming practices, 16 commercial fields were sampled for lygus bug during the early pod stage in 1986. Each field was entered from the roadway and surveyed in an inverted V pattern. Ten sites were chosen by walking a random number of paces, between 50 and 100. At each site, lygus bugs were collected using 10, 180° sweeps, and two plants were uprooted and transported out of the field for later examination. A second visit was made to each field just prior to harvest to collect pods from the top, middle, and bottom of the crop canopy at several sites throughout the field. In the laboratory, a subsample of 50 pods was extracted from each sample and each pod was dissected. The number of healthy, injured, and aborted seeds was recorded as described above. Yields were obtained for each field by asking the farmers for an accurate estimate of the yield in each field. Yields were estimated in bushels per acre based on the storage volume needed to contain the harvest from the entire field, and converted to g/m^2 for the regression analyses. Farmers were informed prior to harvest that these data was needed, and therefore, it is assumed that the yield estimates are as accurate as possible given the methods of harvest.

For the above experiments, linear regressions (y = a + bx) of yield (y) against the number of lygus bugs (x) per 10 sweeps was estimated separately for each of the early pod stages (5.1-5.2). The percentage of injured seed was regressed against the number of lygus bugs per 10 sweeps collected in each plot during the early pod stages (Harper and Berkenkamp 1975). For the seeding date trial, analysis of covariance (SAS Institute 1985) was used to account for the effect of seeding date when comparing the yield parameters to number of insects collected.

Survey of lygus bug injury. In 1982 and 1983, the province of Alberta was divided into three regions: Peace River, central Alberta, and southern Alberta. The Peace River region consisted of an area bounded on the south by Valleyview, the east by High Prairie, the north by Fort Vermilion and the west by the British Columbia border. Central Alberta extended from Athabasca south to Red Deer and east and west to the provincial borders. Southern Alberta was any area south of Red Deer to the U.S.A.-Canada border. Within each region, Canola growing districts were identified (M. Rudakewich, Alberta Agriculture, pers. comm.). Municipal Districts (M.D.), Counties, and Improvement Districts (I.D.) within Canola growing districts of each region were divided into sampling areas identified by central locations. Twenty of these areas were selected at random within each region of the province. The surveyor then drove to a designated area and selected the canola field closest to the central location. The surveyor entered each field from one corner and followed an inverted V pattern. Sampled plants were identified by walking a randomly selected number of paces and sampling the plant immediately to the left. Pods from the top, middle, and bottom of 100 plants were collected and brought back to the laboratory for examination. Seeds were dissected from the pods and divided into categories as described above. Seeds that were collapsed but showed no external signs of injury, i.e., feeding punctures, were included in the healthy category because we assumed that they were not damaged by lygus. Inexperience at detecting feeding punctures may have led to underestimates of injury in some cases. The Canola species in the field and notes on crop condition were recorded for each field sampled. In 1982, seed samples for three sites in southern Alberta were lost before injury could be estimated and therefore, 17 instead of 20 fields were analyzed. An additional thirty-five fields were surveyed in the Peace River region in 1982.

6.4 Results

Insecticidal control and yield loss. In RCB experiments pre-spray counts indicated that there were no significant differences in lygus bug numbers per plot in either *B. campestris* ($F = 0.66$; df = 3,9; $P > 0.05$) or *B. napus* ($F = 1.95$; df = 3,9; $P > 0.05$). Deltamethrin effectively killed lygus bugs at each crop stage. In 1985, 48 h after spraying, 0.8(SD = 1.30) lygus bugs per 10 sweeps were collected in 5 plots of *B. campestris* sprayed in the flower stage compared to 5.2(SD = 3.42) collected in the 5 check plots, and no lygus bugs were collected in 5 plots sprayed in the pod stage compared to 14.6(SD = 10.92) collected in the 5 check plots. In 1986, in *B. campestris* no lygus bugs were collected 48 h after spraying in the 4 plots sprayed in the bud, flower, and pod stages compared to 0.5(SD = 0.57), 1.8(SD = 2.61), and 5.5 (SD = 6.45), at the bud, flower and pod stages, respectively, collected in the 4 control plots. In *B. napus*, no lygus bugs were collected in the 4 sprayed plots whereas 0.25(SD = 0.5), 0.6(SD = 0.89), and 0.71 (SD = 0.95) were collected in the 4 control plots at the bud, flower and pod stages, respectively.

Lygus bug densities at the pod stage were most effectively controlled when insecticide was applied early in the pod stage (Table 19). When plots were sprayed at the bud and flower stages, they were reinfested. When plots were sprayed early in the pod stage, however, no lygus bugs were collected in subsequent growth stages. In all trials, significantly fewer lygus bugs were collected in plots sprayed early in the pod stage than in unsprayed plots (Table 20). Plots sprayed at flowering also had significantly fewer lygus bugs than the controls, but they contained more lygus bugs than plots sprayed early in the pod stage. Plots sprayed at the bud stage had lygus bug densities which were not significantly different than the control plots.

In all insecticide trials, Canola yield was greater in plots sprayed at the pod stage than in the unsprayed plots (Table 20). The yield improvement associated with spraying at the pod stage varied from 11 to 35%, but in only two of the five tests, were the yield differences significant (Table 20). The significant differences in yield were obtained when lygus bug densities were high and when the crop was sprayed early in the pod stage. Yields in the plots sprayed at the bud or flower stage did not differ significantly from those in the control plots and were usually intermediate between yields in the control and those in plots sprayed at the pod stage. There was no consistent relationship between the lygus bug density of the control plots and the size of the

Table 19: Effects of timing of an insecticide application on lygus bug densities at five crop growth stages of *Brassica campestris* in Vegreville in 1986.

Time of application		Plant growth stage sampled				
Date	Stage	Bud (3.1)[1]	Flower (4.1-4.4)	Early pod (5.1)	Middle pod (5.2)	Late pod (5.3-5.4)
June 17	Bud (3.1)	0 (0,4)[2]	0.8(2.1,16)	0(0,2)	2.3(1.7,4)	4.0(2.8,2)
June 24	Flower (4.2)	0.3(0.5,4)	1.1(2.6,16)	0.7(1.1,3)	1.5(2.1,2)	6.3(4.9,3)
July 21	Pod (5.1)	0.8(1.0,4)	1.1(3.8,16)	0(0,1)	0(0,3)	0(0,4)
-	Control	0.5(1.0,4)	1.3(2.1,16)	3.0(0,1)	5.5(6.4,4)	3.5(2.9,3)

[1] Growth stage of Harper and Berkenkamp (1975).

[2] Mean number of lygus per 10 sweeps (SD,n).

Table 20: Effect of an insecticide application for lygus bug control on yield and lygus bug density.

Time of application		Seed damage, %	1000-seed wgt. (g)	Yield (g/m^2)	Lygus density[1]	Stage sampled[2]
Date	Stage					
B. campestris, SP, 1985						
17 Aug	Pod (5.1)	-	-	221.7a	0	5.2
	Check	-	-	164.7b	52.2	5.2
SE				3.18		
17 Aug	Pod (5.3)	-	-	145.5a	0	5.3
	Check	-	-	131.5a	30.6	5.3
SE				2.25		
B. campestris, RCB, 1985						
9 July	Flower	-	-	136.7b	9.5b	5.2
27 July	Pod	-	-	157.3a	0a	5.2
-	Check	-	-	135.1b	22.4c	5.2
SE				2.7	.58	
B. campestris, RCB, 1986						
21 June	Bud	2.0	2.72	189.0	2.0ab	5.2
24 June	Flower	4.7	2.79	181.0	1.3ab	5.2
21 July	Pod	3.6	2.81	189.0	0b	5.2
-	Check	2.5	2.56	155.2	4.2a	5.2
SE		0.9	0.10	11.8	.51	
B. napus, RCB, 1986						
24 June	Bud	2.9	3.78	228.9	0.6a	5.1
1 July	Flower	4.0	3.98	211.7	0.2b	5.1
28 July	Pod	2.5	4.09	250.3	0.1b	5.1
Check	-	3.8	3.12	214.9	0.6a	5.1
SE		1.4	.08	14.7	0.3	

Analysis of variance was conducted using data transformed using $(x + 1)^{0.5}$ for counts. SE's are based on transformed means. Means within each column and group followed by the same letter or by no letter are not significantly different ($P > 0.05$; Duncan's [1955; in Steel and Torrie 1980] Multiple Range Test).

[1] Mean number of lygus bugs per 10 sweeps. Means are back-transformed from transformed means.

[2] Growth stage of Harper and Berkenkamp (1975).

yield difference between the control plots and those sprayed in the pod stage. The percentage of seed injured by lygus bug and the 1000-seed-weight were only measured in 1986 when lygus bug densities were low. Under these conditions there was no significant difference in percentage of seed injured for the different treatments, nor any apparent association between the percentages of injured seed and the lygus bug densities during the pod stage. The 1000-seed-weight was lower in the control plots than in the plots sprayed in the pod stage for both tests in 1986, but not significantly so (Table 20).

Lygus bug density, seed injury, and yield. Lygus bug densities were substantially lower in 1986 than in 1985. This was true for the insecticide trials (Tables 19 and 20) as well as the other trials. For example, in plots at the pod stage in the third seeding of the seeding date trials, lygus bug densities averaged 30.6(SD = 9.7) per 10 sweeps in 1985 versus 2.2(SD = 0.6) in 1986. In the cultivar trials, the mean number of lygus bugs collected at pod stage 5.2 was 26.6 (SD = 17.3, range 4-80) lygus bugs per 10 sweeps in 1985, and 3.86 (SD = 3.14, range 0-12) in the same trial in 1986. The percentage of seed injured showed a similar trend although the differences were smaller. In the cultivar trial of 1985, 5.4% (SD = 5.40, range 2.2-27%) of the seed was injured by lygus bugs compared with 3.2% (SD = 2.4, range 0.13-11.1%) in 1986.

The percentage of seed injured by lygus bugs (y) in 1985 in the cultivar trials increased with the density of insects (x) present in the plots at pod stage 5.2 ($y = 1.82 + .092x$, $n = 24$, $r^2 = 0.23$, $P < 0.05$). Similarly, in 1986 in all three types of trial, the percentage of seed injured by lygus bugs increased with density of insects, although the slopes were significant only for the seeding date trial (Table 21). In the seeding date trial, at crop stage 5.2, the slopes remained significant when adjusted for seeding date using analysis of covariance for B. campestris (b = 0.13; df = 1,15; F = 6.1; $P < 0.05$), and B. napus (b = 0.17; df = 1,15; F = 4.8; $P < 0.05$) indicating that the there was a direct relationship between percent damage and insect numbers. However, at crop stage 5.1 the same relationships were not significant for either species when adjusted for seeding date. Nevertheless, in both 1985 and 1986 lygus bug density, as estimated by sweep samples, accounted for only a small portion of the variation in the percentage of seed injured by lygus bugs. The percentage of seed injured by lygus bugs increased by 0.1-1.1% for each increase of one lygus bug per 10 sweeps.

In the cultivar trials of 1985, yield (y) of B. napus was negatively related to lygus bug density (x) at pod stage 5.1 ($y = 194.42-5.61x$, $r^2 = 0.41$, P = .01 n = 15). The one B. campestris cultivar tested had a yield-density relationship with a similar slope, -3.48, but the relationship was not significant. When the analyses were repeated using densities estimated at pod stage 5.2, there was no significant relationship between yield and lygus bug density. In 1986, in the seeding date trial, there was also a negative relationship between the yield of the plots and the number of insects collected in the plots during the pod stage (Table 22). When the results of this trial were adjusted for differences in seeding date the slope of the relationship between yield and insect numbers was not significant (b = -4.79; SEb = 3.77; $r^2 = 0.06$; $P > 0.05$), indicating that seeding date affected both the yield and the number of lygus bugs. The slope of the

Table 21: Relationship (linear regression) between percentage of Canola seed damaged and the density of lygus bug (mean for 10 sweeps) during the early pod stage in 1986.

Cultivar	Crop stage sampled	Trial	N	Intercept	Slope	r^2	P
B. campestris							
Tobin	5.1	Seeding date	15	3.78	0.33	.098	.276
		Insecticide	7	3.73	-0.58	.080	.538
Tobin	5.2	Seeding date	15	1.19	0.72	.420	.009
		Insecticide	11	3.81	0.28	.194	.175
		Cultivar	5	4.13	0.29	.008	.908
B. napus							
Westar	5.1	Seeding date	15	4.52	0.39	.368	.047
		Insecticide	15	3.28	0.10	.001	.934
		Cultivar	5	2.32	0.51	.384	.265
Westar	5.2	Seeding date	15	4.84	0.78	.459	.029
		Insecticide	5	3.81	1.08	.026	.793
		Cultivar	5	3.91	0.70	.565	.143

relationship for B. campestris cv. Tobin were similar to those observed in 1985, whereas the slopes for B. napus cv. Westar varied for the two stages sampled (Table 22). For B. campestris cv. Tobin, the yield declined by about 6% for each increase of one lygus bug per 10 sweeps. Even for this significant relationship between yield and lygus bug density, pest density accounted for only a small percentage (45%) of the variation in yield.

In the cultivar trials of 1985, the relationship between seed yield and the percentage of seed injured by lygus bugs had a negative slope, but the slope was not significant ($b = -0.36$; $SEb = 5.06$; $r^2 = 0.12$; $P > 0.05$). In 1986, the yield also declined with the intensity of seed injury both in the seeding date trial and in the insecticide trial (Table 23). The relationship was significant for the seeding date trial for both varieties and in the insecticide trial using B. napus. For B. campestris cv. Tobin, about 5% of the yield was lost for each 1% increase in the percentage of seed injured by lygus bugs. For B. napus cv. Westar, about 2% of the yield was lost for each 1% increase in the percentage of seed injured by lygus bugs.

The density of lygus bugs in the commercial fields sampled at the early pod stage in 1986 was low, with a maximum of 2.2 insects per 10 sweeps in one field. The relationships between the percentage of seed injured by lygus bugs and lygus bug density was not significant for either Canola species and the slopes of the relationships were low for both B. campestris ($y = 3.44-0.001x$, $n = 10$, $r^2 = .00$, $P = .99$) and B. napus ($y = 3.83-.002x$, $n = 6$, $r^2 = .02$ $P = .78$). Of the sixteen fields surveyed, yield estimates were obtained for twelve. Yield was not

Table 22: Relationship (linear regression) between yield (g/m^2) and lygus bug density (mean for 10 sweeps) at the early pod stage of Canola, 1986.

Cultivar	Crop stage	Trial	N	Intercept	Slope	r^2	P
B. campestris							
Tobin	5.1	Seeding Date	15	146.03	- 0.58	.000	.917
		Insecticide	7	172.41	- 3.21	.030	.709
Tobin	5.2	Seeding Date	15	212.42	-12.72	.451	.006
		Insecticide	11	183.51	- 0.57	.001	.866
B. napus							
Westar	5.1	Seeding Date	15	206.71	-10.23	.193	.101
		Insecticide	16	230.36	- 7.81	.021	.589
Westar	5.2	Seeding Date	15	175.59	- 0.32	.001	.956
		Insecticide	5	221.75	-11.05	.054	.709

Table 23: Relationship (linear regression) between yield (g/m^2) and the percentage of seed damaged by lygus in two field trials, 1986.

Cultivar	Trial	N	Intercept	Slope	r^2	P
B. campestris						
Tobin	Seeding date	15	203.49	-11.26	.442	.007
	Insecticide	15	185.68	-2.34	.025	.558
B. napus						
Westar	Seeding date	15	215.85	-4.93	.364	.017
	Insecticide	15	250.22	-7.16	.259	.044

significantly related to the percentage of injured seed in B. campestris ($y = 219.96-24.5x$, $n = 6$, $r^2 = 0.39$ $P = .19$) or in B. napus ($y = 229.65-4.04x$, $n = 6$, $r^2 = .01$ $P = .83$). However, for both species, the slopes were negative as was observed in the field plots. Similarly, yields were not significantly related to the number of insects collected in B. campestris ($y = 163.06-0.29x$, $n = 6$, $r^2 = .004$, $P = 0.90$) or in B. napus ($y = 229.9-2.4x$, $n = 6$, $r^2 = .135$, $P = 0.47$). However, the slopes were negative and similar to those found in field plots in 1986.

Survey of lygus bug injury. In 1982, the percentage of seed injured by lygus bugs was highest in the northern part of Alberta and lowest in the southern part of the province. The percentage of seeds destroyed by lygus bugs varied from 2-7% for the regions, and was over 20% in some fields (Table 24). In 1983, southern Alberta received significantly more injury than central Alberta and the Peace River region, with a level of injury across the province similar to that in 1982. Generally, regions which received the most injury were experiencing drought and the plants were in poor condition.

6.5 Discussion

When lygus bugs were controlled at the early pod stage of Canola, yield increased by 11-35%. Lygus bug injury causing yield losses of this magnitude in commercial Canola would warrant control. The highest loss occurred at densities of 52 lygus bugs per 10 sweeps at the early pod stage in 1985. In 1986 when densities at this stage were 1-5 lygus bugs per 10 sweeps, yield losses of 14-18% were observed, but these losses were not statistically significant. Because plant and sweep samples

Table 24: Canola seed damaged by lygus in three regions of Alberta.

	1982			1983		
Region	No. fields	Damage % (SE)	Range	No. fields	Damage % (SE)	Range
Peace River	55	6.88(0.7)a	1.3-28.4	20	1.82(1.2)a	0.4-10.1
Central Alberta	20	4.10(1.2)ab	0.4-21.0	20	0.96(1.2)a	0.3-2.3
Southern Alberta	17	2.15(1.3) b	0.4- 4.3	20	6.21(1.2)b	1.4-29.7

revealed no other pests in numbers that could have affected yield, the yield losses probably reflected lygus bug injury, although no simple association of the yield losses with seed injury or lygus bug density were evident in the insecticide trials. Insecticides applied during the bud and flower stages also did not significantly affect yield. This result was consistent with the conclusion that yield losses resulted primarily from lygus bug control because neither the bud nor the flower sprays provided protection from lygus bug attack during the pod stage, when the Canola plant is most susceptible to lygus bug injury (Section 5). Furthermore, the most injurious stages of the lygus bug are the fifth instars and adults (Gutierrez _et al_. 1977), which predominate when pods are developing (Section 3).

The relationships between lygus bug density, percentage of seed injured by lygus bug, and Canola yield support the conclusion that lygus bug can cause agronomically important losses of Canola under field conditions in Alberta. The percentage of seeds injured increased as lygus bug density increased, and the yield decreased as lygus bug density increased. Furthermore, yield declined as the percentage of seed injured by lygus bug increased. Although these relationships followed the same trends in a number of experiments conducted over two years, many of the slopes defining the trends were not statistically significant and the predictive variables accounted for relatively small proportions of the variation.

The weakness of the relationship between percentage of seed injured and lygus bug density was primarily due to high variation in estimates of lygus bug densities in the Canola crop. Coefficients of variation for density estimates usually exceeded 70%. Sweepnet sampling is also an unreliable method of estimating lygus bug densities in other field crops, e.g. lentils (Schotzko and O'Keefe 1986), and cotton (Byerly et al. 1978, Ellington et al. 1984). However, it is a widely used technique because no other method can capture as many insects at reasonable cost while minimizing injury to the crop (Ruesink and Kogan 1975). In Canola, sweeping is especially difficult once the crop enters the pod stage. Plants become intertwined and form a very dense canopy which is often difficult to penetrate with a sweepnet. Then, insects below the top few inches of the crop canopy are not sampled. Similar difficulties are reported for sampling lygus bug in cotton (Byerly et al. 1978, Ellington et al. 1984). The low lygus bug densities in 1986 contributed to the problem of estimating precisely the relationship between seed injury and lygus bug density.

High variability in the estimates of lygus bug density also contributed to the low r^2 values of the relationships between yield and lygus bug density, as well as affecting the constancy of the slopes. Another contributing factor was variability in yield among adjacent plots or even adjacent areas within a plot. Canola plants can vary considerably in size, shape, and number per unit area in a field. The plants are sensitive to differences in soil nutrients, moisture level, and plant density (Rood and Major 1984). At the Vegreville site, soil types vary within a short distance (R. Johnson, Alberta Environmental Centre, personal communication). To overcome the effect of variations in soil, it may be best to pair plots so that treatments are compared to adjacent controls. When this method was used in 1985, significant differences were found between treated and untreated plots. This technique was used effectively to demonstrate that yield losses occur in rapeseed attacked by pollen beetles, Meligethes spp. (Nilsson 1987). The importance of variability in the estimates of lygus bug density is supported by the relatively high precision of the relationship between yield and seed injury. In field plots, 43-46% of the variation in yield were accounted for by the percentage of seed injured by lygus bugs. This level of precision is high considering the number of extraneous factors that influence yield in Canola field plots, and the low number of lygus bugs present in the plots in 1986 when the tests were conducted.

The regression relationships suggest that 0.3-0.7% of Canola seed might be injured with lygus bug densities approximating 1 lygus bugs per 10 sweeps at the early pod stage (5.1) or 0.3-1% for the same number collected at a slightly later stage (5.2). The yield loss varied from 0.4-6% at about 1 lygus bug per 10 sweeps. The relationship between the yield loss and seed injury indicated that 2-5% of the yield was lost for each 1% of the seed injured. Given the low r^2 of the regression relationships, these estimates are imprecise and should not be used to estimate economic thresholds for lygus bugs. Nevertheless, they indicate that agronomically important losses could be occurring at lygus bug densities observed in the field plots. Furthermore, the relationship between yield and seed injury, which is much more consistent and precise than those derived using lygus bug density, indicate that seed injury levels of 2-5% which were commonly observed in the field plots and in commercial fields would be associated with agronomically important levels of yield loss.

In the 1986 survey of lygus bug density, seed injury, and Canola yield conducted in commercial fields, lygus bug densities were too low to detect significant variation in yield associated with variation in seed injury or lygus bug density. Surveys of canola fields are unlikely to produce significant relationships between pest density, injury and yield (Free and Williams 1978), because of variability between fields in extraneous environmental factors. Although few commercial fields were sampled, the slopes defining the relationship between yield and the percentage of lygus bug injury were negative as were those in the field plots. Thus, the percentage of injured seed may be a reliable indicator of yield losses occurring in the field. This survey also demonstrated that lygus bugs are not necessarily significant pests in all Alberta fields.

The more comprehensive surveys of lygus bug injury in Alberta Canola conducted in 1982 and 1983 also showed that some fields or some regions may show very little evidence of lygus bug injury (less than 1% seed injury). In the same years, however, other fields showed very substantial levels of seed injury attributed to lygus bug feeding. Based on the relationship between seed injury and yield losses, seed injury of 5% or more are probably associated with agronomically important losses in yield (10% or higher). Therefore, in both years, when the average levels of seed injured were 6%, a substantial proportion of Alberta Canola fields would have suffered losses great enough to warrant control.

Based on the evidence presented in this paper, lygus bugs are potentially significant pests in Canola. Insecticidal control of lygus bugs at the early pod stage results in improved yields when sufficient lygus bugs are present. Reductions in yield are related to the percentage of seed injured by lygus bugs, and injury can reach severe levels in some Alberta fields. Insecticidal control of lygus bug is effective at controlling lygus bug injury if insecticide applications are timed correctly. Sampling methods for lygus bug in Canola are unsatisfactory for estimating precisely the relationships between lygus bug density and yield loss, or to provide action thresholds for lygus bug in Canola. Accurate guidelines for control of these pests of Canola need to be developed.

7 GENERAL DISCUSSION

The pest status of lygus bugs in oilseed rape crops such as Canola was virtually unknown. There are no published reports of lygus bug infesting or injuring oilseed rape crops in Canada and very few reports of injury to these crops from other parts of the world (Hori and Hanada 1970). However, lygus bugs are known to be serious pests of a wide range of other crops in many parts of North America (Tingey and Pillemer 1977), and are known to feed on members of the plant family Cruciferae (Scott 1977, Fye 1982b, Getzin 1983). This study establishes that three species of lygus bug use Canola, a low glucosinolate type of oilseed rape, as a host plant in Alberta. The insects feed, oviposit, and develop to maturity on the two species of crop. The consequences of the interaction between lygus bugs and crops such as Canola have only begun to become apparent. In this discussion, I will assess the status of our knowledge of the relationship between lygus bugs and Canola.

7.1 Canola as a Host Plant for Lygus Bugs

Lygus bugs are not present in the vegetative stage of Canola crops. Adults are attracted to the crop after it has begun to bolt and then they feed on buds, flowers, and developing seeds. Nymphs first appear during the flowering stage of the crop. Late instar nymphs and adults are present in the crop as it begins to mature when abundant green seed are available to the lygus bug. Adults apparently migrate out of the crop as the seed becomes mature, presumably they go to other crops at suitable stages of development or to overwintering sites. Only one generation is completed each year in central and northern Alberta, although the available day-degree units indicate that more generations may be completed in other areas of the Canadian Prairies.

The species complex of lygus bug is different in Canola than in alfalfa, which is known to be an important host for lygus bug across the Canadian prairie and parkland. *L. borealis* makes up 70% of the population present in alfalfa whereas, *L. elisus* and *L. lineolaris* predominate in oilseed rape making up 70% of the population in that crop. Lygus bugs are attracted to alfalfa often before Canola has been seeded in Alberta. Therefore, nearby alfalfa stands have been suggested as a possible source of the lygus bug populations present in Canola. However, lygus bugs remain on alfalfa for extended periods of time migrating out only if it is cut (Stern 1976), or if it matures (Khattat and Stewart 1980). Considering the attractiveness of alfalfa and the relative scarcity of *L. elisus* and *L. lineolaris* in alfalfa, it is likely that the source of lygus bugs for the Canola crops is weeds, especially cruciferous weeds, which are abundant in rural Alberta, and not alfalfa.

The time Canola crops are seeded influences the numbers of lygus bugs in the crop. The number of lygus bugs in a field apparently depends more on the timing of bud development than on the crop species or cultivar. Later seeded crops accumulate lower numbers of lygus bugs. This suggests that there is a finite pool of overwintered adults that move from crop to crop in the spring as the bud stage is reached in each crop. As the season progresses fewer adults are available and therefore, the number of migrants declines resulting in lower populations. *Brassica napus* L. crops are often seeded earlier in the spring than *B. campestris* L. crops because *B. napus* takes longer to mature (Thomas 1984). Therefore, regardless of cultivar, it is likely that the number of lygus bugs in B. napus crops will be higher than in B. campestris crops grown in the same area.

Production of oilseed rape on the Canadian Prairies shifted in the late 1970's from cultivars containing high levels of glucosinolates in their seeds to those with low levels (i.e. the Canola cultivars) (Thomas 1984). The glucosinolates are thought to be defensive compounds that deter feeding by generalist herbivores, whereas crucifer specialists use the breakdown products of glucosinolates as attractants (Feeny 1977). The crucifer specialists so far studied have not been affected by this transition to Canola cultivars (Gerber and Obadofin 1981, Ahman 1982, Larsen et al. 1985, Weber et al. 1986, Lamb 1989). Although lygus bugs are generalist herbivores, they too are unaffected by the glucosinolate status of oilseed rapes. Survival and developmental rates are equal for lygus bugs reared on five cultivars of oilseed rape regardless of their glucosinolate status. In field plots, the number of lygus bugs in each of the five cultivars is equal indicating that all five cultivars are suitable hosts for lygus bugs. The transition from high-glucosinolate to low-glucosinolate cultivars probably has not affected the pest status of lygus bugs in Canadian oilseed rape.

Canola is as good a host for lygus as alfalfa. Nymphs collected from Canola or alfalfa show the same survival and rate of development when fed Canola. Resulting adults are similar sizes. Therefore, host switching has little effect on nymphal development. Other studies have shown that changing the host of polyphagous larvae reduces the production of biomass (Scriber and Slansky 1981). However, this does not appear to be the case for lygus bugs.

7.2 Plant Injury

Lygus bug feeding injury to Canola consists of lesions on stems and pods, and blasted buds, flowers, and seeds. The response of the canola plant to this injury is complex. With increased bud and flower injury, pod numbers increase but the weight of seed per pod, and the weight of seed per plant often declines. When lygus bug injury is severe, pods are produced later on the raceme and contain fewer, lighter seeds presumably due to a shortage of carbon assimilates (Tayo and Morgan 1979). When buds and flowers are injured artificially, the Canola plant fully compensates for the lost buds (Williams and Free 1979, Tatchell 1983). However, when the buds and flowers of Canola plants are injured by lygus bugs, the degree of compensation varies with environmental conditions. There are situations under which losses in seed production result from bud or flower injury by lygus bugs. Further experiments, examining the conditions under which Canola plants will compensate for bud and flower injury, are necessary to clarify the impact of this injury on Canola.

Direct and indirect seed injury apparently occurs too late in plant development to induce compensation in the Canola plant. No evidence was found to indicate that Canola plants can compensate for seed blasting, so that at least one seed is lost for each seed blasted. Losses in seed production associated with seed injury may in fact be higher than what can be accounted for by direct seed loss. For example, some seeds in injured pods may not be injured, but nevertheless their weight declines with the number of injured seeds in the pod. This indicates either that plant resources are reallocated to healthy plant parts at the expense of seeds developing in the injured pods, or that lygus bug injury causes a drain on the assimilates available to pods that cannot compensate. The plant's ability to respond to this indirect seed injury varies with environmental conditions.

7.3 Impact of Lygus Bugs on the Production of Canola

Lygus bugs are present in their highest numbers during the most susceptible stages of the Canola crop and injury to plants is occurring which appears to be caused by lygus bugs. However, there are several additional lines of evidence needed to determine whether or not lygus bugs are important pests of Canola. In particular, it needs to be demonstrated that the observed injury is caused by lygus bugs and that the injury results in agronomically important reductions in yield.

First, the injury found in the crop is typical of injury caused by lygus bugs infesting other crops. In this study, growth patterns of injured buds, flowers, and pods all fall into categories of injury previously described in the literature as lygus bug injury (see literature review). Symptoms of lygus injury in Canola seed are similar to symptoms evident in lentil seeds injured by lygus bugs (Summerfield _et al_. 1982). Second, symptoms of injury are induced in the presence of the insects being investigated. In Canola, bud and flower blasting increase on plants confined with a single lygus bug. The number of seeds injured increases and seed weight declines under the same conditions.

Third, seed production per plant declines with increased injury. Bud and flower blasting in Canola result in a reduction in seed weight per pod without influencing the number of seeds produced. Seed injury results in fewer healthy seeds and lower seed weight per pod.

Fourth, yield reductions occur in the field in the presence of lygus bugs and are related to the level of insect injury. Yield reductions are negligible in field plots sprayed during the early pod stage and substantial when lygus bugs are not controlled. Furthermore, yield is negatively related to lygus bug numbers and to the percentage of injured seed occurring because of lygus bug feeding. However, only a small proportion of the variation in yield could be accounted for by lygus bug numbers and injury. More studies are needed to clarify the relationship between insect numbers and yield reductions in Canola.

Fifth, yield increases occur when lygus bugs are controlled. When lygus bugs were controlled in field plots at the early pod stage of oilseed rape yield increased by 11-35% (Section 6). Surveys of percent injury occurring in commercial fields indicates that injury can range from 0.3 to 29.7% injury. Therefore, assuming that there is no compensation for seed injury, losses occurring in commercial fields are comparable to those estimated in field plot trials. More precise yield-loss estimates are needed to confirm the impact of lygus bugs in commercial fields.

More accurate sampling methods would also help improve estimates of lygus bug numbers present in Canola and their effects on yield. During the bud stage lygus bugs are difficult to sample with a sweep net. For a short time during flowering the crop is tall and open; however, once the pods start to form, the crop canopy becomes intertwined and difficult to penetrate with a sweep net. Furthermore, sweep net samples of lygus bugs correlate poorly with absolute population counts (Schotzko and O'Keefe 1986). Therefore, it is difficult to obtain high correlations between lygus bug numbers and injury occurring in the field even if the level of injury can be measured precisely. Until more accurate and precise methods of assessing lygus bug numbers are found, developing an economic threshold for this insect will be difficult. Nevertheless, based on the evidence presented in this thesis, lygus bugs are important pests of Canola and warrant further study to clarify their impact on Canola production in western Canada and to identify suitable control measures.

8 SUMMARY AND CONCLUSIONS

Lygus species successfully complete one generation in oilseed Brassica crops grown in Alberta. Three primary species are Lygus elisus Van Duzee, L. lineolaris (Palisot de Beauvois), and L. borealis (Kelton). All three species are present in rape and alfalfa.

Lygus development is highly synchronized with the development of it's host plant. It enters the crop during the bud stage and reaches peak numbers during the early pod stage regardless of the date of seeding. Later seeded crops accumulate fewer lygus bugs. Young nymphs are present during flowering stage. Older nymphs and adults are present during the early pod stage, which is the crop stage most susceptible to damage. Therefore, lygus bugs are potentially serious pests of oilseed rape because their phenology assures that the later-instar nymphs and adults are present in the crop when seeds are developing.

Glucosinolate content of oilseed Brassica cultivars has no impact on the development or survival of lygus bug nymphs, nor on the oviposition by lygus bug adults. The numbers of lygus bugs collected in the field are not influenced by the glucosinolate content of the rape cultivar. These results demonstrate that oilseed Brassica crops with high or low levels of glucosinolates are both suitable hosts for Lygus species.

The symptoms of injury by lygus bugs in oilseed rape are similar to those described in other crops. Reproductive organs which have been injured by lygus bug may turn brown, shrivel up, and abscise. This type of injury is termed "blasting". Lygus bug-injury results in significant increases in the number of "blasted" buds, flowers, and seeds. Bud loss may compensated for by the production of more pods on injured plants.

However, the pods on injured plants are lighter in weight, resulting in a decline in seed production with increased injury. Some compensation for flower loss also occurs, but seed production declines as injury increases. Compensation for seed injury does not occur. These results indicate that lygus bug-injury does occur in oilseed rape and has the potential to result in economic losses in this crop.

When lygus bugs are controlled at the early pod stage of oilseed rape, yield increases. Neither insecticide applications at bud stage nor flowering result in increased yields. The percentage of seeds injured increases, and the yield decreases, as lygus bug density increases. Also, yield declines as the percentage of seed injured by lygus bug increases. The relationships between lygus bug density, percentage of seed injured by lygus bug, and oilseed rape yield support the conclusion that lygus bug can cause agronomically important losses of oilseed rape under field conditions in Alberta.

9 CONTRIBUTIONS TO KNOWLEDGE

This study demonstrated for the first time that lygus bug develop and complete one generation in oilseed *Brassica* crops grown in Central and Northern Alberta. By demonstrating that lygus bug development is synchronous with host development this study has shown that lygus bugs are potentially serious pests of oilseed rape because their phenology assures that the later-instar nymphs and adults are present in the crop when seeds are developing.

By demonstrating lygus bug development is the same on high and low glucosinolate cultivars it has been shown that most of the commercial cultivars of oilseed *Brassicas* are equally suitable hosts for lygus bugs. Other factors other than glucosinolate content should be sought to confer resistance. Possibly physical barriers, i.e., trichomes could be incorporated into future cultivars to deter or prevent feeding by lygus bugs. Further research into the factors influencing host attraction and acceptance would also help in the development of resistant varieties.

Lygus bug injury does occur in oilseed rape and has the potential to result in economic losses in this crop. The relationships between lygus bug density, percentage of seed injured by lygus bugs, and oilseed rape yield support the conclusion that lygus bugs can cause agronomically important losses of oilseed rape under field conditions in Alberta. However, much more research is needed to develop accurate sampling methods so the stronger relationship between lygus bug numbers and damage can be established. This study has demonstrated that spraying during the pod stage may result in yield increases. However, there is still need for economic thresholds which will determine if an insecticide application is necessary.

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Appendix 1: Mean ± SE, of lygus bug adults collected in commercial fields of *Medicago sativa* cv. beaver *Brassica campestris* cv. Tobin, *B. napus* cv. Westar from 1984-1986.

Cultivar	year	Date (Julian)	No. sites	Lygus species		
				borealis	*elisus*	*lineolaris*
Beaver	1984	155	10	1.0 ± 0.28	0.5 ± 0.17	0.2 ± 0.13
Beaver	1984	160	10	0.3 ± 0.16	0.5 ± 0.26	0
Beaver	1984	165	10	2.2 ± 0.95	1.0 ± 0.28	0.8 ± 0.24
Beaver	1984	169	10	1.0 ± 0.35	1.0 ± 0.35	0.5 ± 0.26
Beaver	1984	172	10	2.2 ± 0.54	1.5 ± 0.59	0.8 ± 0.31
Beaver	1984	177	10	6.3 ± 2.07	1.3 ± 0.33	0.3 ± 0.16
Beaver	1984	179	10	1.7 ± 0.59	0.8 ± 0.24	0
Beaver	1984	185	10	2.2 ± 0.68	0.5 ± 0.17	0
Beaver	1984	187	10	0	0	0.7 ± 0.16
Beaver	1984	191	10	1.6 ± 0.26	3.7 ± 0.97	0.5 ± 0.26
Beaver	1984	194	10	1.7 ± 0.43	1.7 ± 0.38	0.3 ± 0.16
Beaver	1984	197	10	1.2 ± 0.37	0.7 ± 0.16	0.2 ± 0.13
Beaver	1984	205	10	4.0 ± 1.00	0.5 ± 0.26	0.3 ± 0.16
Beaver	1984	208	10	3.5 ± 0.69	0.2 ± 0.13	0
Beaver	1984	211	10	9.0 ± 2.14	0.3 ± 0.26	0
Beaver	1985	150	10	0.3 ± 0.16	0.2 ± 0.13	0
Beaver	1985	155	10	0	0.7 ± 0.26	0
Beaver	1985	158	10	1.2 ± 0.24	0	0.8 ± 0.31
Beaver	1985	162	10	0.2 ± 0.13	0.3 ± 0.16	0
Beaver	1985	165	10	0	0	0
Beaver	1985	169	10	1.3 ± 0.48	1.8 ± 0.54	0.7 ± 0.26
Beaver	1985	171	10	1.2 ± 0.47	0.8 ± 0.31	0.2 ± 0.13
Beaver	1985	176	10	0.8 ± 0.42	0	0.2 ± 0.13
Beaver	1985	178	10	0.7 ± 0.26	0.2 ± 0.13	0
Beaver	1985	180	10	1.0 ± 0.40	0.7 ± 0.26	0.7 ± 0.38
Beaver	1985	183	10	0.3 ± 0.16	0.2 ± 0.13	0
Beaver	1985	185	10	1.0 ± 0.20	0.3 ± 0.16	0
Beaver	1985	190	10	0.5 ± 0.26	0.2 ± 0.13	0.2 ± 0.13

Appendix 1: (Con't)

Cultivar	year	Date (Julian)	No. sites	Lygus species		
				borealis	elisus	lineolaris
Beaver	1985	193	10	1.2 ± 0.37	0.3 ± 0.16	0
Beaver	1985	198	10	0.3 ± 0.16	0	0
Beaver	1985	200	10	1.5 ± 0.59	0	0
Beaver	1985	204	10	2.2 ± 0.83	0	0
Beaver	1985	211	10	8.8 ± 1.52	0.7 ± 0.26	0.7 ± 0.26
Beaver	1985	214	10	21.3 ± 2.45	0.8 ± 0.37	0.5 ± 0.17
Beaver	1985	218	10	29.2 ± 1.67	2.3 ± 0.68	1.0 ± 0.49
Beaver	1985	233	10	20.0 ± 3.76	5.0 ± 0.82	0.8 ± 0.24
Beaver	1985	239	10	16.5 ± 3.82	3.8 ± 0.24	2.7 ± 0.38
Beaver	1985	242	10	20.5 ± 2.65	5.3 ± 0.62	3.8 ± 1.05
Beaver	1985	246	10	17.3 ± 1.85	4.8 ± 0.79	3.0 ± 0.40
Beaver	1986	143	10	0.2 ± 0.13	0	0
Beaver	1986	146	10	0	0.2 ± 0.13	0
Beaver	1986	149	10	0.7 ± 0.38	0	0.7 ± 0.38
Beaver	1986	153	10	0	0.3 ± 0.16	1.2 ± 0.65
Beaver	1986	156	10	0	0.2 ± 0.13	0
Beaver	1986	160	10	0.8 ± 0.24	0	0.5 ± 0.26
Beaver	1986	163	10	0.5 ± 0.17	0	0.3 ± 0.16
Beaver	1986	167	10	0.5 ± 0.17	0	0
Beaver	1986	171	10	0.5 ± 0.39	0	0
Beaver	1986	174	10	0.2 ± 0.13	0	0.2 ± 0.13
Beaver	1986	177	10	0	0	0
Beaver	1986	184	10	0	0.2 ± 0.13	0
Beaver	1986	188	10	0	0	0
Beaver	1986	191	10	0.2 ± 0.13	0	0
Beaver	1986	195	10	0.5 ± 0.26	0	0
Beaver	1986	202	10	0	0	0
Beaver	1986	205	10	0.5 ± 0.17	0	0.2 ± 0.13
Beaver	1986	209	10	0	0	0
Beaver	1986	212	10	0	0	0.2 ± 0.13

Appendix 1: (Con't)

Cultivar	year	Date (Julian)	No. sites	Lygus species		
				borealis	elisus	lineolaris
Beaver	1986	217	10	2.0 ± 0.45	0.3 ± 0.26	0.2 ± 0.13
Beaver	1986	219	10	1.3 ± 0.33	0.2 ± 0.13	0.2 ± 0.13
Beaver	1986	223	10	2.7 ± 0.59	0.3 ± 0.26	0.3 ± 0.16
Beaver	1986	226	10	0.7 ± 0.26	0	0.8 ± 0.51
Beaver	1986	230	10	1.3 ± 0.38	0.3 ± 0.26	1.3 ± 0.33
Beaver	1986	233	10	1.5 ± 0.33	0.3 ± 0.26	0.8 ± 0.31
Beaver	1986	237	10	1.0 ± 0.20	0	1.3 ± 0.38
Beaver	1986	240	10	3.2 ± 0.37	0.5 ± 0.26	1.7 ± 0.52
Tobin	1984	187	10	0	0	0
Tobin	1984	191	10	0	0	0
Tobin	1984	197	10	0	0	0
Tobin	1984	205	10	0.2 ± 0.13	0.2 ± 0.13	0
Tobin	1984	208	10	0.8 ± 0.24	0.3 ± 0.16	0
Tobin	1984	211	10	0	0.3 ± 0.16	0
Tobin	1984	220	10	0.3 ± 0.26	0.2 ± 0.13	0.2 ± 0.13
Tobin	1984	222	10	0.2 ± 0.13	0.3 ± 0.16	0.2 ± 0.13
Tobin	1984	228	10	0.5 ± 0.26	2.5 ± 0.56	1.0 ± 0.40
Tobin	1984	239	10	1.5 ± 0.52	2.0 ± 0.53	0
Tobin	1985	183	10	0.1 ± 0.10	0	0
Tobin	1985	185	10	0.2 ± 0.13	0.1 ± 0.10	0.3 ± 0.15
Tobin	1985	190	10	0.4 ± 0.40	0.3 ± 0.15	0
Tobin	1985	193	10	0.1 ± 0.10	0	0
Tobin	1985	198	10	0.2 ± 0.13	0.1 ± 0.10	0.1 ± 0.10
Tobin	1985	200	10	0	0.1 ± 0.10	0
Tobin	1985	204	10	0	0	0
Tobin	1985	211	10	0	0	0
Tobin	1985	214	10	0.1 ± 0.10	0	0
Tobin	1985	218	10	0.2 ± 0.13	0.1 ± 0.10	0
Tobin	1985	225	10	0.8 ± 0.25	1.1 ± 0.78	0.1 ± 0.10
Tobin	1985	232	10	2.8 ± 0.33	4.0 ± 0.97	0.6 ± 0.34

Appendix 1: (Con't)

Cultivar	year	Date (Julian)	No. sites	Lygus species borealis	elisus	lineolaris
Tobin	1985	235	10	1.2 ± 0.49	5.1 ± 0.81	0.2 ± 0.13
Tobin	1985	239	10	2.0 ± 0.47	7.1 ± 0.85	1.0 ± 0.30
Tobin	1986	171	10	0	0	0
Tobin	1986	174	10	0	0	0.1 ± 0.10
Tobin	1986	177	10	0	0	0
Tobin	1986	181	10	0	0	0
Tobin	1986	184	10	0	0.1 ± 0.10	0
Tobin	1986	188	10	0	0	0.1 ± 0.10
Tobin	1986	195	10	0	0	0
Tobin	1986	202	10	0	0	0
Tobin	1986	205	10	0	0	0
Tobin	1986	209	10	0	0	0
Tobin	1986	212	10	0	0	0
Tobin	1986	219	10	0	0	0
Tobin	1986	223	10	0	0	0.7 ± 0.47
Tobin	1986	226	10	0	0	0
Tobin	1986	230	10	0	0	0
Tobin	1986	233	10	0	0	0
Andor	1984	172	10	0	0	0
Andor	1984	177	10	0.5 ± 0.17	0	0
Andor	1984	179	10	0	0	0
Andor	1984	185	10	0.3 ± 0.16	0.2 ± 0.13	0.2 ± 0.13
Andor	1984	187	10	0.8 ± 0.24	0	0.3 ± 0.16
Andor	1984	191	10	0.3 ± 0.16	0	0.3 ± 0.16
Andor	1984	194	10	0	0.2 ± 0.13	0.2 ± 0.13
Andor	1984	197	10	0.5 ± 0.26	0	0
Andor	1984	205	10	0	0	0.2 ± 0.13
Andor	1984	208	10	0	0	0
Andor	1984	211	10	0.5 ± 0.17	0	0
Andor	1984	220	10	2.0 ± 0.28	8.5 ± 1.69	0.2 ± 0.13

Appendix 1: (Con't)

Cultivar	year	Date (Julian)	No. sites	Lygus species borealis	 elisus	 lineolaris
Andor	1984	222	10	3.7 ± 0.76	3.0 ± 0.40	1.0 ± 0.40
Andor	1984	228	10	5.0 ± 0.82	10.5 ± 1.75	4.0 ± 1.00
Andor	1984	239	10	4.5 ± 0.59	0	0.8 ± 0.24
Westar	1985	171	10	0	0.2 ± 0.13	0.1 ± 0.10
Westar	1985	175	10	0.3 ± 0.21	0.5 ± 0.22	0
Westar	1985	179	10	0.6 ± 0.22	0.6 ± 0.22	0.6 ± 0.31
Westar	1985	183	10	0.4 ± 0.16	0.6 ± 0.27	0.5 ± 0.17
Westar	1985	185	10	0.4 ± 0.31	0.3 ± 0.15	0.5 ± 0.22
Westar	1985	190	10	0.8 ± 0.29	0.3 ± 0.15	0
Westar	1985	193	10	0.1 ± 0.10	0.2 ± 0.13	0.1 ± 0.10
Westar	1985	198	10	0.1 ± 0.10	0.1 ± 0.10	0
Westar	1985	200	10	0	0	0
Westar	1985	204	10	0	0.2 ± 0.13	0.1 ± 0.10
Westar	1985	211	10	0.3 ± 0.15	0.3 ± 0.21	0
Westar	1985	214	10	2.0 ± 0.78	2.7 ± 0.87	1.0 ± 0.61
Westar	1985	218	10	2.4 ± 0.40	5.3 ± 1.14	1.2 ± 0.42
Westar	1985	225	10	4.3 ± 1.37	10.5 ± 1.63	5.1 ± 1.05
Westar	1985	233	10	8.6 ± 1.69	15.7 ± 2.20	6.8 ± 1.35
Westar	1985	235	10	7.7 ± 1.37	9.7 ± 1.75	3.6 ± 0.65
Westar	1985	239	10	6.0 ± 2.09	12.0 ± 3.77	5.4 ± 0.73
Westar	1985	242	10	5.8 ± 1.20	11.9 ± 2.02	8.0 ± 1.15
Westar	1986	177	10	0.1 ± 0.10	0	0.3 ± 0.21
Westar	1986	181	10	0	0	1.0 ± 0.42
Westar	1986	184	10	0	0.1 ± 0.10	0.7 ± 0.21
Westar	1986	189	10	0	0	0.6 ± 0.34
Westar	1986	195	10	0	0	0.1 ± 0.10
Westar	1986	202	10	0	0	0.2 ± 0.20
Westar	1986	205	10	0	0.2 ± 0.13	0.4 ± 0.16
Westar	1986	209	10	0	0	0.3 ± 0.15
Westar	1986	212	10	0.1 ± 0.10	0	0.4 ± 0.16

Appendix 1: (Con't)

Cultivar	year	Date (Julian)	No. sites	Lygus species borealis	 elisus	 lineolaris
Westar	1986	219	10	0	0	1.1 ± 0.35
Westar	1986	223	10	0	0	2.0 ± 0.39
Westar	1986	226	10	0	0	2.4 ± 0.48
Westar	1986	230	10	0	0	2.7 ± 0.67
Westar	1986	233	10	0	0	2.1 ± 0.62

Appendix 2: Mean ± SE, of lygus bug nymphs collected in commercial fields of *Medicago sativa* cv. beaver *Brassica campestris* cv. Tobin, *B. napus* cv. Westar, 1984-1986.

Cultivar	year	Date (Julian)	No. Sites	Instar 1	2	3	4	5
Beaver	1984	155	10	0	0	0	0	0
Beaver	1984	160	10	0	0	0	0	0
Beaver	1984	165	10	0	0	0	0	0
Beaver	1984	169	10	0	0	0	0	0
Beaver	1984	172	10	0	1.2 ± 0.47	0	0	0
Beaver	1984	177	10	0.5 ± 0.17	4.8 ± 1.32	0	0.2 ± 0.13	0
Beaver	1984	179	10	0.5 ± 0.39	2.5 ± 1.03	0.3 ± 0.16	0.5 ± 0.17	0.3 ± 0.16
Beaver	1984	185	10	0	0.5 ± 0.39	0.3 ± 0.26	1.5 ± 0.74	0.7 ± 0.26
Beaver	1984	187	10	0.3 ± 0.16	0.8 ± 0.13	1.3 ± 0.33	1.3 ± 0.52	1.3 ± 0.33
Beaver	1984	191	10	0.8 ± 0.51	0.8 ± 0.24	1.3 ± 0.38	3.2 ± 0.47	2.0 ± 0.49
Beaver	1984	194	10	0	0.8 ± 0.24	1.3 ± 0.33	3.5 ± 1.16	2.7 ± 0.48
Beaver	1984	197	10	0	0.7 ± 0.26	2.3 ± 0.62	5.2 ± 1.24	4.3 ± 0.48
Beaver	1984	205	10	0.3 ± 0.16	3.8 ± 1.38	3.0 ± 0.49	11.2 ± 2.01	8.5 ± 0.97
Beaver	1984	208	10	0	3.0 ± 0.49	2.0 ± 0.63	7.3 ± 1.42	12.0 ± 2.22
Beaver	1984	211	10	0.3 ± 0.16	2.3 ± 0.43	2.8 ± 0.58	12.2 ± 1.91	16.0 ± 1.64
Beaver	1985	150	10	0	0	0	0	0
Beaver	1985	155	10	0	0	0	0	0

Appendix 2: (Con't)

Cultivar year	Date (Julian)	No. Sites	Instar				
			1	2	3	4	5
Beaver 1985	158	10	0	0	0	0	0
Beaver 1985	162	10	0	0	0	0	0
Beaver 1985	165	10	0	0.2 ± 0.13	0.2 ± 0.13	0	0
Beaver 1985	169	10	0.2 ± 0.13	0.3 ± 0.16	0.2 ± 0.13	0	0
Beaver 1985	171	10	0	0	0.3 ± 0.16	0.2 ± 0.13	0.2 ± 0.13
Beaver 1985	176	10	3.7 ± 1.63	4.7 ± 0.79	2.3 ± 0.33	0.7 ± 0.16	0.3 ± 0.26
Beaver 1985	178	10	0.8 ± 0.31	7.3 ± 1.09	5.0 ± 1.36	1.2 ± 0.31	0.3 ± 0.16
Beaver 1985	180	10	0	4.7 ± 0.71	1.5 ± 0.56	0.8 ± 0.24	0.2 ± 0.13
Beaver 1985	183	10	0	5.0 ± 0.80	6.7 ± 1.03	1.8 ± 0.37	1.2 ± 0.42
Beaver 1985	185	10	0.2 ± 0.13	15.2 ± 3.28	10.3 ± 2.86	6.3 ± 1.41	1.3 ± 0.33
Beaver 1985	190	10	2.0 ± 0.80	12.7 ± 1.75	19.2 ± 2.24	16.5 ± 2.30	4.7 ± 0.95
Beaver 1985	193	10	1.7 ± 0.38	8.5 ± 1.41	18.2 ± 1.41	13.7 ± 1.97	6.3 ± 0.65
Beaver 1985	198	10	2.5 ± 0.59	9.5 ± 1.73	14.8 ± 2.58	20.8 ± 0.97	8.0 ± 0.89
Beaver 1985	200	10	4.3 ± 0.77	7.3 ± 1.16	8.2 ± 0.79	15.5 ± 1.34	13.2 ± 1.33
Beaver 1985	204	10	3.0 ± 1.02	9.5 ± 1.91	10.0 ± 1.11	10.5 ± 2.18	18.8 ± 2.02
Beaver 1985	211	10	0	3.7 ± 1.21	2.8 ± 0.51	10.7 ± 0.99	20.2 ± 4.55
Beaver 1985	214	10	0.3 ± 0.16	4.5 ± 1.21	8.3 ± 1.56	13.8 ± 1.71	30.0 ± 3.07
Beaver 1985	218	10	0	1.7 ± 0.48	4.7 ± 1.29	11.3 ± 2.79	29.7 ± 5.41

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar 1	2	3	4	5
Beaver	1985	233	10	0	0	0.5 ± 0.26	3.7 ± 0.82	13.5 ± 3.88
Beaver	1985	239	10	0	0	0.2 ± 0.13	1.0 ± 0.77	7.7 ± 1.07
Beaver	1985	242	10	0	0	0.8 ± 0.24	1.8 ± 0.76	11.2 ± 2.53
Beaver	1985	246	10	0	0	0	0	1.8 ± 0.42
Beaver	1986	143	10	0	0	0	0	0
Beaver	1986	146	10	0	0	0	0	0
Beaver	1986	149	10	0	0	0	0	0
Beaver	1986	153	10	0	0	0	0	0
Beaver	1986	156	10	0	0	0	0	0
Beaver	1986	160	10	0	0	0	0	0
Beaver	1986	163	10	0.2 ± 0.13	0.3 ± 0.16	0.5 ± 0.17	0.3 ± 0.16	0
Beaver	1986	167	10	0	0.8 ± 0.24	0.5 ± 0.39	0.5 ± 0.39	0
Beaver	1986	171	10	0.2 ± 0.13	0.5 ± 0.26	0.3 ± 0.16	0	0.5 ± 0.17
Beaver	1986	174	10	0.8 ± 0.65	1.2 ± 0.58	0.8 ± 0.31	1.3 ± 0.68	0.2 ± 0.13
Beaver	1986	177	10	0.7 ± 0.52	1.2 ± 0.37	1.2 ± 0.31	0.8 ± 0.37	0
Beaver	1986	184	10	0.8 ± 0.24	1.2 ± 0.31	3.0 ± 0.66	0.7 ± 0.26	0.3 ± 0.16
Beaver	1986	188	10	0.2 ± 0.13	0.8 ± 0.24	1.5 ± 0.44	0.8 ± 0.24	0.3 ± 0.16
Beaver	1986	191	10	0	0.3 ± 0.16	0.7 ± 0.38	0.5 ± 0.39	0.5 ± 0.17

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar 1	Instar 2	Instar 3	Instar 4	Instar 5
Beaver	1986	195	10	0.2 ± 0.13	0.2 ± 0.13	1.5 ± 0.44	1.5 ± 0.52	1.3 ± 0.48
Beaver	1986	202	10	0.2 ± 0.13	0.2 ± 0.13	0.3 ± 0.16	1.3 ± 0.48	0.8 ± 0.42
Beaver	1986	205	10	0	0.8 ± 0.13	0.8 ± 0.24	0.8 ± 0.24	3.7 ± 0.52
Beaver	1986	209	10	0	0	0.5 ± 0.17	0.7 ± 0.33	1.8 ± 0.58
Beaver	1986	212	10	0.2 ± 0.13	0.2 ± 0.13	0.8 ± 0.37	1.7 ± 0.52	2.3 ± 0.62
Beaver	1986	217	10	0	0	0.3 ± 0.16	0.2 ± 0.13	1.2 ± 0.13
Beaver	1986	219	10	0.3 ± 0.16	0.3 ± 0.16	0	0.3 ± 0.16	1.7 ± 0.48
Beaver	1986	223	10	0	0.2 ± 0.13	0	0.3 ± 0.16	1.2 ± 0.24
Beaver	1986	226	10	0	0	0.2 ± 0.13	0.8 ± 0.51	0.8 ± 0.31
Beaver	1986	230	10	0	0	0.3 ± 0.16	0.2 ± 0.13	1.3 ± 0.33
Beaver	1986	233	10	0	0	0.2 ± 0.13	0	1.2 ± 0.42
Beaver	1986	237	10	0	0	0.2 ± 0.13	0.5 ± 0.26	1.0 ± 0.49
Beaver	1986	240	10	0	0	0.2 ± 0.13	0.5 ± 0.39	1.3 ± 0.48
Tobin	1984	187	10	0	0	0	0	0
Tobin	1984	191	10	0	0	0	0	0
Tobin	1984	197	10	0	0	0	0	0
Tobin	1984	205	10	0	0	0	0	0
Tobin	1984	208	10	0	0	0	0.3 ± 0.26	0

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar 1	2	3	4	5
Tobin	1984	211	10	0	0.3 ± 0.16	0.5 ± 0.17	0.7 ± 0.33	0
Tobin	1984	220	10	0	0	0.3 ± 0.16	2.7 ± 0.93	2.3 ± 0.91
Tobin	1984	222	10	0	0.2 ± 0.13	0.3 ± 0.16	0.8 ± 0.37	1.0 ± 0.49
Tobin	1984	228	10	0	1.0 ± 0.40	1.0 ± 0.28	3.5 ± 0.91	4.3 ± 0.79
Tobin	1984	239	10	0	0	0	0.7 ± 0.26	1.3 ± 0.26
Tobin	1985	183	10	0	0	0	0	0
Tobin	1985	185	10	0	0	0	0	0
Tobin	1985	190	10	0	0	0	0	0
Tobin	1985	193	10	0	0	0	0	0
Tobin	1985	198	10	0	0	0	0	0
Tobin	1985	200	10	0.1 ± 0.10	0.1 ± 0.10	0	0	0
Tobin	1985	204	10	0	0	0	0	0
Tobin	1985	211	10	0.1 ± 0.10	0	0	0.2 ± 0.20	0
Tobin	1985	214	10	0.4 ± 0.16	0.8 ± 0.42	1.7 ± 0.47	1.4 ± 0.50	1.8 ± 0.44
Tobin	1985	218	10	0.3 ± 0.21	1.0 ± 0.49	2.2 ± 0.71	2.4 ± 0.87	3.3 ± 0.37
Tobin	1985	225	10	0	0.5 ± 0.31	0.7 ± 0.26	5.1 ± 0.59	5.2 ± 0.68
Tobin	1985	232	10	0	0.1 ± 0.10	0.4 ± 0.22	2.1 ± 0.62	8.0 ± 1.61
Tobin	1985	235	10	0	0	0	0.5 ± 0.22	6.3 ± 0.94

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar 1	2	3	4	5
Tobin	1985	239	10	0	0	0	0.7 ± 0.21	3.7 ± 0.76
Tobin	1986	171	10	0	0	0	0	0
Tobin	1986	174	10	0	0	0	0	0
Tobin	1986	177	10	0	0	0	0	0
Tobin	1986	181	10	0	0	0	0	0
Tobin	1986	184	10	0	0	0	0	0
Tobin	1986	188	10	0	0	0	0	0
Tobin	1986	195	10	0	0	0	0	0
Tobin	1986	202	10	0	0	0	0	0
Tobin	1986	205	10	0	0	0	0	0
Tobin	1986	209	10	0.1 ± 0.10	0	0	0	0
Tobin	1986	212	10	0.1 ± 0.10	0.1 ± 0.10	0.1 ± 0.10	0	0
Tobin	1986	219	10	0	0.2 ± 0.13	0	0	0.2 ± 0.13
Tobin	1986	223	10	0.1 ± 0.10	0	0	0.1 ± 0.10	0.4 ± 0.31
Tobin	1986	226	10	0	0.3 ± 0.30	0.3 ± 0.15	0.5 ± 0.31	0.5 ± 0.22
Tobin	1986	230	10	0	0.2 ± 0.13	0	0.2 ± 0.13	0.6 ± 0.27
Tobin	1986	233	10	0	0.1 ± 0.10	0	0.1 ± 0.10	0.3 ± 0.15
Andor	1984	172	10	0	0	0	0	0

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar 1	2	3	4	5
Andor	1984	177	10	0	0	0	0	0
Andor	1984	179	10	0	0	0	0	0
Andor	1984	185	10	0	0	0	0	0
Andor	1984	187	10	0	0	0	0	0
Andor	1984	191	10	0	0	0	0	0
Andor	1984	194	10	0	0.3 ± 0.26	0.5 ± 0.17	0	0
Andor	1984	197	10	0	0	0	0	0
Andor	1984	205	10	0.3 ± 0.16	2.7 ± 0.77	2.0 ± 0.57	1.5 ± 0.33	4.3 ± 0.59
Andor	1984	208	10	0	0.2 ± 0.13	0.3 ± 0.16	1.8 ± 0.31	1.3 ± 0.16
Andor	1984	211	10	0	0.8 ± 0.31	0.8 ± 0.24	2.0 ± 0.28	7.8 ± 0.97
Andor	1984	220	10	0	0	0	1.5 ± 0.44	6.3 ± 1.58
Andor	1984	222	10	0	0	0	0.3 ± 0.16	1.3 ± 0.38
Andor	1984	228	10	0	0.2 ± 0.13	0.2 ± 0.13	1.5 ± 0.33	9.2 ± 2.53
Andor	1984	239	10	0	0	0	0	0.5 ± 0.26
Westar	1985	171	10	0	0	0	0	0
Westar	1985	175	10	0	0	0	0	0
Westar	1985	179	10	0	0	0	0	0
Westar	1985	183	10	0	0	0	0	0

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar				
				1	2	3	4	5
Westar	1985	185	10	0	0	0	0	0
Westar	1985	190	10	0.3 ± 0.15	0	0	0	0
Westar	1985	193	10	0	0.6 ± 0.34	0	0	0
Westar	1985	198	10	0.6 ± 0.16	0.7 ± 0.30	0.6 ± 0.27	0.4 ± 0.31	0
Westar	1985	200	10	0.5 ± 0.27	0.9 ± 0.28	0	0.8 ± 0.42	0.1 ± 0.10
Westar	1985	204	10	0.5 ± 0.22	1.8 ± 0.89	1.5 ± 0.58	1.3 ± 0.52	0.4 ± 0.22
Westar	1985	211	10	0.7 ± 0.30	0.6 ± 0.27	1.4 ± 0.48	1.3 ± 0.50	2.5 ± 0.69
Westar	1985	214	10	0.1 ± 0.10	3.1 ± 0.95	3.0 ± 0.71	10.8 ± 2.17	12.8 ± 1.94
Westar	1985	218	10	0	1.1 ± 0.41	3.7 ± 1.24	7.7 ± 1.47	14.3 ± 2.78
Westar	1985	225	10	0	0	0.3 ± 0.21	6.6 ± 1.19	17.6 ± 3.24
Westar	1985	233	10	0	0	0.2 ± 0.20	1.2 ± 0.47	10.9 ± 1.43
Westar	1985	235	10	0	0	0	0.2 ± 0.13	3.6 ± 1.20
Westar	1985	239	10	0	0	0	0	4.1 ± 2.17
Westar	1985	242	10	0	0	0	0	2.1 ± 0.68
Westar	1986	177	10	0	0	0	0	0
Westar	1986	181	10	0	0	0.1 ± 0.10	0.1 ± 0.10	0
Westar	1986	184	10	0	0	0	0	0
Westar	1986	189	10	0	0	0	0	0.1 ± 0.10

Appendix 2: (Con't)

Cultivar	year	Date (Julian)	No. Sites	Instar				
				1	2	3	4	5
Westar	1986	195	10	0	0	0	0.2 ± 0.13	0
Westar	1986	202	10	0.1 ± 0.10	0.7 ± 0.33	0.2 ± 0.13	0.1 ± 0.10	0.5 ± 0.22
Westar	1986	205	10	0.2 ± 0.13	0.3 ± 0.21	0.6 ± 0.31	0.1 ± 0.10	0.8 ± 0.33
Westar	1986	209	10	0.5 ± 0.34	0.7 ± 0.26	1.1 ± 0.46	0.7 ± 0.33	1.0 ± 0.26
Westar	1986	212	10	0	0	0.7 ± 0.21	0.2 ± 0.13	1.0 ± 0.21
Westar	1986	219	10	0.3 ± 0.30	1.1 ± 0.41	0.8 ± 0.42	1.4 ± 0.52	3.2 ± 0.93
Westar	1986	223	10	0	0.2 ± 0.20	0.1 ± 0.10	1.7 ± 0.45	3.1 ± 0.48
Westar	1986	226	10	0	0.3 ± 0.21	0.1 ± 0.10	1.1 ± 0.35	3.4 ± 1.03
Westar	1986	230	10	0	0.3 ± 0.21	0.7 ± 0.33	1.5 ± 0.79	3.9 ± 0.71
Westar	1986	233	10	0	0.1 ± 0.10	0.2 ± 0.20	0.5 ± 0.22	2.1 ± 0.64