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Safflower susceptibility and response to feeding by grasshoppers

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SUMMARY

Feeding by three grasshopper species, *Camnula pellucida, Melanoplus packardii* and *Melanoplus sanguinipes*, on three safflower (*Carthamus tinctorius*) lines for a 6-wk period from anthesis was monitored under field conditions. Ratings of feeding damage to different plant parts (leaves, floral parts, capitula, and peduncles) and measurements after termination of feeding (dry weight, seed yield, seed weight, seeds per capitulum, and capitula per row) were compared among grasshopper species and safflower lines.

The *Melanoplus* species fed preferentially on leaves, floral parts, and capitula, while *C. pellucida* exhibited only peduncle feeding, which resulted in head clipping. Defoliation of 20 to 30% was associated with significant increases in total dry matter, seed yield, and number of capitula. Further defoliation resulted in decreases.

The safflower lines differed in response to grasshopper feeding. S-208 was most susceptible to defoliation by grasshopper feeding, exhibiting decreased dry weight, seed yield, and capitula number. Lesaf 34C-00 was most tolerant and only *M. packardii* caused significant dry weight and seed yield reductions. Feeding by *C. pellucida* on this line resulted in an overall seed yield increase. Feeding by *M. sanguinipes* on Seedtec-5 resulted in yield increases of up to 16%. It appears that certain grasshopper species can increase seed yield in some safflower lines by stimulating the production of additional capitula. Therefore, moderate populations of such grasshoppers in fields of appropriate safflower cultivars do not necessarily require control.

INTRODUCTION

Small areas of safflower (*Carthamus tinctorius* L.), up to approximately 20 000 ha/year, have been grown on the Canadian prairies since the early 1940's. Field observations in research plots and farmers' fields over the past several years have indicated that grasshoppers are a potential threat to safflower, especially at the time when adjacent cereal crops and plants along field margins have dried down or been harvested resulting in concentrations of grasshoppers in later maturing crops such as safflower. Grasshoppers are reported to be the most injurious of insect pests of safflower in North Dakota (Hoag, French, Geiszler & Schneiter, 1969). Grasshopper populations on the Canadian prairies have increased in the last few years (Grace & Johnson, 1985) and safflower production is also on the increase. While in many years the low grasshopper densities may not result in serious crop damage, in years of high densities damage may become severe.

We observed differential feeding on safflower lines in a research plot near Milk River, Alberta, in 1983 when grasshopper densities were 70/m^2. Seed yields of two standard US cultivars were less than half of those of Lesaf 34C-00, although production in sites without or having low densities of grasshoppers showed yield differences of less than 10% (Table 1). Subsequently, the study reported here was undertaken to quantify feeding preferences by three

Table 1. *Safflower seed yields (kg/ha) of Lesaf 34C-00 and two US cultivars, 1982–84*

Entry	Milk River*	Mean of 21 other sites
Lesaf 34C-00	1085	1940
S-208	406	1807
Hartman	424	1959

* Intense grasshopper feeding observed at this site.

common pest species of grasshoppers on three quite diverse safflower lines, under field conditions. Differences in preferences for plant parts by the grasshopper species were also measured, and the effect of different levels of defoliation on seed yield was determined.

MATERIALS AND METHODS

The study was carried out at the Lethbridge Research Station under dryland conditions during the summer of 1984.

Three safflower lines were planted 2.5 cm deep in six-row plots, 6-m long, rows spaced 37.5 cm apart using a conventional cone-type plot seeder, on 2 May. The plantings were replicated four times in randomised complete blocks. The lines were all spiny, including the late-maturing commercial US cultivar, S-208; an early maturing Lethbridge-developed experimental line, Lesaf 34C-00, which was subsequently licensed as Saffire, the first Canadian safflower variety (Mündel, Huang, Burch & Kiehn, 1985); and an experimental line from the Seedtec Company in California, coded as Seedtec-5. On 14 June, after elongation had started, four central sections (each 1 m^2) straddling three rows were marked out and thinned to eight plants in each row to permit four cage treatments per safflower line per replicate.

With safflower lines as main plots, the three grasshopper treatments and a grasshopper-free check were superimposed as subplots, in a split-plot design. Three grasshopper species common in the Canadian prairies were included: a mixed-grass feeder, *Camnula pellucida* (Scudder), and two polyphagous species, *Melanoplus sanguinipes* (Fab.) and *Melanoplus packardii* (Scudder). Cages, 1.25 × 0.8 × 1 m, were installed over central sections of each plot. Cages were wooden framed with 1-mm wire mesh. Spring-loaded hatches permitted access from the top. On 24 July, when the safflower had just commenced flowering, 50 adult grasshoppers were added to each cage. As grasshoppers died, their numbers were replenished to 50 per cage at least once a week. The crops reached physiological maturity from 20 to 26 August and grasshopper feeding continued until cool weather in early September. Daytime air temperatures exceeded the grasshopper feeding threshold of approximately 15 °C for all but the last few days of the trial.

Feeding damage by the grasshoppers was rated in the field. During the week prior to physiological maturity, the following were rated in each cage:

(1) initial defoliation – the percentage of leaf area removed was assessed visually,
(2) floral feeding – capitula (the small seed heads produced by safflower) with over half of the flowers removed were counted and expressed as a percentage of the total number of capitula, and
(3) capitula feeding – the number of capitula showing obvious feeding damage was expressed as a percentage of the total number of capitula.

After the experiment was terminated, the following were rated:

(1) total defoliation – the percentage of leaf area removed was assessed visually, and
(2) capitula clipped – capitula lying on the ground in each cage were counted. These were the result of peduncle feeding.

All plants in each row (subsample) were separately harvested on 26 September by cutting them at ground level, and were oven-dried to constant weight at 60 °C. The following plant characters were then measured for each subsample:

(1) dry weight – the weight of the total top growth, including seeds,
(2) seed yield – weight of the seeds,
(3) seed weight – weight of 100 seeds,
(4) seeds per capitulum – the average number of seeds in a capitulum, and
(5) capitula per row – the number of capitula.

Analyses of variance (ANOVA) were conducted to determine the effect of defoliation by grasshoppers on dry weight, seed yield, seed weight, capitula per row, and seeds per capitulum. Orthogonal comparisons were made on preselected combinations of grasshopper species and safflower lines (e.g., early *vs* late-maturing). All statistical analyses were conducted using the general linear model routines (Anon., 1982).

RESULTS

Feeding damage variables

The only plant part for which feeding damage among safflower lines differed significantly was the peduncle, as expressed by the number of clipped capitula (Table 2). Line S-208 differed significantly from the other two lines. The least peduncle feeding and associated capitula clipping occurred on S-208, averaging 1.2 clipped capitula per cage, and the most occurred on Lesaf 34C-00, averaging 5.2 clipped capitula per cage.

Significant differences in feeding occurred among the grasshopper species for all plant parts measured or rated (upper half of Table 2). Grasshoppers fed significantly on leaves, flowers,

Table 2. *Probability levels and treatment means for grasshopper feeding on safflower plant parts*

	Initial defoliation (%)	Total defoliation (%)	Floral feeding (% of capitula)	Capitula feeding (% of capitula)	Capitula clipped (no./cage)
	Probability levels†				
Main effects					
Safflower line	N.S.	N.S.	N.S.	N.S.	0·050
Grasshopper species	0·003	<0·001	0·003	<0·001	0·028
Comparisons					
Grasshopper *vs* Check	0·013	<0·001	0·008	<0·001	N.S.
Melanoplus vs Camnula	0·003	<0·001	0·003	0·006	0·009
Seedtec-5 + Lesaf 34C-00 *vs* S-208	N.S.	N.S.	N.S.	N.S.	0·022
	Treatment means‡				
Grasshopper species					
Check	1	3	1	0·1	1·0
Camnula pellucida	3	12	7	2·5	8·6
Melanoplus sanguinipes	28	75	42	7·1	1·0
Melanoplus packardii	34	67	50	9·5	1·6
Safflower line					
Lesaf 34C-00	—	—	—	—	5·2
Seedtec-5	—	—	—	—	2·8
S-208	—	—	—	—	1·2

† N.S. indicates $P > 0·05$.
‡ Treatment means only for significant differences within group.

and capitula (orthogonal comparisons, Table 2). Differences in the feeding of the *Melanoplus* spp. compared with *C. pellucida* were also significant for all plant parts considered.

The significant differences in feeding on plant parts and the significant comparisons are shown on the lower half of Table 2. The *Melanoplus* spp. caused the greatest amount of defoliation, averaging 71% by the end of the experiment, contrasted to 12% by *C. pellucida*. Similarly, floral feeding and capitula feeding were more severe (46% and 8.3%, respectively) than for *C. pellucida* (7% and 2.5%, respectively). *Camnula pellucida* effected the greatest peduncle damage, as manifested by the greater number of capitula clipped (8.6/cage compared with an average of 1.3/cage for the two *Melanoplus* spp.).

Yield variables

The levels of significance for main effects, interactions, and orthogonal comparisons for plant characters recorded after harvest are shown in Table 3 for all comparisons for which $P < 0.05$. The safflower line × grasshopper species interactions were significant for all characters measured. Means expressed as percentages of the check (no grasshopper feeding) are shown in Table 4. Values for replicate 1 were excluded from these comparisons, because the differences apparent during the experiment had been obscured by harvest time due to heavy feeding.

Table 3. *Significance levels for plant characters recorded for three safflower lines affected by feeding of three grasshopper species, measured at harvest*

	Dry weight	Seed yield	Seed weight	Seeds/ capitulum	Capitula/ row
Source of variation					
Safflower line (S)	N.S.†	N.S.	0·025	0·029	N.S.
Grasshopper species (G)	<0·001	0·002	N.S.	N.S.	N.S.
S × G	0·003	0·045	0·002	0·038	0·014
Orthogonal comparisons					
G *vs* Check	<0.001	0·006	0·040	0·024	0·004
Melanoplus vs Camnula	<0·001	0·032	0·042	N.S.	N.S.
M. sanguinipes vs M. packardii	0·028	0·039	0·044	N.S.	0·001
Early *vs* late lines‡	0·002	0·009	0·010	N.S.	0·001
Seedtec-5 *vs* Lesaf 34C-00	N.S.	N.S.	N.S.	0·006	N.S.

† N.S. indicates (P > 0·05).
‡ There were eight plants per row.

In Lesaf 34C-00 and S-208, dry weight was most reduced by *M. packardii* (to 73% and 54% of the check, respectively) with a minor reduction in Seedtec-5 (Table 4). *Melanoplus sanguinipes* caused the greatest reduction (to 84% of check) of any of the three species in Seedtec-5, a major reduction in S-208 (to 64% of check) and no reduction in Lesaf 34C-00. *Camnula pellucida* had no effect on the dry weight of Seedtec-5, caused a small (5%) increase in Lesaf 34C-00, but caused a significant decrease in S-208 (to 76% of check). On the average, grasshopper feeding caused reductions averaging 79% of that in check plots. The *Melanoplus* spp. reduced dry weight more than did *C. pellucida*. While Lesaf 34C-00 and Seedtec-5 together averaged 8% dry weight reduction due to grasshopper feeding, S-208 sustained a 35% reduction.

Seed yield was significantly reduced by feeding of all grasshopper species on S-208 (Tables 3 and 4). For Lesaf 34C-00, only *M. packardii* caused significantly reduced yields (69% of check). Feeding by *C. pellucida* resulted in a yield increase of 12% in Lesaf 34C-00. Feeding on Seedtec-5 by all three grasshopper species resulted in increased yields from a low of 4% for

Table 4. *Effect of grasshopper feeding on safflower variables measured at harvest, expressed as % of check*

Grasshoppers	Safflower† Lesaf 34C-00	Seedtec-5	S-208	All lines‡
	Dry weight (check mean = 125 g/row)			
Camnula pellucida	105	99	76	90
Melanoplus sanguinipes	100	84	64	79
Melanoplus packardii	73	95	54	71
	Seed yield (check mean = 34.6 g/row)			
Camnula pellucida	112	108	73	94
Melanoplus sanguinipes	96	104	76	89
Melanoplus packardii	69	116	60	78
	Seed weight (check mean = 4·41 g/100)			
Camnula pellucida	98	101	97	
Melanoplus sanguinipes	96	99	90	
Melanoplus packardii	100	108	86	
	Seeds/capitulum (check mean = 17·4)			
Camnula pellucida	107	89	90	
Melanoplus sanguinipes	87	75	109	
Melanoplus packardii	76	83	99	
	Capitula/row (check mean = 46·7)			
Camnula pellucida	104	118	86	100
Melanoplus sanguinipes	118	138	78	106
Melanoplus packardii	89	126	73	91

† % of check mean for respective safflower line.
‡ % of overall check mean.
Only significant ($P < 0·05$) effects and interactions listed as means.

M. sanguinipes to a high of 16% over the check for *M. packardii*. Line S-208 sustained a seed yield reduction averaging 30% over all grasshopper species.

Seed weight was the variable least affected by grasshopper feeding (Table 4). In S-208, a decrease occurred as a result of feeding by the two *Melanoplus* spp. In Seedtec-5, on the other hand, feeding by *M. packardii* caused an 8% increase in seed weight.

Seed numbers per capitulum were increased slightly in Lesaf 34C-00 by feeding of *C. pellucida* and in S-208 by feeding of *M. sanguinipes* (Table 4). For S-208, *C. pellucida* reduced the seeds per capitulum significantly below that of the *Melanoplus* spp. In Lesaf 34C-00 and Seedtec-5, the relationship was the reverse. Reductions in seed numbers were, at least in part, associated with seeds shattering due to feeding on capitula.

Feeding by all three grasshopper species resulted in increases in the number of capitula for Seedtec-5 and by *C. pellucida* and *M. sanguinipes* for Lesaf 34C-00 (Table 4). All three species resulted in decreased capitula numbers in S-208, but only *M. packardii* reduced capitula in Lesaf 34C-00. Across safflower lines, feeding by *M. sanguinipes* resulted in a 6% increase in the number of capitula per row, while feeding by *M. packardii* resulted in a 9% reduction compared with the check and feeding by *C. pellucida*. Lesaf 34C-00 and Seedtec-5 averaged 116% of check for capitula per row compared with 79% of check for the late maturing line, S-208.

Effect of defoliation by grasshoppers

Defoliation occurring between commencement of flowering and physiological maturity ('initial defoliation') was not significantly associated with final dry weight in any of the three

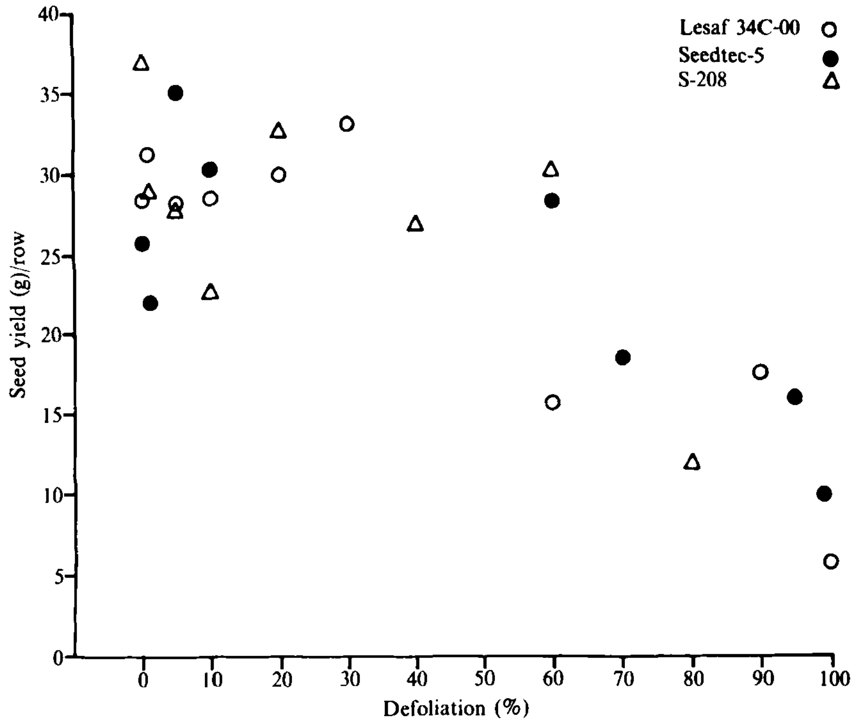

Fig. 1. Seed yield (g) per row associated with differing levels of defoliation, prior to physiological maturity, by grasshopper feeding on safflower lines Lesaf 34C-00 (○), Seedtec-5 (●), and S-208 (△).

safflower lines tested. However, combining the defoliation over the whole feeding period of the grasshoppers ('total defoliation') resulted in detectable linear ($P \simeq 0.005$ to 0.076) and quadratic ($P \simeq 0.005$ to 0.073) effects of defoliation on the final dry weight in the three safflower lines. Lesaf 34C-00 had the most significant ($P < 0.005$ for both linear and quadratic orthogonal components) effect of defoliation on dry weight. A small amount of defoliation resulted in slight dry matter increases associated with increased capitula numbers discussed below. Further defoliation resulted in dry matter decreases.

No strong effects of defoliation prior to physiological maturity of the safflower were observed ($P > 0.03$). Effects were stronger for Seedtec-5 and S-208 than for Lesaf 34C-00. Nevertheless, a general decline in seed yield occurred with increasing defoliation beyond 20 to 30% (Fig. 1).

Linear effects of defoliation prior to physiological maturity on capitula per row were evident. These effects were strongest for Lesaf 34C-00 ($P \simeq 0.01$) and Seedtec-5 ($P \simeq 0.001$). For these two lines, strong quadratic effects ($P \simeq 0.019$, 0.004) were also observed. Combining all three safflower lines obscured any of the noted tendencies due to differences in response. Fig. 2 illustrates the effect of defoliation on capitula per row for each of the three safflower lines separately. Both Lesaf 34C-00 and Seedtec-5 show an increase in capitula per row with low levels of defoliation damage followed by a decrease in number of capitula. A trend to reduced capitula per row with increasing defoliation is generally discernible for S-208.

Fig. 3 illustrates the effect of defoliation by each of the grasshopper species tested on capitula per row. A sharp drop in capitula is observed with even the minimal amount of feeding carried out by *C. pellucida*, due to their tendency to feed on the peduncle rather than the leaves. *Melanoplus packardii* caused a general decrease in capitula with increasing

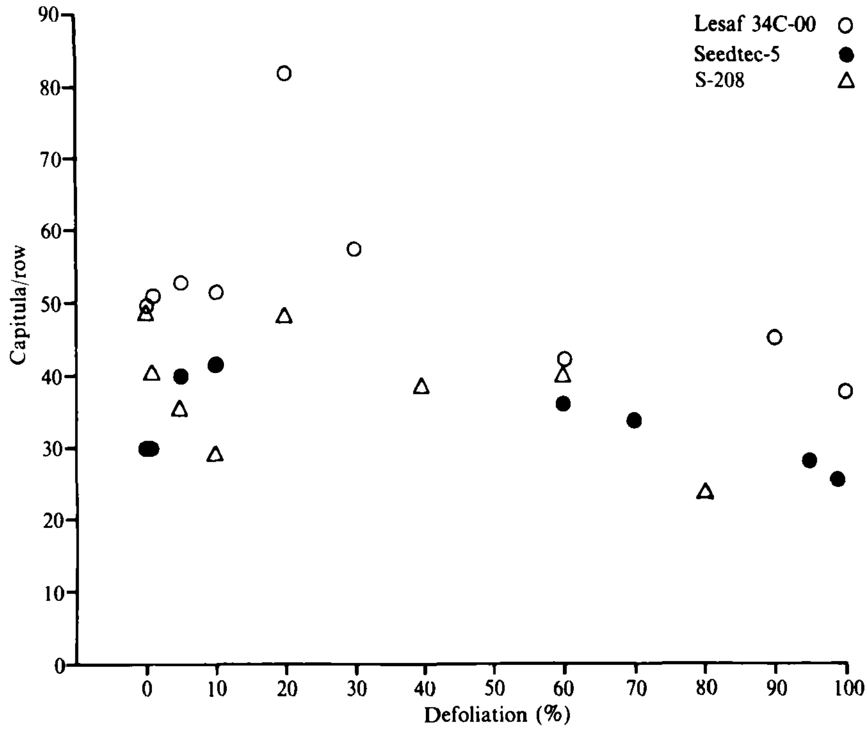

Fig. 2. Capitula per row associated with differing levels of defoliation, prior to physiological maturity, by grasshopper feeding on safflower lines Lesaf 34C-00 (○), Seedtec-5 (●), and S-208 (△).

defoliation. An increase in capitula at low levels of defoliation by *M. sanguinipes* was followed by a sharp decline on further defoliation. The grasshopper species × safflower line interaction was significant ($P \simeq 0.03$, ANOVA), resulting from the difference in feeding behaviour of *C. pellucida* and *M. sanguinipes*.

DISCUSSION

Leaves, floral parts, and capitula of safflower were damaged to a greater extent by the two *Melanoplus* spp. than by *C. pellucida*, reflecting the former's polyphagous habits and the latter's preference for grasses. In separate studies, Johnson & Mündel (1987) found that *C. pellucida* had the lowest survival of four species and ate much less than the other species when leaves of individual safflower lines were fed in controlled temperature cages. Approximately 70% of leaves were damaged in the phytotron by the *Melanoplus* spp., while approximately 50% of florets and less than 10% of capitula had feeding damage. On the other hand, most peduncle feeding, resulting in up to 6% of capitula being clipped and dropped to the ground, was carried out by *C. pellucida*. Less than 1% of capitula were clipped by the *Melanoplus* spp.

Approximately 20 – 30% defoliation by grasshopper feeding prior to physiological maturity was associated with increased seed yield, total dry matter, and numbers of capitula produced. Greater amounts of defoliation resulted in decreases in seed yield. Numbers of capitula did not decrease as drastically with increasing defoliation, reflecting that the formation of most primary and secondary capitula had occurred prior to grasshopper feeding.

While defoliation of S-208 by grasshopper feeding was similar to that in the other lines, the effect on seed yield, dry weight, and capitula reduction in S-208 was greatest among the

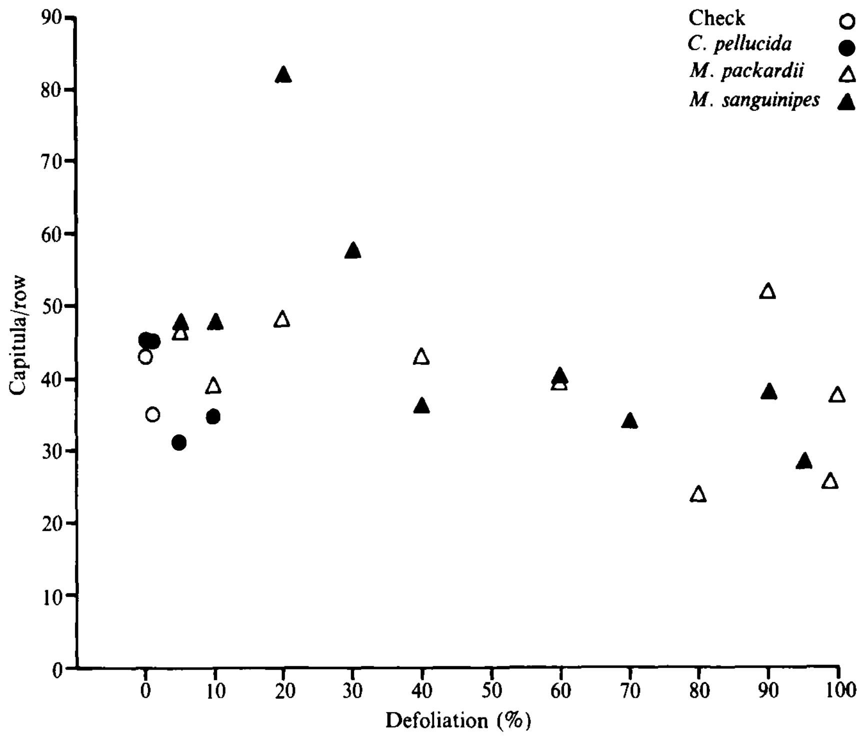

Fig. 3. Capitula per row associated with differing levels of defoliation, prior to physiological maturity, associated with the check (○) and the following grasshopper species: *Camnula pellucida* (●), *Melanoplus packardii* (△), and *Melanoplus sanguinipes* (▲).

Table 5. *Capitula/plant† of two safflower lines grown under diverse conditions*

Location	Safflower line: Lesaf 34C-00	Safflower line: S-208
1983		
Lethbridge, Alta.	10·0	6·5
Milk River, Alta.	8·7	5·1
1984		
Glasniven, Sask.		
Rocky slope	6·0	2·8
Low spot	5·6	4·1
Indian Head, Sask.	5·0	3·1
Lethbridge, Alta.		
Seed rate: 20 kg/ha	4·5	3·0
Seed rate: 12 kg/ha	6·7	5·3
Mean	6·6	4·3
Range	4·5–10·0	2·8–6·5

† Mean of 10 consecutive plants in a row bordered on both sides.

safflower lines. While *C. pellucida* clipped very few heads of S-208 and fed very little on the leaves, significant yield reductions, associated with decreases in capitula and seeds per capitulum, occurred. This lack of plasticity in S-208 was also observed in other field studies

(Table 5) where a lower number of capitula per plant was combined with a lower range of capitula produced over greatly varying environmental conditions, compared with Lesaf 34C-00.

Only *M. packardii* caused significant seed yield and dry weight reductions in Lesaf 34C-00. *Camnula pellucida*, while doing the most peduncle feeding on this line, caused an overall seed yield increase associated with small increases in capitula and seeds per capitulum. The increase in numbers of capitula associated with feeding of *M. sanguinipes* on Lesaf 34C-00 was not reflected in increased seed yield due to a concomitant decrease in number of seeds per capitulum. The difference may be attributed to the lack of leaf damage caused by *C. pellucida*, as opposed to heavy feeding by *M. sanguinipes*.

Feeding by *M. packardii* on Seedtec-5 resulted in considerable yield increases (16%) associated with a significant increase in the number of capitula produced, indicating a difference among lines in response to grasshopper feeding. Similar yield increases from artificial nipping of primary capitula in safflower occur in India (Anon., 1968). Less dry weight reduction in Seedtec-5 than in S-208, associated with grasshopper feeding in this field experiment, is corroborated in the phytotron studies by Johnson & Mündel (1987). In those studies, Seedtec-5 showed significantly less feeding by grasshoppers than did other safflower lines. However, the feeding that did occur can be postulated to stimulate the formation of additional capitula which produce seed and contribute to an increased seed yield. Such an occurrence supports the hypothesis put forth by Harris (1974) that, in apically dominant plants the removal of the terminal releases the lateral buds from correlative inhibitors. In this way, apically indeterminate plants will branch to more fully utilise the available nutrient and moisture supply.

These results are indicative of differential tolerances, or stimuli, associated with feeding by the different grasshopper species on the safflower lines used in this test. We suggest that increases in numbers of capitula produced in Lesaf 34C-00 and Seedtec-5 by grasshopper feeding result from hormonal stimuli on axillary meristems. Increased tillering and dry matter production on blue grama grass grazed by grasshoppers caused Dyer & Bokhari (1976) to similarly conclude that plant growth processes were triggered by grasshopper feeding.

Differential feeding by grasshopper species on plant parts and safflower lines is presumably based on physical, physiological or biochemical differences. Why S-208 was unable to compensate for even a small amount of feeding, while the other safflower lines were stimulated to produce more capitula, requires further study. Cultivars such as Lesaf 34C-00 and Seedtec-5, which not only withstand but also respond through increased yield to a limited amount of grasshopper feeding, are useful choices to farmers in areas of moderate grasshopper infestations.

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