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Growth, development, survival and food selection in larvae of the red turnip beetle, *Entomoscelis americana* Brown (Coleoptera:Chrysomelidae), on species of Cruciferae

by

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GROWTH, DEVELOPMENT, SURVIVAL AND FOOD SELECTION IN LARVAE OF THE RED TURNIP BEETLE, *Entomoscelis americana* BROWN (Coleoptera:Chrysomelidae), ON SPECIES OF CRUCIFERAE

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ABSTRACT

Growth, development, survival and food selection were investigated in the larvae of the red turnip beetle, Entomoscelis americana Brown, in the laboratory on 18 cultivars belonging to 11 species of Cruciferae. The plants tested for their suitability as host plants were: the cotyledon and first true leaf stages of Torch, Echo, Candle and R500 cultivars of Brassica campestris L. (turnip rape) and of Midas, Target and Tower cultivars of B. napus L. (rape); the cotyledons of three commercial mustards, Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea (L.) Coss. and Gisilba (Yellow mustard) cultivar of B. hirta Moench; and the first true leaves of seven cruciferous weeds, Erucastrum gallicum (Willd) Schulz, Sinapis arvensis L., Capsella bursa-pastoris (L.) Medic., Sisymbrium loeselii L., Descurainia sophia (L.) Webb, B, nigra (L.) Koch, and Thlaspi arvense L. Six criteria were used in judging the suitability of the plants: the percent survival to adult emergence; the length of the developmental period from larval eclosion to adult emergence; the weights of the adults at emergence; the percentage of malformed adults and the severity of the malformations; the larval growth rate index; and the nutritional index.

In the red turnip beetle, there are four larval instars, a pupal stage and an adult stage. The growth curve for the larval stage was S-shaped.

Torch, Echo, Candle and R500 cultivars of B. campestris and Midas, Target and Tower cultivars of B. napus were suitable host plants for red turnip beetle larvae, but R500 appeared to be marginally inferior to the other six cultivars. Survival was relatively high, the weights and developmental times were similar, and the percentage of malformed adults was low on all the cultivars. Survival was lower and the larval growth rate indices and nutritional indices were smaller on R500 than on the other six cultivars.

In B. campestris and B. napus, the cotyledon stage was more suitable than the first true leaf stage as food for red turnip beetle larvae. Survival usually was higher, the adults at emergence were heavier, and the larval growth rate indices and the nutritional indices were larger in larvae reared on cotyledons than in those on the first true leaves. The developmental times were similar and the percentage of malformed adults was low on both stages of plant growth.

Blaze and Lethbridge 22A cultivars of B. juncea and Gisilba cultivar of B. hirta were suitable host plants for red turnip beetle larvae. Blaze and Lethbridge 22A seemed to be as suitable as Torch cultivar of B. campestris as food for the larvae, but Gisilba appeared to be marginally inferior to Torch. Survival was relatively high; the weights, developmental times, the larval growth rate indices and the nutritional indices were similar; and the percentage of malformed adults was low on all the mustard cultivars.

Survival was lower and the larval growth rate index and the nutritional index were smaller on Gisilba than on Torch, but only the larval growth rate indices and the nutritional indices for Blaze and Lethbridge 22A were smaller than those for Torch.

The cruciferous weeds, Er. gallicum, S. arvensis, C. bursa-pastoris, D. sophia, Sy. loeselii, B. nigra and T. arvense, were classified into three groups on the bases of their suitability as host plants for red turnip beetle larvae. The three weeds of the first group, Er. gallicum, S. arvensis and C. bursa-pastoris, appeared to be equal in suitability and as suitable as Torch cultivar of B. campestris as food for the larvae. The three weeds of the second group, D. sophia, Sy. loeselii and B. nigra, were nutritionally inferior to the weeds in the first group and to Torch cultivar of B. campestris. D. sophia and Sy. loeselii seemed to be equal in suitability, but probably are superior to B. nigra. Survival was higher, except on B. nigra; the developmental times were shorter; the adults were heavier; the percentage of malformed adults was lower, except on D. sophia; and the larval growth rate indices and the nutritional indices were larger on species of the first group than on those of the second group. The percentage of malformed adults was the greatest on B. nigra. The only weed in the third group, T. arvense, was a nonhost plant of red turnip beetle larvae, because all of the larvae died in the first instar.

In food selection studies, newly-hatched larvae were tested in two-choice and four-choice experiments. The plants used were Torch, Echo, Candle and R500 cultivars of B. campestris; Midas, Target, Tower and Regent cultivars of B. napus; Blaze and Lethbridge 22A cultivars of B. juncea; Gisilba cultivar of B. hirta; S. arvensis; and B. nigra. The results from the food selection studies were compared with those from the growth, development and survival studies.

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1. INTRODUCTION

The red turnip beetle, Entomoscelis americana Brown (Coleoptera:Chrysomelidae), is an oligophagous insect which feeds on members of the family Cruciferae (Stewart 1973). It is found in the four western provinces, Yukon and North West Territories in Canada and in Alaska, Colorado, Idaho, Minnesota, Montana, North Dakota, Washington, Wisconsin and Wyoming in the United States. In the Prairie Provinces and British Columbia, it is mainly a pest of rape (Brassica campestris L. and B. napus L.) and commercial mustard (B. juncea (L.) Coss. and B. hirta Moench) crops, but it has been reported as a sporadic pest of cruciferous garden crops (Stewart 1973; Gerber 1974).

The red turnip beetle overwinters in the egg stage (Gerber 1974). The eggs hatch in late April or early May shortly after the snow has melted. The larvae complete their development by the end of May or early June. They feed on the cotyledons and first true leaves of seedling volunteer rape and mustard and of cruciferous weeds (Gerber 1975).

The availability and nutritional adequacy of the host plant have long been recognized as important factors affecting the distribution and population dynamics of phytophagous insects (Painter 1936; Andrewartha and Birch 1954). Although there are many reports dealing with the effects of different host plants on the growth, development and survival of phytophagous insects (Force 1966; Cibula

et al. 1967; Chiang 1968; Latheef and Harcourt 1972; Gaylor and Sterling 1976), there is no such study for the larvae of the red turnip beetle on its host plants. Also, information on the biology and ecology of the larvae of the red turnip beetle is scant. In addition, there is confusion in the literature as regards the number of larval instars in this beetle. Hanford (1932) reported four instars and Stewart (1973) five instars.

The present study was undertaken to determine the suitability of various cultivars of rape and commercial mustards and of a number of cruciferous weeds for growth, development and survival in the larvae of the red turnip beetle. This study is part of the research program which is being conducted by the Integrated Pest Control Section, Research Station, Agriculture Canada, Winnipeg, on the biology and ecology of the red turnip beetle. The information obtained from the study will be utilized in formulating a pest management system for the insect. Many weeds and volunteer crop plants are known to support growth, development and population build up of certain insects. A knowledge of the influence of the host plants on the growth, development and survival of the red turnip beetle larvae may be of importance in determining the population level of the insect and in predicting potential damage. Also, information on the rate of development will be useful in timing control procedures.

The study is divided into six sections. The first

part consists of an investigation of the patterns of growth and development from the time of hatching to the time of adult eclosion. Daily changes in body weight and the number of moults during the developmental period were determined. In the second section, the growth, development and survival of the larvae on two different stages of plant growth (cotyledons and first true leaves) in the two species of rape, B. campestris (cultivar Torch) and B. napus (cultivar Midas), were compared. The third section evaluates the growth, development and survival of the larvae on the cotyledons and first true leaves of seven rape cultivars which differ in the amounts of erucic acid and glucosinolate in their seed (Target, Midas and Tower, cultivars of B. napus; R500, Echo, Torch and Candle, cultivars of B. campestris). The fourth section evaluates the growth, development and survival of the larvae on the cotyledons of three types of commercial mustards (Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea, and Gisilba (Yellow mustard) cultivar of B. hirta). The fifth section deals with the growth, development and survival of the larvae on the first true leaves of seven species of cruciferous weeds (Brassica nigra (L.) Koch, Black mustard; Sinapis arvensis L., Wild mustard; Descurainia sophia (L.) Webb, Flixweed; Capsella bursa-pastoris (L.) Medic., Shepherd's purse; Erucastrum gallicum (Willd.) Schulz, Dog mustard; Sisymbrium loeselii L., Tall hedge mustard; and Thlaspi arvense L., Stinkweed).

The sixth section is devoted to food selection by newly-hatched larvae offered the cotyledons or first true leaves of rape, commercial mustards, B. nigra, and S. arvensis.

2. LITERATURE REVIEW

2.1 Life history of the red turnip beetle

The red turnip beetle overwinters in the egg stage (Stewart 1973; Gerber 1974, 1975, unpublished). The eggs are laid in loose clusters on the soil surface or in the top one cm of the soil of rape and mustard fields during August, September and October. The eggs enter a diapause phase after embryonic development is almost completed, and hatch in late April or early May of the following year.

The larvae at the time of hatching are about 2 mm in length (Stewart 1973). They are dark grey above and yellowish underneath and covered with short hairs. The larvae usually are found on the soil surface, but climb on to the food plants when feeding. The larvae feed on seedlings of cruciferous weeds and volunteer rape and mustard (Gerber 1974, 1975, unpublished). They will move into new rape and mustard fields, if they run short of food and (or) if such fields are nearby. The larvae can cause economic damage on rape and mustard crops at the seedling stage in May. The cotyledons, first true leaves, petioles and stems may be fed upon sufficiently to cause death of the plants. In the field, larval development is completed in about four weeks, and pupation takes place near the soil surface. The pupae are orange in colour, and the pupal period lasts about two weeks.

The adults emerge during the first three weeks in June and feed for two to three weeks on cruciferous weeds and on volunteer rape and mustard (Gerber 1975, 1976). If the supply of these plants is not adequate, the adults may invade new rape and mustard fields if the fields are nearby. At the end of June, they enter the soil to aestivate for about a month. The adults re-emerge in late July and early August, migrate to new rape and mustard fields, and feed on the flowers, pods, leaves and stems of rape, mustard and cruciferous weeds. A few days after re-emergence, the adults mate and begin oviposition. In rape and mustard, the main damage caused by adults is in June and very little damage is done in August.

2.2 Food selection by phytophagous insects

Phytophagous insects show various degrees of specificity to plants (Dethier 1947, 1966; Beck 1974). They are polyphagous, oligophagous, or monophagous, depending on whether they feed on many, a few, or a single species of plant, respectively. Host plant specificity is determined by the chemical and morphological characteristics of the plant.

The chemical composition of plants is of fundamental importance in their acceptance or rejection as food by insects. This probably is true with regard both to selection between different plant species (Nayar and Thorsteinson 1963; Hsiao and Fraenkel 1968) and to selection between different parts of a plant (Rees 1969). Some plant chemicals may attract an insect to its food source (attractants), others may induce the insect to initiate continuous feeding (incitants), and others may stimulate the insect to feed (feeding stimulants) (Dethier et al. 1960). In some instances, plant chemicals may repel an insect from the food source (repellents), suppress feeding activity such as biting (suppressants), or deter the insect from further feeding (deterrents).

Two theories have been proposed to describe host plant selection by insects. One of the theories (Painter 1951, 1958; Thorsteinson 1960; Kennedy 1965) claims that the choice of food plants is governed by primary

chemicals in the plant. Primary chemicals are defined as being that set of chemicals which are indispensable to the metabolic and developmental process of the insect (nutrients) (Beck 1974). They include various proteins, amino acids, lipids, carbohydrates, vitamins and minerals. An important feature of this theory is the prominence given to the probability that insects derive the stimuli for feeding from generally distributed substances.

Most primary chemicals in plants are feeding incitants and stimulants for insects (Beck 1965; Davis 1968), but some have been shown to depress feeding (Chapman 1974). The presence or absence of one or more primary chemicals in a plant may determine its acceptance or rejection as food. For some insects, the concentration of primary chemicals significantly influences the choice of a plant or plant part (Beck 1956; Auclair et al. 1957; Soo Hoo and Fraenkel 1966a; Gothilf and Beck 1967; Ma 1972). The balance or dietary proportions of primary chemicals may be of greater importance than their absolute quantities in food selection (House 1967, 1970, 1971; Cartier 1968). Diets which lack one or more primary chemicals or have unsatisfactory ratios of these chemicals may be less acceptable by an insect.

The second theory of food selection states that secondary plant chemicals are responsible for host plant selection by phytophagous insects (Dethier 1954, 1970; Fraenkel 1959, 1969; Schoonhoven 1972). Secondary plant

chemicals are defined as non-nutrients usually elaborated as by-products of metabolic systems in the plant (Whittaker 1970; Whittaker and Feeny 1971). They are characteristically toxic, unpalatable, or offensive to non-adapted insects. They include glucosinolates, cucurbitacins and essential oils. This theory implies that the majority of host plants are nutritionally adequate for phytophagous insects and that host plant selection is based on the presence or absence of secondary plant chemicals.

Many secondary plant chemicals are known to function as chemical signals (attractants, incitants, feeding stimulants) in host plant selection (Schoonhoven 1972; Hedin et al. 1974). For some insects, the presence or absence of such chemicals signals the favourableness of the particular plant as food. Some insects which are adapted to a particular plant family use the secondary plant chemicals characteristic of the family to locate their host plants (Gupta and Thorsteinson 1960; Feeny et al. 1970). Other insects, which are not adapted to these secondary plant chemicals, are repelled from the plants of this family (Ishikawa and Hirano 1965). Some secondary plant chemicals incite an insect to take a bite and subsequently stimulate feeding (Nayar and Thorsteinson 1963; Chambliss and Jones 1966). The same chemicals may inhibit feeding in other insects (Chapman 1974; Swain 1977).

In recent years, it has been recognized that both primary and secondary plant chemicals jointly are involved

in host plant selection (Hsiao 1972; Beck 1974; Dethier 1976). Synergistic effects of plant chemicals are not restricted to any particular group of chemicals (Davis 1965; Hsiao 1974). Two or more primary chemicals may act jointly to incite an insect to feed. The effect of a secondary plant chemical as a feeding stimulant may be enhanced in the presence of a primary chemical. Both primary and secondary chemicals can also act jointly to inhibit feeding. Dethier (1976) concluded that although a particular compound or category of compounds may dominate the chemical composition of a plant and may contribute the major sensory cue, it is the total chemical complex of the plant that forms the basis of selection.

The morphological characteristics of the plant may also influence host plant selection in phytophagous insects (Painter 1951; 1969; Sweetman 1958; Beck 1974). Such plant characteristics include leaf toughness, pubescence and thickened cuticle. Succulent leaves are usually preferred to leaves which are tough to bite or chew. Small insects and early instars of relatively large species often avoid pubescent leaves, because the hairs either injure or trap the insects. A plant with a thick cuticle may be rejected because the insect has difficulty penetrating the cuticle with its mouth parts. Some insects will also select leaves of a definite size, shape or colour (Thorsteinson 1960).

2.3 Effects of plants on the growth, development and survival of phytophagous insects

Food plants have profound effects on the growth, development and survival of phytophagous insects (Painter 1951; Maxwell 1972; Beck 1974; Beck and Maxwell 1976). A favourable host plant must provide the insect with a suitable physical environment and a nutritional substrate that is adequate, non-toxic, and utilizable from the standpoint of digestion, assimilation, and conversion into body tissues. When an insect feeds on an unfavourable plant, one or more abnormal effects may occur (House 1963; Painter 1969): (1) High mortality of the first instar larvae or nymphs may occur. In some cases, death occurs just before the adult stage. (2) Smaller size and lower weight often result when the effect is not sufficient to cause the death of the insect. (3) There may be a change in the length of the life cycle. This change may occur as a lengthened larval or nymphal period, or as a shortened adult stage. A longer larval or nymphal period may expose the insect to its enemies for a longer period of time, or may lead to fewer generations per year. A shortened adult stage limits the time available for females to mate and lay eggs. (4) A lowered reproductive rate in the adult may occur. (5) The insect may accumulate less food reserves in the fat body. This affects the ability of the insect to survive, if it hibernates or aestivates.

(6) Various physiological and morphological abnormalities, such as a failure to moult, malformed wings, deformed heads, bent antennae, abnormal tarsi, and reduced pigmentation of wings and body, sometimes appear.

Chemical characteristics of the plant are the most important factors affecting the growth, development and survival of phytophagous insects (Beck and Reese 1976; Beck and Maxwell 1976). In order to be fully adequate, a host plant must provide specific primary chemicals or balanced ratios of the primary chemicals required by the insect (House 1965, 1974). Also, toxins and feeding inhibitors should be absent in the plant (Chapman 1974; Swain 1977). The deficiencies of specific primary chemicals, or abnormal proportions or ratios of primary chemicals may inhibit growth (Friend 1958; House 1965, 1967), change developmental rates (McGinnis and Kasting 1961), and reduce survival (Allen and Selman 1957; House 1969). Many insects alter their rate of food consumption in response to variations in the levels of primary chemicals in the plant (Hirano and Noguchi 1963; Taylor and Bardner 1968; Slansky and Feeny 1977). They consume more food if the plant is low in primary chemicals in order to obtain sufficient nutrients required for growth and development. Variations in the levels of primary chemicals also affect the proportion of the food consumed that is digested, assimilated and converted into body tissues.

Many secondary chemicals in plants serve as toxins or

feeding inhibitors to insects which are not adapted to these plants (Erickson and Feeny 1974; Beck and Reese 1976). Such chemicals may cause instant death to insects which do not have the mechanisms to detoxify or tolerate them. In other instances, such chemicals prevent feeding. For some insects (Reese 1977), secondary plant chemicals have chronic effects which may show up later in the life of the insect, such as at the time of pupation or during the adult stage. In addition, secondary chemicals may interfere with essential primary chemicals by blocking their availability to the insect.

The morphology of the host plant also plays an important role in growth, development and survival of insects. The thickness of plant cuticle may prevent or reduce feeding (Tanton 1962; Agarwal 1969). This is particularly important for small insects including the early instars of relatively large species (Bernays and Chapman 1973; Nielsen 1977). Leaves with hairy surfaces may reduce feeding, increase mortality and depress growth in some phytophagous insects (Schillinger and Gallun 1968; Levin 1973; Wellso 1973). Hairy surfaces sometimes prevent insects from coming in contact with the leaf cuticle, thus acting as a physical obstruction to feeding. Also, the hairs may cause the death of young insects by wounding.

2.4 Larval growth rate and nutritional indices

Two types of indices are often used to determine the value of plants as food for insects. These are the larval growth rate index and the nutritional index. The larval growth rate index is a ratio of the weight gained by the larvae to the duration of developmental period. It is used for estimating the rate at which the larvae convert food into body tissue. The nutritional index is an overall measure of the suitability or adequacy of a food to an insect. It provides means by which nutritional influences on growth, development and survival of an insect can be evaluated. Information on larval growth rate indices and nutritional indices are useful in that they can be used to compare the performance of members of one species of an insect on different foods, or of different species on one food.

2.4.1 Larval growth rate indices

Larval growth rate indices are determined in three different ways. They are calculated from the weight gained by the larvae (Waldbauer 1964, 1968; Soo Hoo and Fraenkel 1966b), or from either the pupal (Fatzinger 1970) or adult (Dunbar and Bacon 1972) weights.

Waldbauer (1964, 1968) and Soo Hoo and Fraenkel (1966b) expressed the larval growth rate index as a ratio of the weight gained by the larvae to the duration of the larval period. The larval weight gain is found by subtracting its weight at the beginning of a feeding period from its weight

at the end.

$$\text{Larval growth rate index} = \frac{\text{Weight gained}}{\text{Duration of feeding}}$$

The index is useful in that it permits an evaluation of growth during any arbitrarily-defined period, the entire larval period, or one or more larval instars.

Fatzinger (1970) calculated the larval growth rate index from the pupal weight and expressed the index as a ratio of the weight at pupation to the duration of the larval period.

$$\text{Larval growth rate index} = \frac{\text{Pupal weight}}{\text{Duration of larval period}}$$

Two assumptions were made. Firstly, growth is linear. Secondly, the weight of pupae is dependent upon the weight of the mature larvae.

The larval growth rate index of Dunbar and Bacon (1972) is similar to that of Fatzinger (1970), but it utilizes the adult weight at emergence instead of the pupal weight.

$$\text{Larval growth rate index} = \frac{\text{Weight of unfed adult}}{\text{Days to maturity}}$$

The indices of Fatzinger (1970) and Dunbar and Bacon (1972) have two disadvantages. Firstly, they cannot be used to evaluate growth during any arbitrarily-defined period, or during a particular instar. Secondly, growth in most insects is sigmoid (Wigglesworth 1972) and not linear.

2.4.2 Nutritional indices

There are two types of nutritional indices. The first type (Waldbauer 1964, 1968; Soo Hoo and Fraenkel 1966b) is based on gravimetric measurements and takes into account the amount of food ingested, the amount of fecal output, and the weight gained. The second type (Dakshayani and Mathad 1973) is based in part on non-gravimetric measurements and takes into consideration the effects of nutrition on survival, duration of development and weight gain.

Three nutritional indices based on gravimetric measurements are found in the literature. They are the approximate digestibility index (A·D), the efficiency of conversion of digested food index (E·C·D), and the efficiency of conversion of ingested food index (E·C·I):

$$A.D. = \frac{\text{Weight of food ingested - Weight of feces}}{\text{Weight of food ingested}} \times 100$$

$$E.C.D. = \frac{\text{Weight gained by larvae during experimental period}}{\text{Weight of food ingested - Weight of feces}} \times 100$$

$$E.C.I. = \frac{\text{Weight gained by larvae during experimental period}}{\text{Weight of food ingested}} \times 100$$

The approximate digestibility index provides an estimate of the percentage of ingested materials that is absorbed by the insect. The efficiency of conversion of digested food index provides an estimate of the percentage of the digested food that is converted into body tissues. The efficiency of conversion of ingested food index is an estimate of the

percentage of the ingested food utilized for growth and development. While these indices indicate the physiological usefulness of the plants, they fail to take into consideration the effects of food on survival, duration of development and percentage of adults at emergence that were deformed.

Dakshayani and Mathad (1973) have developed the only nutritional index based on nongravimetric measurements. They expressed the index as a ratio of the sum of the average weight of adults and percentage survival at emergence, and the duration of development.

$$\text{Nutritional index} = \frac{\text{Average weight of adult} + \% \text{ Survival}}{\text{Duration of development}}$$

This index has two disadvantages. Firstly it fails to take into account the percentage of adults that were deformed. Secondly, addition of the two variables in the numerator causes each of them to be given much less weight than the variable in the denominator. There is no reason to give the three variables different weights in the index. Therefore the two variables in the numerator ought to be multiplied.

2.5 The family Cruciferae

2.5.1 Taxonomic relationship

The Cruciferae is a large plant family composed of approximately 400 genera and 3000 species, the vast majority of which are herbaceous (Vaughan et al. 1976). There are various systems used in the classification of tribes and genera in this family (Hedge 1976). In the present studies, I have adopted the system described by Hedge (1976). Appendix 1 shows the taxonomic relationship of the cruciferous plants tested for growth, development and survival of the red turnip beetle. Sisymbrium and Descurainia are in the tribe Sisymbrieae, Capsella and Thlaspi in Lepidieae, and Brassica, Sinapis and Erucastrum in Brassiceae.

The taxonomic relationship of the four species of the genus Brassica (B. campestris, B. napus, B. juncea and B. hirta) used in the experiments is as follows (Appendix 2) (Downey et al. 1975; Hemingway 1976; McNaughton 1976). B. campestris is subdivided into three subspecies: oleifera which includes the cultivars Echo, Torch and Candle; dichotoma which is known as Toria or Indian rape; and trilocularis which includes the Yellow-seeded sarson and R500. B. napus originated from crosses between B. campestris and B. oleracea and includes the cultivars Target, Midas, Tower and Regent. B. juncea arose from interspecific crosses between B. campestris and B. nigra and includes the cultivars Blaze and Lethbridge 22A. B.

hirta, known as Sinapis alba L. in Europe, is distantly related to the other species.

2.5.2 Chemical composition of Cruciferae

The major chemical components in cruciferous plants are fatty acids, proteins and carbohydrates which are primary plant chemicals, and glucosinolates, which are secondary plant chemicals (Appelqvist 1976; Crisp 1976; Kjaer 1976). Most of the information available on the chemical composition of cruciferous plants are on oilseed crops of the genus Brassica and have been restricted to two major compounds, fatty acids and glucosinolates.

Fatty acids in cruciferous plants are usually classified into two categories, common fatty acids and uncommon fatty acids (Appelqvist 1972). The common fatty acids consist of one saturated acid, palmitic acid, and three unsaturated acids, oleic, linoleic, and linolenic acids. These fatty acids represent about 90% of the total fatty acids of most plant leaves (Galliard 1974). The most characteristic fatty acid constituents of oilseed crucifers are the uncommon fatty acids, eicosenoic and erucic acids. However, some crucifers are totally devoid of erucic acid. Generally, it has been reported that erucic acid occurs only in the seeds of crucifers (Shorland 1963; Hilditch and Williams 1964). Recently, Appelqvist (1970, 1976) reported the occurrence of small amounts (0.5%) of erucic acid in the leaves of Gulle cultivar of B. napus,

which has high erucic content (34.3%) in the seeds. Eicosenoic acid is absent in the leaves of crucifers, but it is present in the seeds.

The growth and survival of an insect may be influenced by the type and amount of fat in the diet (Wigglesworth 1972; House 1974). Although there is no information on the effects of erucic acid on growth, development and survival of insects, it has been shown that erucic acid causes physiological disorders in mammals (Aae-Jorgensen 1972; Beare-Rogers 1975; Vles 1975). High erucic acid levels in experimental diets were found to reduce food consumption in non-ruminant animals. At very high levels, growth rate is reduced, mortality is increased, and reproduction may be affected. High amounts of eicosenoic acid and low levels of linoleic acids were also found to have similar effects on the animals. Food preferences by the animals were also affected by erucic acid levels in the diet. Diets which were high in erucic acid were the least selected.

The most characteristic chemicals of the family Cruciferae are the glucosinolates, which are also referred to as thioglucosides or mustard oil glucosides (Kjaer 1960, 1974; Ettlinger and Kjaer 1968). Glucosinolates are a class of sulphur compounds (Appendix 3) present in the roots, stems, leaves, flowers and seeds of crucifers, and are synthesized from amino acids. More than 60 glucosinolates have been reported within the family Cruciferae. They are

uniform in structure, varying solely in the character of the side-chain (R). Besides occurring in Cruciferae, glucosinolates have been found in other dicotyledonous families including Capparaceae and Resedaceae. Glucosinolates are hydrolyzed when plant tissues are damaged typically giving rise to volatile isothiocyanates (mustard oils). The hydrolysis of the glucosinolates is catalyzed by a group of enzymes which are referred to as myrosinases (thioglucoside glucohydrolase) (Bjorkman 1976; Kjaer 1976). In acidic medium, or by the action of certain other catalysts, hydrolysis of glucosinolates gives rise to nitriles or thiocyanates.

In the various crucifer species, qualitative and quantitative differences occur in the glucosinolates present (Kjaer 1960; Van Etten et al. 1969; Josefsson 1970; Cole 1976). Whereas some species contain only one or two glucosinolate(s), others contain many different glucosinolates. Cultivars within a species usually have the same type(s) of glucosinolates, but the amount of the glucosinolate(s) present varies among the cultivars.

Many crucifers contain additional secondary plant chemicals unrelated to glucosinolates. The genera Erysimum and Cheiranthus contain cardenolides (cardiac glycosides), the genus Iberis contains cucurbitacins, and plants of the genera Lunaria and Capsella contain alkaloids (Gheorghiu et al. 1959; Hegnauer 1964).

Glucosinolates are believed to represent the prime

line of defense in crucifers against attack by herbivores and pathogens (Whittaker and Feeny 1971; Feeny 1976, 1977). These compounds have powerful antibacterial, antifungal and insecticidal properties. Glucosinolates or the cleavage products derived from them are toxic, even at small concentrations, to insects which do not naturally feed on crucifers (Brown 1951, Lichtenstein et al. 1964; Erickson and Feeny 1974). In mammals (Kingsbury 1964), glucosinolates or their cleavage products are powerful tissue irritants. The hydrolysis products of glucosinolates present in rapeseed and mustard meals are known to cause thyroid enlargement in non-ruminant animals (Josefsson 1972). In high concentrations, they damage the skin and mucous membranes, depress growth, and cause death of the animals.

Glucosinolates or their cleavage products are not toxic to insects which feed on crucifers (Slansky and Feeny 1977; Blau et al. 1978). Such insects are able to detoxify or tolerate large amounts of these compounds. In some instances, glucosinolates are stored by the insect for defensive purposes (Alpin et al. 1975).

Cruciferae-feeding insects utilize glucosinolates or isothiocyanates derived from them as behavioral attractants for locating their food source (Hovanitz et al. 1963; Feeny et al. 1970), or as feeding stimulants (David and Gardiner 1966; Schoonhoven 1967; Hicks 1974; Nielsen 1978). Such insects are not only able to distinguish between different types of glucosinolates, but also have preferences for certain types of glucosinolates. For some Cruciferae-feeders,

attraction to a host plant and stimulation to feed are determined by both the types and quantity of the glucosinolate(s) present. The insect may not be attracted if the concentration of the glucosinolate is low and may be repelled or not initiate feeding if the concentration is very high (Hicks 1974; Finch 1978).

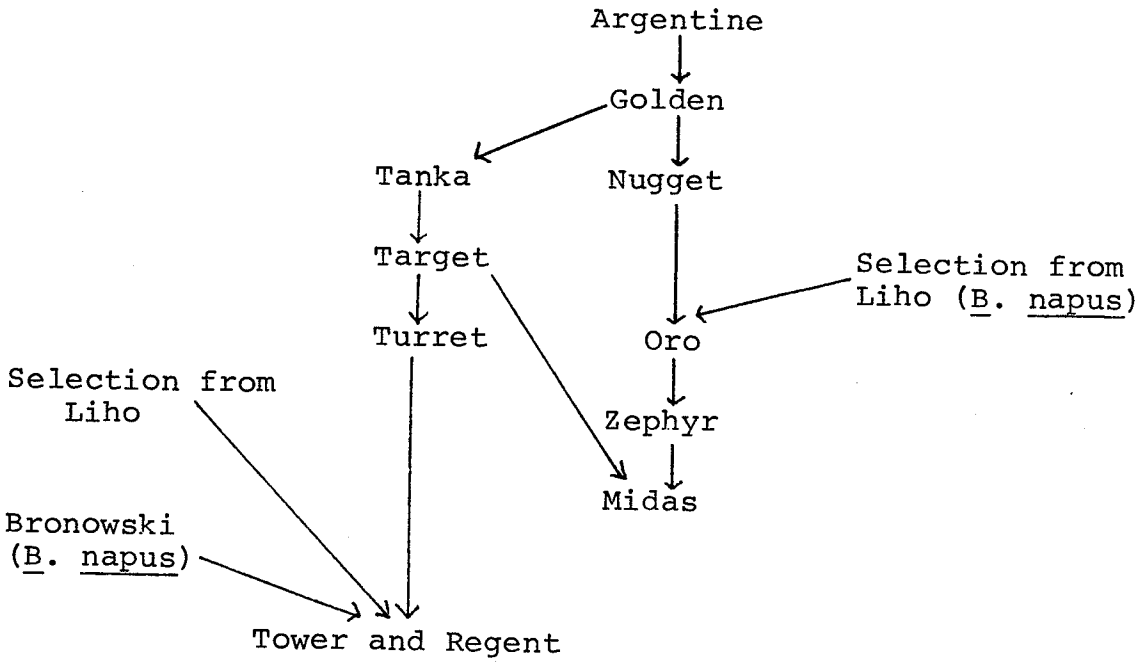
2.6 History of Rapeseed and Mustard crops in Canada

Rapeseed was introduced from Poland into Canada in 1936 (White 1975; Runciman and Olson 1975). Because of the origin, it was named Polish rape. It was later established that it belonged to B. campestris oleifera, which is known as turnip rape in Europe. The first commercial production of rapeseed began in 1943 with the Argentine-type rape, B. napus, which had been introduced from Argentina. Mustards (B. juncea and B. hirta) were introduced earlier than rapeseed (Pawlowski 1974), and they have been grown under contract since 1945.

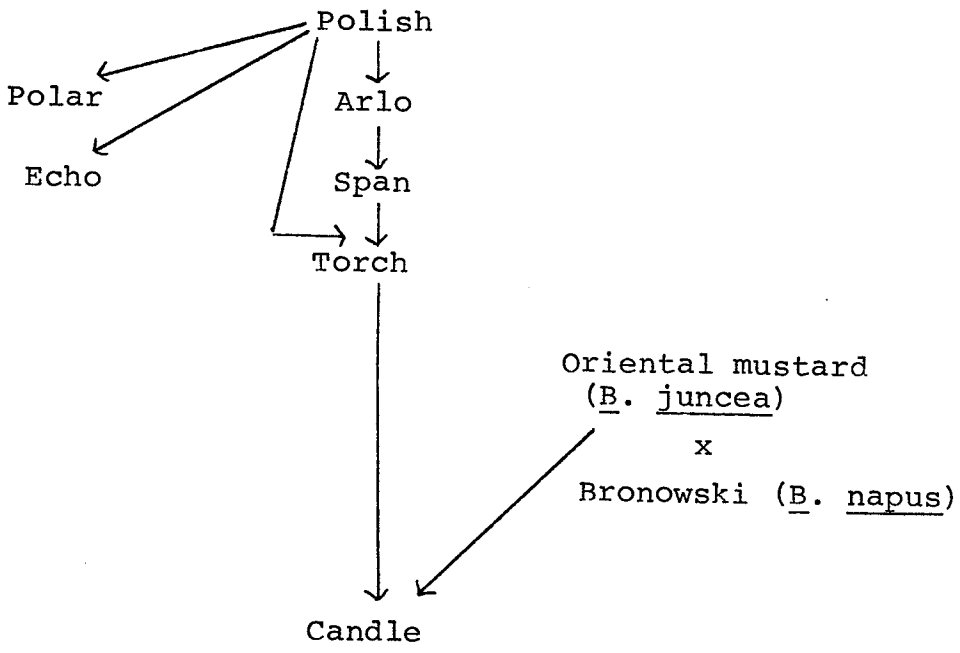
Rapeseed breeding in Canada began in 1943 using seed stocks of B. napus which were introduced from Argentina (Stefansson 1975; Downey et al. 1975). The first Canadian rape cultivars of B. napus can be traced to Golden. The breeding work on B. campestris was initiated in 1948 from seed stocks imported from Poland. These seed stocks were not licenced, but they contributed to the ancestry of all the cultivars of B. campestris.

The names and origin of the Canadian cultivars of B. napus and B. campestris are shown in the diagram below (Stefansson 1975). A single arrow leading from one cultivar to another indicates that the latter was derived from the former by selection. Two or more arrows leading to a cultivar indicate that the cultivar was selected from the progeny of crosses involving the parents indicated.

B. napus



B. campestris



The third type of rape is R500, a cultivar of B. campestris trilocularis. R500 is a reselection of a yellow sarson cultivar introduced from India. It is high in erucic acid and grown by contract solely for industrial use.

One of the major aims of rapeseed and mustard breeding programs in Canada is to improve the quality of the oil by reducing the erucic acid content (Stefansson 1975; Downey et al. 1975). A low erucic acid oil is desirable, because high erucic acid levels cause physiological disorders in mammals. This objective has been achieved with the development of the following low erucic acid cultivars: Oro, Zephyr, Midas, Tower and Regent cultivars of B. napus; and Span, Torch and Candle cultivars of B. campestris. A cultivar is considered high, normal or low in erucic content if the oil composition of the seed contains greater than 50%, 20-45% and less than 2% in erucic acid, respectively (Appendix 4).

An equally important objective of the breeding program is the development of rapeseed which is low in or has no glucosinolates in the meal (Stefansson 1975; Downey et al. 1975). The meal is used as high protein feed supplements for livestock and poultry (Bowland et al. 1965). If the meal contains glucosinolates, it may be toxic to non-ruminant animals. The presence of glucosinolates in rapeseed has been a major constraint in the use of rapeseed meals in non-ruminant animal feeds. The development of low glucosinolate cultivars (Tower, Regent and Candle) as

replacement for cultivars normal in glucosinolates (Golden, Nugget, Tanka, Target, Oro, Turret, Zephyr and Midas cultivars of B. napus; and Echo, Polar, Span and Torch cultivars of B. campestris) has provided a solution to the quality problem in rapeseed meal. A rapeseed cultivar is considered normal in glucosinolate if it contains 7 to 11 milligrams of 3-butenylisothiocyanate per gram of oil free meal, and low of it contains 0.5 to 1.5 milligrams of 3-butenylisothiocyanate per gram of oil free meal (Appendix 4).

The two major objectives of rapeseed breeding program have been achieved with the development of Tower, Regent and Candle. These cultivars are low in both erucic acid and glucosinolate contents.

3. MATERIALS AND METHODS

3.1 Procedures for growth, development and survival studies

3.1.1 Plants tested

Seventeen different types of plants belonging to 11 species of the family Cruciferae were evaluated as food plants for larvae of the red turnip beetle (Table 1). Regent cultivar of B. napus was not tested. The plants were offered as food in the cotyledon stage (stage 1 of Harper and Berkenkamp (1975)) or first true leaf stage (stage 2.1). The plants were grown in a greenhouse with a light cycle of 16h light:8h dark. Seeds were sown daily in wooden flats throughout the course of the experiments to provide plants of the same age for each day of the experiment. The experiments were initiated approximately six days after planting when the cotyledons were used and two weeks after planting when the first true leaves were used.

3.1.2 Insect

Newly-hatched larvae of the red turnip beetle were used in all of the experiments. The eggs for the experiments were obtained from stock colonies of this beetle maintained at Winnipeg in 1976 and 1977. In 1976, the adults in the stock colonies came from growers' fields near Shortdale, Manitoba. In 1977, the beetles were obtained from growers' fields near The Pas, Manitoba.

Table I. Plants tested in feeding experiments with larvae of *Entomoscelis americana*.

Species	Common name	Cultivar	Abbreviations*
Brassica campestris oleifera L.	Turnip rape	Echo	EC
		Torch	TO
		Candle	CA
B. campestris trilocularis L.		R500	R5
B. napus L.	Rape	Target	TG
		Midas	MI
		Tower	TW
		Regent	RG
B. juncea (L.) Coss.	Brown mustard	Blaze	BR
	Oriental mustard	Lethbridge 22A	OR
B. hirta Moench	Yellow mustard	Gisilba	YW
B. nigra (L.) Koch	Black mustard		BL
Sinapis arvensis L.	Wild mustard		WD
Descurainia sophia (L.) Webb.	Flixweed		FL
Capsella bursa-pastoris (L.) Medic.	Shepherd's purse		SP
Erucastrum gallicum (Willd) Schulz	Dog mustard		DG
Sisymbrium loeselii L.	Tall hedge mustard		TH
Thlaspi arvense L.	Stinkweed		ST

*These abbreviations will be used elsewhere in the thesis.

Eggs obtained from stock colonies in 1976 were kept in a cold room at 2.5° ± 1°C. Prior to storage, the eggs were kept at room temperature for three weeks to permit embryonic development (Stewart 1973), and at 15° ± 1°C for two weeks and 10° ± 1°C for two weeks to permit acclimatization.

In 1977, the eggs were handled in two different ways. One group of eggs was stored in the cold room as described above. The other group was kept out-of-doors during the winter. The eggs were placed on the surface of soil in plastic containers and covered with a layer of rape leaves. The containers were 8cm in diameter and 11cm in height and were covered with coarse screen at the top to retain the eggs, and fine screen at the bottom to allow water to drain while retaining the soil. The containers were buried in the field so that the top of the soil in the container was at soil level. The eggs were left out in the field until the end of April when a few of the eggs were hatching.

In March 1978, it was discovered that the hatch rate of the 1977 eggs kept in the cold room and the viability of larvae from these eggs were poor. Thus, I had to use the larvae from the 1977 eggs kept out-of-doors.

All the experiments were conducted in plant growth cabinets where the temperature was 15° ± 0.5°C, the relative humidity was 60%, and the light cycle was 16h light:8h dark. Eggs were removed from cold storage the

day before the start of each experiment and were placed at room temperature. Hatching began within 24 hours after removal from cold storage. The larvae were placed individually in plastic, ribbed creamer cups (Bucher and Bracken 1976) a few hours after hatching and confined in these cups for the duration of the experiment. In all experiments, 100 larvae were used for each plant tested. The larvae were weighed the day the experiment was set up and at regular intervals thereafter as described in each of the following sections. Weights were taken to the nearest 0.01mg. The larvae were given fresh plant material daily until the time the larvae stopped feeding and more food was presented than they consumed. Old food and faeces were removed each day and the larvae were transferred into new cups at two-day intervals.

Records were kept on the time of each moult, on the weights at the beginning of the experiment and at each moult, and on the number of deaths and when they occurred. At emergence, the adults were sexed and observed for deformities. The numbers of normal and malformed adults were recorded.

Data obtained on each life stage for each food plant were subjected to statistical analyses. The age-class survival was calculated by dividing the number of individuals alive at the end of a life stage by the number of individuals which entered that stage. Percent survival from larval eclosion to adult emergence on each food

plant was obtained by summing up the number of individuals that emerged as adults and expressed as a percentage of the 100 individuals at the start of the experiment. The percentage of malformed adults on each food plant was calculated by summing up the number of adults that were deformed and expressed as a percentage of the 100 individuals at the start of the experiment. The data were analysed using Chi-squared test (2x2 contingency tables) (Snedecor and Cochran 1967). Differences at the 5% level of confidence were considered significant.

The mean developmental time for each life stage, the mean total developmental time (larval eclosion to adult emergence), and the mean weights for each life stage were determined for each sex and food plant. The data were subjected to analysis of variance and Duncan's multiple range test. Differences at the 5% level of confidence were considered significant.

The larval growth rate index was calculated for each larva using the pupal weights as described by Fatzinger (1970).

$$\text{Larval growth rate index} = \frac{\text{Pupal weight}}{\text{Duration of larval period}}$$

After these calculations were made, the mean larval growth rate index was calculated for each food plant. The indices were subjected to analysis of variance and Duncan's multiple range test. Differences at the 5% level of confidence were considered significant. A large larval growth rate index indicates that the rate of weight gain is faster on that

food. A low larval growth rate index indicates that the rate of weight gain is slower on that food.

The larval growth rate index was chosen, because it permits estimation of the growth rates of the larvae from the pupal weights. The pupal weights were used, because the weights of the larvae at the end of the feeding period were not determined for most of the experiments.

A nutritional index, adapted from Dakshayani and Mathad (1973), was used to evaluate the nutritional suitability of the plants.

$$\text{Nutritional index} = \frac{\text{Average weight of adults} \times (\%\ \text{Survival} - \%\ \text{deformed})}{\text{Duration of development}}$$

Two modifications were made to the nutritional index. Firstly, the index was modified to take into account not only the duration of development from larval eclosion to adult emergence, the weight of adult at emergence, and the percentage survival, but also the percentage of malformed adults. Two assumptions were made for subtracting the percentage of malformed adults from the percentage of larvae that survived to the adult stage: a) Adults that are severely deformed are unlikely to survive and lay eggs. Therefore, such adults will not contribute to future population of the insect. b) Adults that are not severely deformed are likely to lay fewer eggs than normal adults. Therefore, the impact such adults would have on future population of the insect is minimal. Adults that are not severely deformed are described on pages 54, 72, 83, 93 and 101 and those that are severely deformed are described on page 101. The second modification consisted of

multiplying the average weight of adults with the value obtained from the difference between the percent survival and the percentage of malformed adults, instead of adding these two variables together.

The nutritional index for each food plant was not subjected to any statistical analysis. A large nutritional index indicates that the food is nutritionally adequate and superior. A low nutritional index indicated that the food is nutritionally inadequate and inferior.

3.2 Procedures for food selection studies

Thirteen of the 18 different types of plants (Table I) were tested at the cotyledon or first true leaf stage to determine which plants were selected by newly-hatched larvae of the red turnip beetle. The eggs were from the 1977 stock colony and were kept out-of-doors during the winter. All experiments were conducted in a plant growth cabinet where the temperature was 15° ± 0.5°C, the relative humidity was 60%, and the light cycle was 16h light:8h dark.

Two methods (two-choice and four-choice experiments) (Feeny et al. 1970) were used to determine which food plant was selected by the larvae. For both methods, a 9cm-diameter Whatman no. 1 filter paper was placed in the bottom of a glass Petri dish (10cm in diameter x 4.5 cm in height). In the two-choice experiment, the paper was divided into quadrants. In the four-choice experiment, the paper was divided into eight sections of equal size. Distilled water was introduced to moisten the filter paper and prevent the leaves from desiccating during the test period. Equal weights of the plants were arranged in the Petri dishes as described under each method. Newly-hatched larvae, a few hours old, were released at the center of the Petri dish. The larvae were not exposed to food plants before the experiment. Larval distribution on the plants was used as the criterion for food selection. Each experiment was replicated 12 times.

In the two-choice experiments, the larvae were exposed to two plants simultaneously. At the cotyledon stage, the plants tested were Echo, Torch, Candle and R500 cultivars of B. campestris; Target, Midas and Tower cultivars of B. napus; Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea; and Gisilba (Yellow mustard) cultivar of B. hirta. At the first true leaf stage, the plants tested were Torch cultivar of B. campestris, B. nigra and S. arvensis. Torch at the cotyledon stage was used as the control. Torch was chosen, because preliminary investigations showed that it is a good food plant for growth, development and survival of the larvae. In each experiment, the test plant together with Torch were offered as food to the larvae. The test plant and Torch were so arranged that each appeared in two of the quadrants, the order within the quadrants being assigned alternately. Thirty larvae were used in each replicate, giving a total of 360 larvae for each plant tested.

In the four-choice experiments, the larvae were exposed to four plants at the same time. At the cotyledon stage, the plants tested were Echo, Torch, Candle and R500 cultivars of B. campestris; Target, Midas, Regent and Tower cultivars of B. napus; Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea; Gisilba (Yellow mustard) cultivar of B. hirta; and S. arvensis. At the first true leaf stage, the plants tested

were Torch and Candle cultivars of B. campestris and Midas and Tower cultivars of B. napus. In each experiment, each of the four plants were so arranged that each food appeared in two of the eight sections, the order being assigned at random. Fifty larvae were used in each replicate, giving a total of 600 larvae for each group of plants tested.

In the two-choice and four-choice experiments, the number of larvae on each plant were counted 24h after the experiments were set up. At the time of the count, almost all of the larvae usually were found on the plants. The number of larvae found on each plant was expressed as a percentage of the number of larvae released at the center of the Petri dish. The data were analysed using Chi-squared goodness of fit test. The replicate totals were pooled together as the Chi-squared values among the replicates in all experiments were not significant.

4. RESULTS

4.1 The pattern of growth and development

The number of larval instars and the pattern of growth and development of the red turnip beetle from the time of larval eclosion to the time of adult emergence was investigated. The cotyledon stage of Torch cultivar of B. campestris was used as food for the larvae, because Torch was a cultivar widely used by growers in 1976 and because rape is in the cotyledon stage at the time the eggs hatch in the field. The eggs used in teh experiment were obtained from the 1976 stock colony. The larvae were weighed daily from the time the experiment began until the day of adult emergence. Records were kept on the daily weights and on the number and time of moults. The adults were not sexed at emergence. The growth curve was based on both sexes for 73 larvae, which survived to the adult stage, out of 100 larvae at the beginning of the experiment.

In the red turnip beetle, there are four larval instars, a pupal stage and an adult stage (Figs. 1, 2). The total nean development time from hatching to adult emergence was 46.9 ± 2.9 days (range, 44-51) at 15°C. About two-thirds (31.9 ± 2.1 days) of this time was spent in the larval phase. The larvae spent 6.9 ± 0.8 days in the first instar, 5.1 ± 0.9 days in the second instar, 5.0 ± 0.6 days in the third instar, 14.9 ± 1.0 days in the fourth instar, and 15.0 ± 0.7 days in the pupal stage. Subsequent experiments showed that at each stage, the mean development times for males and females were not significantly different.

Figure 1 gives the growth curve for the red turnip beetle. The curve was S-shaped. The larvae weighed about 0.28 mg at hatching and attained an average maximum weight of 76.88 mg in the fourth instar when they were 23.1 ± 1.8 days old. Most of the weight gain occurred in the fourth instar (72%). The larvae stopped feeding when they were 26.9 ± 2.0 days old. About 18% of the maximum weight attained was lost by the time the larvae pupated. This can be attributed to the clearing of the gut of ingested material and the casting of the last larval skin. A small further loss (4%) in weight occurred during the pupal period. Subsequent experiments showed that female adults were about 24% heavier than male adults.

Fig. 1. Growth curve for Entomoscelis americana from the time of egg hatching to adult emergence (both sexes combined) when reared on the cotyledons of Torch cultivar of B. campestris. I_2, I_3 and I_4 represent the average time of the moult and average weight of the larvae at the time they moulted into the second, third and fourth instars, respectively. P and A represent the average time of and weight at pupation and adult emergence, respectively.

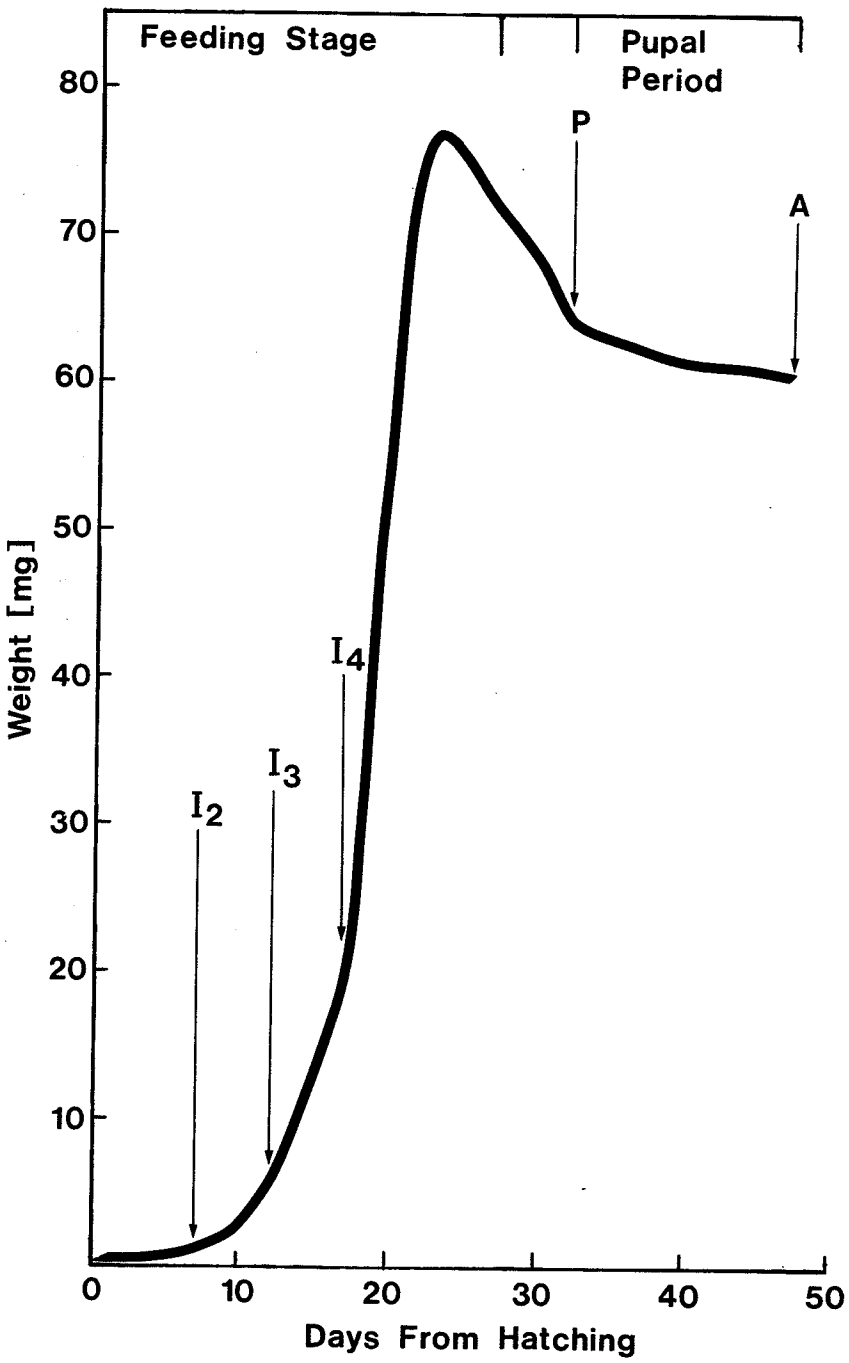

Feeding Stage
Pupal Period
P
A
I2
I3
I4
Weight [mg]
80
70
60
50
40
30
20
10
0
10
20
30
40
50
Days From Hatching

Fig. 2. Stages in the life cycle of the red turnip beetle, Entomoscelis americana.

(A) Eggs (x7).

(B) First instar larva (x7).

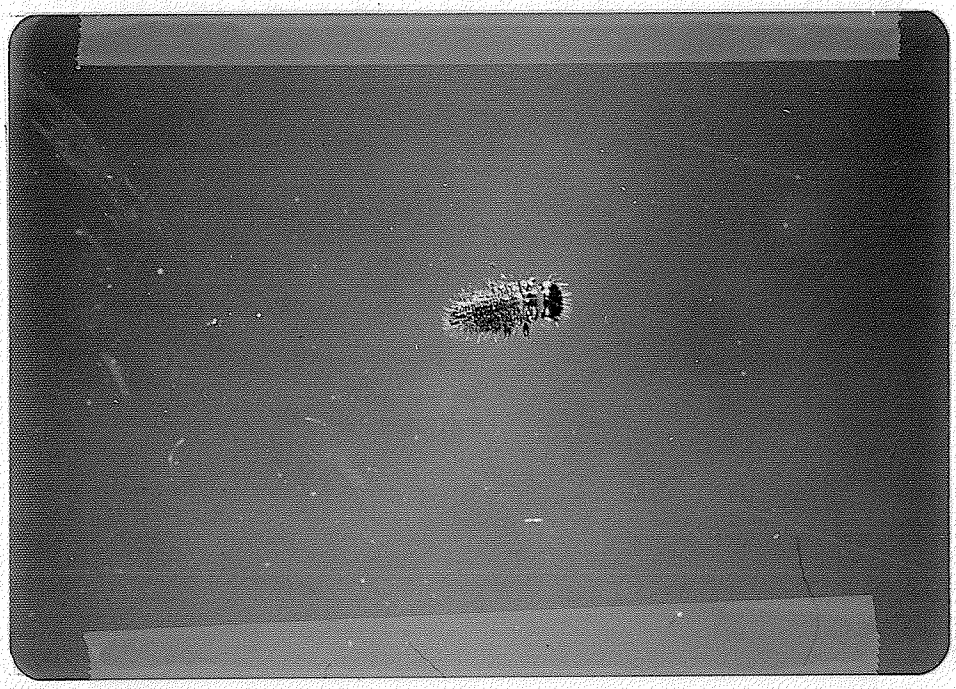


Fig. 2. (Cont.) (C) Second instar larva (x7).

(D) Third instar larva (x7).

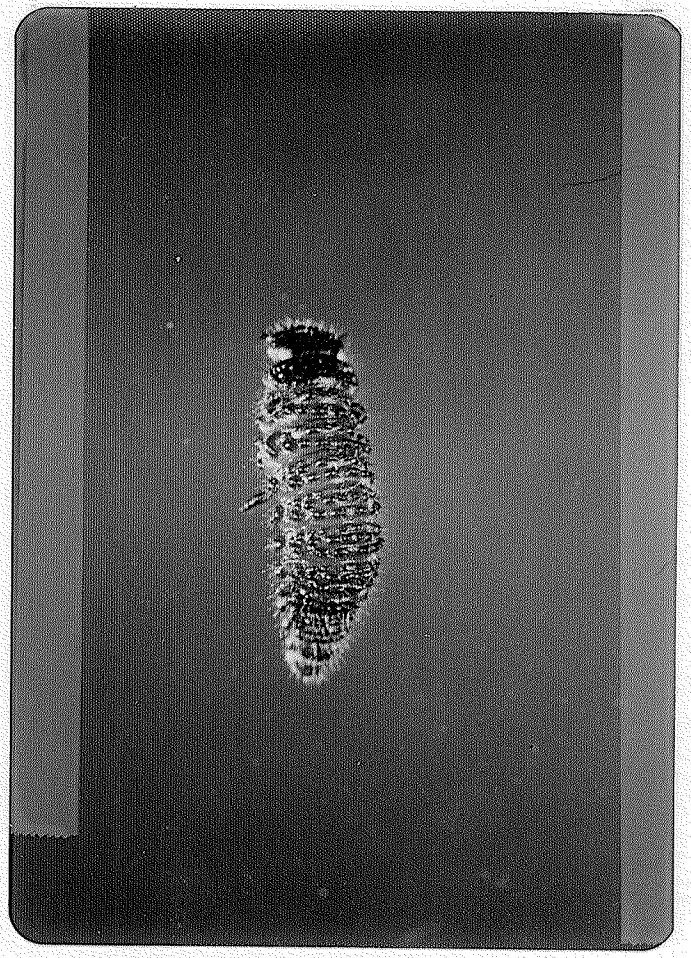
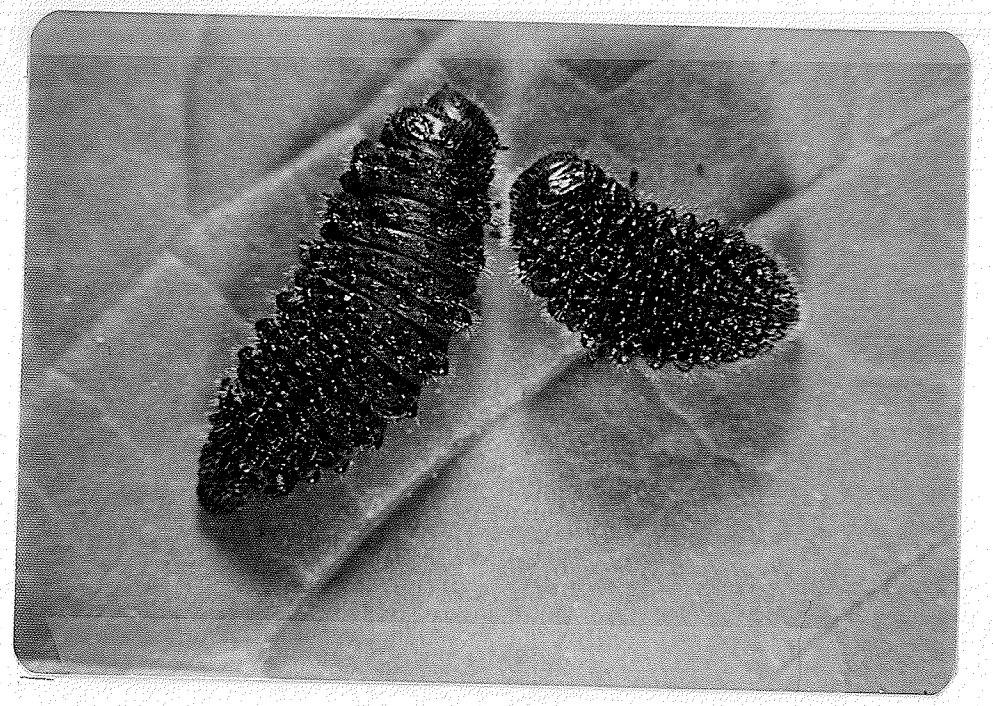


Fig. 2. (Cont.) (E) Fourth instar larva (x7).

(F) Prepupa (left) and Pupa (right) (x10).



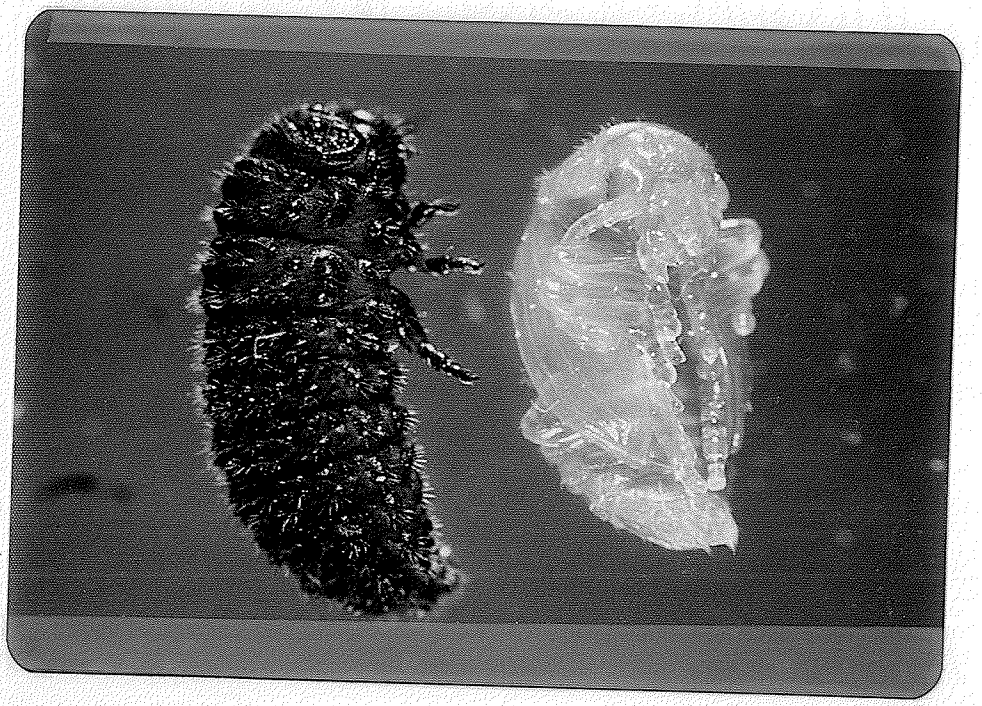


Fig. 2. (Cont.) (G) Adult (x8).

4.2 Growth, development and survival on two stages of plant growth

The cotyledons and the first true leaf stages of Torch cultivar of B. campestris and Midas cultivar of B. napus were compared for growth, development and survival of the red turnip beetle larvae. These two stages of plant growth were chosen because rape is in these growth stages during most of the larval period. The two rape cultivars were selected, because they were the cultivars commonly used by growers in 1976. The eggs were from the 1976 stock colony. The larvae were weighed at the time the experiment was set up and just after each moult. Records were kept on the time of each moult, on the weights at the beginning and at each moult, on the numbers of deaths and when they occurred, and on the numbers of normal and malformed adults.

Survival from larval eclosion to adult emergence was significantly higher in larvae reared on the cotyledons than in those reared on the first true leaves (Figs. 3, 4; Table II). On the two cultivars, 50-72% more larvae reached the adult stage when fed on the cotyledons than when fed the first true leaves. At each stage of plant growth, the differences in survival between the cultivars were not significant. Mortality was the highest (23-58%) in the first larval instar regardless of the type of food, but was higher in those first instar larvae fed the first true leaves than on those fed cotyledons (42-58% vs 23-32%).

In the last three larval instars and in the pupa, mortality usually was less than 10% in each of these life stages and was the lowest in the third larval instar. Most of the mortality in the fourth larval instar resulted from a failure to cast the last larval skin at pupation (Fig. 5).

Fig. 3. Survival of Entomoscelis americana from egg hatching to adult emergence when reared on the cotyledons and first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus.

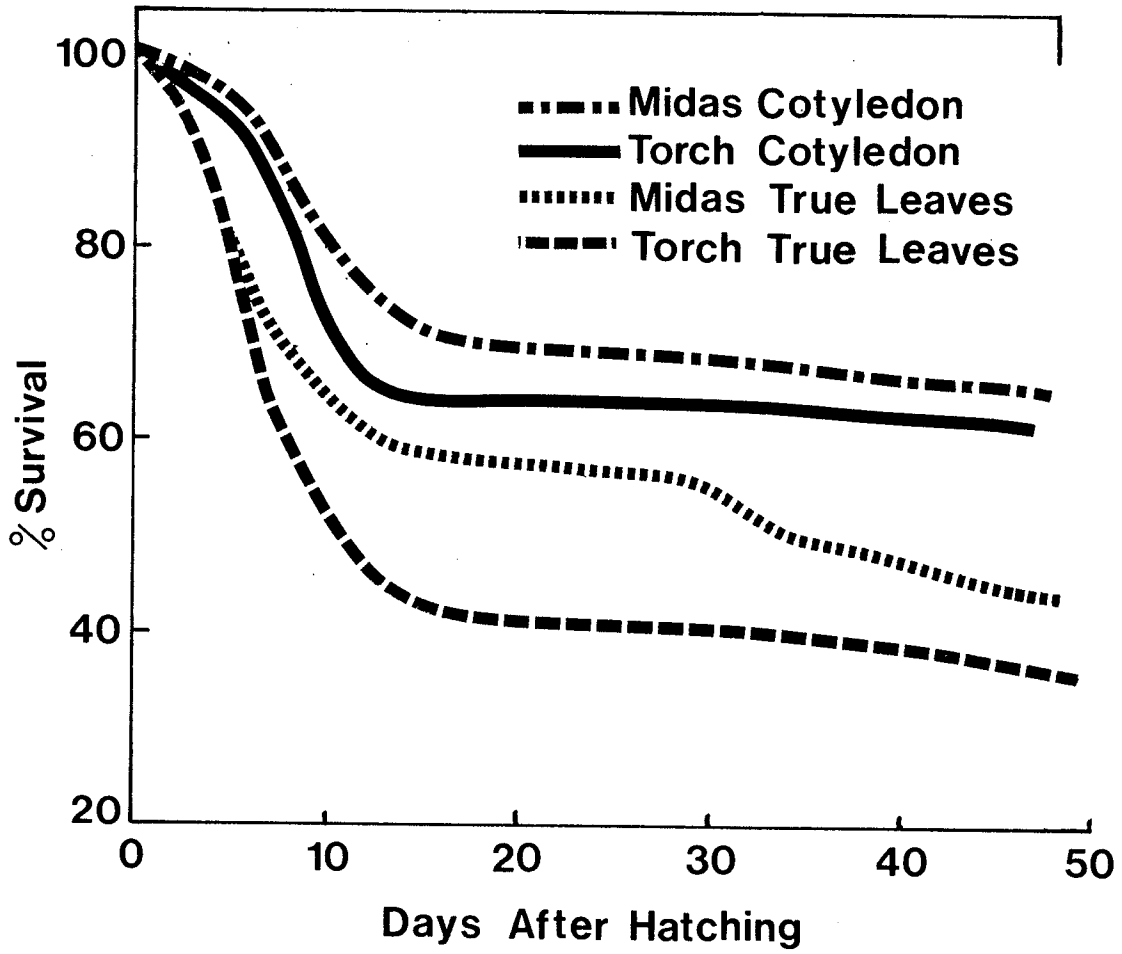

100
80
60
40
20
% Survival
0
10
20
30
40
50
Days After Hatching
Midas Cotyledon
Torch Cotyledon
Midas True Leaves
Torch True Leaves

Fig. 4. Age-class survival of Entomoscelis americana on the cotyledons and first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus.

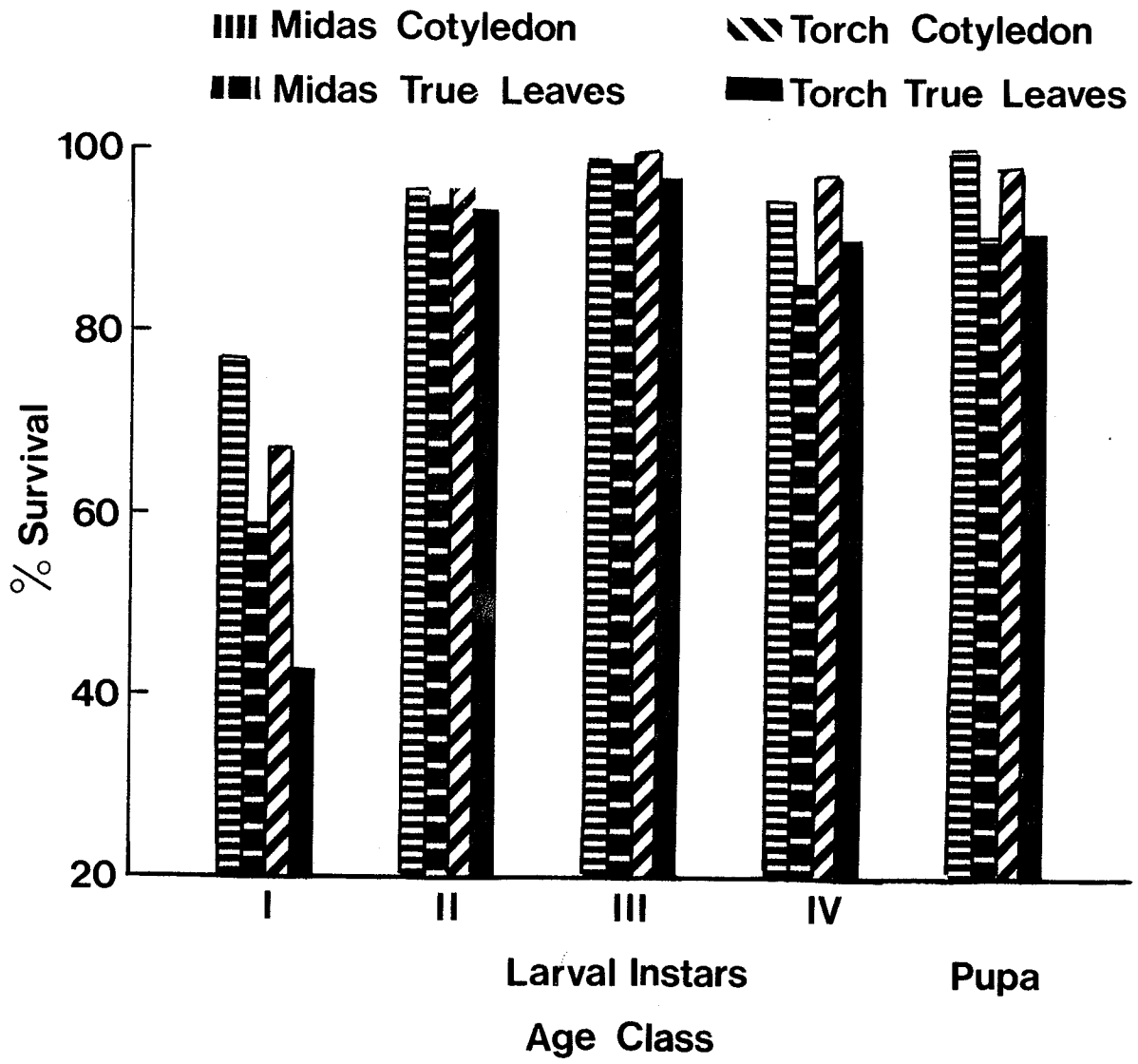

Midas Cotyledon
Midas True Leaves
Torch Cotyledon
Torch True Leaves
100
80
60
40
20
% Survival
I
II
III
IV
Pupa
Larval Instars
Age Class

Table II. Percent survival to the adult stage and % deformed adults when larvae of Entomoscelis americana were reared on the cotyledons or the first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus; 100 larvae were used for each cultivar for each stage of plant growth.

Stage of plant growth	% Survival		% Deformed Adults	
	Midas*	Torch*	Midas	Torch
Cotyledons	66a	62a	1	0
1st true leaves	44b	36b	0	1

*The percentage within the rows and columns followed by the same letter are not significantly different at the 1% level according to Chi-squared test (2 x 2 contingency table).

Fig. 5. Two pictures showing pupae of Entomoscelis americana failing to cast the last larval skin.

(A) (x12)

(B) (x18)

The developmental times for the larvae reared on the cotyledons were not significantly different from those reared on the first true leaves (Table III). Also, the mean development times for males and females were not significantly different. The average length of the developmental period from larval eclosion to adult emergence ranged from 47.4 days for males given Torch cotyledons to 48.9 days for females given Midas first true leaves.

Adults of both sexes obtained from larvae reared on the cotyledons were significantly heavier than those from larvae reared on the first true leaves (Table IV). In Torch, the adults on cotyledons were about 16% heavier than those on the first true leaves, and in Midas the adults on cotyledons weighed about 18% more than those on the first true leaves. For both stages of plant growth, the differences in weights between the two cultivars for each sex were not significantly different.

Table III. Mean number of days ($\bar{X}$ ± SD) spent in each stage by larvae of Entomoscelis americana reared on the cotyledons and first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus.

Food and stage of growth	No.*	Number of days in each life stage: Larval instars i $\bar{X}$ ± SD**	i Range	ii $\bar{X}$ ± SD**	ii Range	iii $\bar{X}$ ± SD**	iii Range	iv $\bar{X}$ ± SD**	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Total days to adult emergence $\bar{X}$ ± SD**	Total days to adult emergence Range
						Males							
Cotyledons													
Torch	32	6.5±0.8	5-9	4.5±0.6	4-6	5.0±0.7	4-6	15.4±1.4	12-18	16.0±1.5	13-19	47.4±4.3	40-53
Midas	25	7.0±1.2	5-10	4.7±0.8	4-7	5.2±0.6	4-6	16.3±1.6	14-21	15.0±2.4	13-18	48.2±3.1	44-56
1st true leaves													
Torch	11	6.9±0.6	5-8	5.3±0.5	5-6	5.6±0.5	5-6	14.7±2.2	13-17	15.6±0.5	15-16	48.1±1.1	44-54
Midas	25	6.4±0.8	5-8	4.8±0.6	4-6	5.8±0.4	5-6	16.2±1.9	15-19	15.4±0.8	14-16	48.6±1.4	45-51
						Females							
Cotyledons													
Torch	30	6.3±0.8	6-9	4.6±0.8	4-7	5.0±0.6	4-6	15.7±1.2	12-16	16.3±1.7	14-19	47.9±2.9	40-54
Midas	41	6.7±1.0	5-10	4.8±0.8	4-6	5.2±0.7	4-7	16.1±1.1	14-18	15.9±1.0	13-17	48.7±2.6	42-54
1st true leaves													
Torch	25	7.1±1.7	5-9	5.3±0.6	4-6	5.6±0.5	5-6	15.1±1.0	14-18	15.3±0.5	15-16	48.4±2.5	46-51
Midas	19	6.5±0.9	5-8	5.1±0.5	4-5	6.0±1.1	5-9	16.2±1.6	13-18	15.1±0.7	14-16	48.9±2.1	45-50

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each plant species and stage of plant growth.

**No significant difference between means at the 5% level according to F-Test.

Table IV. Mean weight (mg ± SD) of Entomoscelis americana at the beginning of each stage when reared on the cotyledons and first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus.

Food and stage of growth	No.*	Larval instars i $\bar{X}$ ± SD	i Range	ii $\bar{X}$ ± SD	ii Range	iii $\bar{X}$ ± SD	iii Range	iv $\bar{X}$ ± SD	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Adult $\bar{X}$ ± SD**	Adult Range
Males													
Cotyledons													
Torch	32	0.24±0.04	0.25-0.32	1.74±0.42	1.25-2.59	6.10±1.16	4.10-8.24	21.27±5.13	13.61-29.39	55.99±7.27b	40.67-71.00	52.95±9.33b	36.27-67.69
Midas	25	0.31±0.06	0.22-0.36	1.77±0.32	1.13-2.36	5.89±1.24	4.07-8.68	20.85±4.52	13.04-29.70	54.83±6.36b	38.41-69.66	51.59±7.02b	33.86-67.33
1st true leaves													
Torch	11	0.32±0.05	0.27-0.33	1.76±0.32	1.26-2.29	5.62±0.94	4.01-7.06	18.74±3.96	12.46-26.74	48.05±3.18c	43.93-51.36	45.54±5.35c	46.22-58.81
Midas	25	0.30±0.03	0.26-0.34	1.73±0.30	1.09±2.24	5.22±0.92	4.00-7.14	19.94±2.79	12.32-24.83	46.39±2.49c	38.17-50.62	43.73±2.64c	35.00-54.23
Females													
Cotyledons													
Torch	30	0.29±0.06	0.25-0.36	1.89±0.30	1.42-2.37	6.31±1.34	4.21-8.76	23.08±4.15	16.49-30.45	68.96±9.08a	49.62-84.64	65.08±10.58a	40.63-79.70
Midas	41	0.30±0.05	0.24-0.37	1.84±0.41	1.05-2.62	6.29±1.37	3.76-10.04	22.41±5.8	14.20-33.76	68.42±9.42a	45.98-93.84	64.70±9.75a	36.18-85.95
1st true leaves													
Torch	25	0.31±0.05	0.23-0.34	1.61±0.34	1.29-2.59	5.49±0.97	3.76-7.19	19.12±4.38	14.00-27.88	59.38±10.17b	42.27-74.29	56.30±10.06b	35.04-72.73
Midas	19	0.29±0.02	0.24-0.38	1.70±0.29	1.51-2.69	5.85±1.17	4.34-7.56	20.71±6.78	16.67-37.62	57.04±6.30b	40.11-76.78	54.98±6.57b	34.98-71.00

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each food plant and stage of plant growth.

**Means within each column followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

The percentage of malformed adults was less than 2% for larvae on the cotyledons and on the first true leaves (Table II). The only morphological abnormality observed was crinkled elytra (Fig. 6). However, the crinkled elytra did have the red colouration and the three black stripes typically found in normal elytra. Though the malformed elytra did not lie flat on the abdomen, these adults probably could fly and likely would survive to lay eggs.

The larval growth rate indices for the larvae reared on the cotyledons were significantly larger than those for larvae reared on the first true leaves (Table V). For both stages of plant growth, the differences in the larval growth rate indices between the cultivars were not significant. The nutritional indices for larvae on cotyledons were 1.75 to 2.15 times larger than those for larvae on the first true leaves.

Fig. 6. A malformed adult of Entomoscelis americana from a larva reared on the cotyledons of Midas cultivar of Brassica napus, showing crinkled elytra (x12).

Table V. Larval growth rate indices and nutritional indices on the cotyledons and first true leaves of Torch cultivar of Brassica campestris and Midas cultivar of B. napus.

Stage of plant growth	Larval growth rate index		Nutritional index	
	Midas*	Torch*	Midas	Torch
Cotyledons	1.86a	1.95a	78.01	79.27
1st true leaves	1.54b	1.64b	44.55	36.94

*Means within the rows and columns followed by different letters are significantly different at the 5% level according to F-Test and Duncan's multiple range test.

4.3 Growth, development and survival on different rape cultivars

Two experiments were conducted to determine whether there were any differences in the growth, development and survival of the red turnip beetle larvae reared on different cultivars of B. campestris and B. napus.

4.3.1 Experiment I

In the first experiment, the cultivars of B. campestris used were Torch, Candle and R500 and the cultivars of B. napus used were Midas, Tower and Target. These cultivars were selected on the bases of the erucic acid and glucosinolate contents in their seeds (Appendix 4). Tower and Candle are low in erucic acid and low in glucosinolates; Midas and Torch are low in erucic acid and normal in glucosinolates; Target is normal in erucic acid and normal in glucosinolates; and R500 is high in erucic acid and normal in glucosinolates. In all the cultivars, both the cotyledons and the first true leaves were tested. The eggs used were from the 1977 stock colony and were stored in the cold room. The larvae were weighed at the time the experiment was set up and just after each moult. Records were kept on the time of each moult, on the weights at the beginning and at each moult, on the number of deaths and when they occurred, and on the numbers of normal and malformed adults.

On the cotyledons, the survival rate among the

cultivars was significantly different (Table VI). Mortality was the lowest on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch) and the highest on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target). These differences in survival between these two groups were significant ($P<0.01$). Survival on the cultivars low in both erucic acid and glucosinolates was intermediate between the other two groups. However, the differences in survival between the B. campestris cultivar Candle which is low in erucic acid and low in glocosinolates and the B. campestris cultivar Torch which is low in erucic acid and normal in glucosinolates were not significant.

On the cotyledon stage, mortality was the highest in the first two larval instars (Fig. 7). In the first instar, mortality was the highest (49-62%) on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target) and the lowest (0%) on the B. campestris cultivar Candle which is low in both erucic acid and glucosinolates. Mortality was also low (4-5%) on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch), and on the B. napus cultivar Tower (14%) which is low in both erucic acid and glucosinolates. Mortality in the second instar was lower than that in the first instar on R500, Target and Tower, but was higher in the second instar than in the first instar on Candle. Mortality on Midas

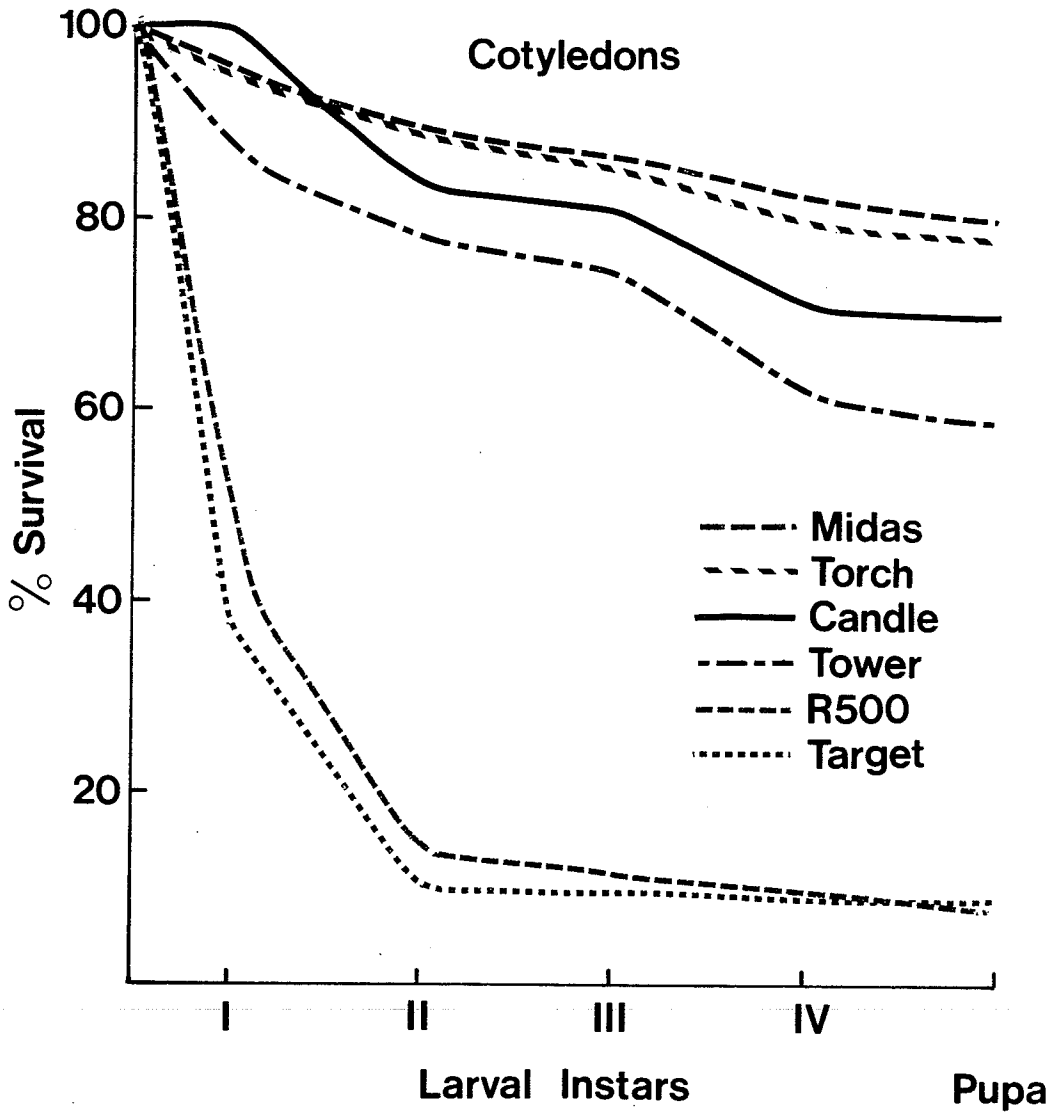
and Torch in the second instar was similar to that in the first instar. In the second instar, mortality was the highest (27-35%) on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target) and lowest (5-6%) on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch). Mortality also was low (8-16%) on the cultivars which are low in both erucic acid and glucosinolates (Candle and Tower). In the last two larval instars and in the pupa, mortality on all the cultivars was less than 3%, except on the cultivars low in erucic acid and glucosinolates (Candle and Tower) which had 10-13% mortality in the fourth instar.

Table VI. Experiment I: Percent survival to the adult stage and % deformed adults when larvae of Entomoscelis americana were reared on the cotyledons and first true leaves of three cultivars of Brassica campestris and three cultivars of B. napus; 100 larvae were used for each stage of plant growth for each cultivar.

Food	% Survival		% Deformed adults	
	Cotyledons	1st true leaves	Cotyledons	1st true leaves
B. campestris				
R500	8ef	11ef	0	1
Torch	78a	58cd	0	1
Candle	70ab	54d	1	0
B. napus				
Target	9ef	7f	0	0
Midas	80a	62c	3	0
Tower	60cd	14e	0	0

*The percentages within the rows and columns followed by the same letter are not significantly different at the 5% level according to Chi-squared Test (2x2 contingency table).

Fig. 7. Experiment I: Survival of Entomoscelis americana at the end of each larval instar and at the end of the pupal stage when reared on the cotyledons of Torch, Candle and R500 cultivars of Brassica campestris and Midas, Tower and Target cultivars of B. napus.


Cotyledons
100
80
60
40
20
% Survival
Midas
Torch
Candle
Tower
R500
Target
I
II
III
IV
Larval Instars
Pupa

Survival on the first true leaves differed significantly among the cultivars (Table VI). Survival was the highest on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch) and the lowest on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target). These differences in survival between these two groups were significant ($P<0.01$). Survival on the B. campestris cultivar Candle which is low in erucic acid and low in glucosinolates was similar to that on the B. campestris cultivar Torch which is low in erucic acid and normal in glucosinolates, but was significantly higher ($P<0.01$) than that on the B. napus cultivar Tower which is low in both erucic acid and glucosinolates. Survival on Tower was as low as that on R500 and Target.

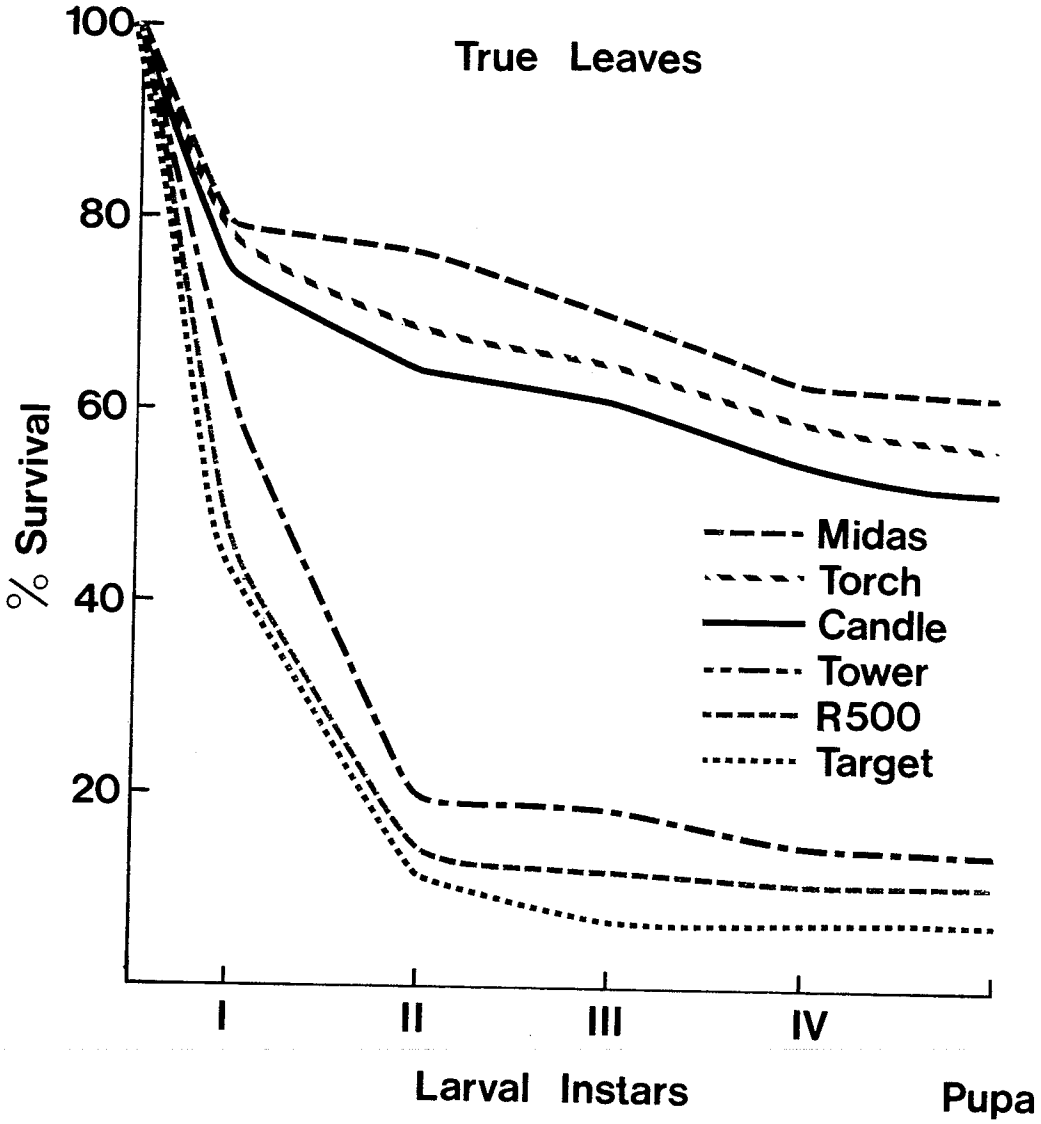
On the first true leaves, mortality generally was the highest in the first larval instar regardless of the type of food (Fig. 8). In this stage, mortality was the highest (54-57%) on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target) and the lowest (20-22%) on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch). Mortality on the B. campestris cultivar Candle (25%) was similar to that on Midas and Torch, but on the B. napus cultivar Tower it was higher (38%) than on these three. Mortality in

the second instar was lower than that in the first instar, except on Tower which had similar mortality in both the first and second instars. In the second instar, mortality was the highest (41%) on Tower and the lowest (3%) on Midas. Mortality on R500 and Target was 31% and was lower than that on Tower, but higher than that on Torch and Candle (9-10%). Mortality in each of the last two larval instars and in the pupa was lower than that in the second instar and was less than 4%, except on Midas and Candle which had 6% and 7% mortality, respectively, in the fourth instar.

Survival to the adult stage was significantly higher for larvae reared on the cotyledons than for larvae reared on the first true leaves in four of the six cultivars (Figs. 7, 8; Table VI). On the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch), 29-34% more larvae reached the adult stage on the cotyledons than on the first true leaves. On these two cultivars, mortality was the highest in the first larval instar, and in this instar it was higher on the first true leaves than on the cotyledons. In the last three larval instars and in the pupa, the mortality was similar for both stages of plant growth. On the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target), the percentage survival at emergence was low and was similar on both the cotyledons and the first true leaves. On these two cultivars, about two-thirds of the mortality occurred in the first instar

and about one-third of the mortality occurred in second instar for both stages of plant growth. Very few larvae died after the second instar. On the cultivars which are low in both erucic acid and glucosinolates (Candle and Tower), 30-32.9% more larvae reached the adult stage on the cotyledons than on the first true leaves. On Candle, the mortality in the first instar was higher on the first true leaves than on the cotyledons, but in the second instar mortality was higher on the cotyledons than on the first true leaves. However, the total mortality in these two instars was higher on the first true leaves than on the cotyledons (35% vs 19%). On Tower, the mortality in the first and second larval instars was 3 to 5 times higher on the first true leaves than on the cotyledons. On Candle and Tower, the mortality in the third larval instar and in the pupa was low, but in the fourth larval instar the mortality was 1.5 to 3 times higher on the cotyledons than on the first true leaves.

Fig. 8. Experiment I: Survival of Entomoscelis americana at the end of each larval instar and at the end of the pupal stage when reared on the first true leaves of Torch, Candle and R500 cultivars of Brassica campestris and Midas, Tower and Target cultivars of B. napus.


True Leaves
100
80
60
40
20
% Survival
Midas
Torch
Candle
Tower
R500
Target
I
II
III
IV
Larval Instars
Pupa

At the cotyledon and first true leaf stages, the mean developmental times were not significantly different among the cultivars (Tables VII, VIII). On the cotyledons, the average length of the developmental period from larval eclosion to adult emergence ranged from 53.1 days for males given the B. campestris cultivar Torch, which is low in erucic acid and normal in glucosinolates, to 56.0 days for females given the B. napus cultivar Target, which is normal in both erucic acid and glucosinolates. On the first true leaves, the average length of the developmental period ranged from 52.4 days for females given the B. napus cultivar Midas, which is low in erucic acid and normal in glucosinolates, to 54.1 days for females given the B. napus cultivar Tower, which is low in both erucic acid and glucosinolates.

Table VII. Experiment I: Mean number of days ($\bar{X}$ ± SD) spent in each stage by larvae of Entomoscelis americana reared on the cotyledons of three cultivars of Brassica campestris and three cultivars of B. napus.

Food	No.*	Number of days in each life stage: Larval instars i $\bar{X}$ ± SD**	i Range	ii $\bar{X}$ ± SD**	ii Range	iii $\bar{X}$ ± SD**	iii Range	iv $\bar{X}$ ± SD**	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Total days to adult emergence $\bar{X}$ ± SD**	Total days to adult emergence Range
Males													
B. campestris													
R500	4	7.3 ± 0.5	7-8	5.3 ± 0.5	5-6	6.5 ± 0.6	6-7	17.5 ± 0.6	17-18	18.8 ± 0.5	18-19	55.4 ± 0.5	55-56
Torch	42	6.9 ± 0.6	5-8	5.2 ± 0.5	4-6	5.4 ± 0.7	5-8	17.1 ± 1.1	17-20	18.5 ± 0.8	17-20	53.1 ± 1.6	52-57
Candle	33	6.5 ± 0.6	6-8	5.2 ± 0.6	4-6	5.3 ± 0.7	4-7	19.0 ± 1.3	16-21	19.6 ± 1.8	17-27	55.6 ± 2.7	52-67
B. napus													
Target	3	7.3 ± 0.6	7-9	5.4 ± 0.5	5-7	6.0 ± 1.0	5-7	18.0 ± 2.7	17-21	19.3 ± 0.6	19-20	56.0 ± 1.2	55-57
Midas	49	7.1 ± 0.9	6-10	5.4 ± 0.5	4-6	5.4 ± 0.8	4-7	18.0 ± 1.4	14-21	18.8 ± 1.4	16-21	54.7 ± 2.0	51-63
Tower	38	7.0 ± 0.6	6-9	5.0 ± 0.5	4-6	5.3 ± 0.6	4-6	17.6 ± 0.8	16-19	19.1 ± 1.0	17-20	54.0 ± 1.3	52-56
Females													
B. campestris													
R500	4	7.0 ± 0.2	6-8	5.3 ± 1.0	5-7	6.5 ± 0.5	6-7	18.0 ± 0.8	17-19	19.0 ± 1.0	18-20	55.8 ± 2.8	53-59
Torch	36	7.0 ± 0.6	6-8	5.3 ± 0.6	4-7	5.8 ± 0.4	5-6	17.3 ± 1.5	14-20	18.5 ± 1.0	17-21	53.9 ± 2.2	52-59
Candle	37	6.7 ± 0.6	6-8	5.0 ± 0.5	4-6	5.6 ± 0.5	5-6	18.7 ± 1.0	17-21	18.9 ± 1.1	17-21	54.9 ± 1.8	52-57
B. napus													
Target	6	7.7 ± 0.9	7-10	5.8 ± 1.0	5.7	6.0 ± 1.1	5-7	17.2 ± 1.0	16-19	18.7 ± 1.0	18-20	55.4 ± 2.3	53-59
Midas	31	7.2 ± 0.8	6-10	5.5 ± 0.6	5-7	5.5 ± 0.6	5-7	18.2 ± 1.2	16-21	18.5 ± 1.0	16-21	54.9 ± 1.5	52-58
Tower	21	7.2 ± 0.7	6-9	5.1 ± 0.7	4-6	5.4 ± 0.7	4-6	17.7 ± 0.9	16-20	18.9 ± 0.9	18-20	54.3 ± 1.9	52-58

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

Table VIII. Experiment I: Mean number of days ($\bar{X}$ ± SD) spent in each stage by larvae of Entomoscelis americana reared on the first true leaves of three cultivars of Brassica campestris and three cultivars of B. napus.

		Number of days spent in each life stage												Total days to adult emergence	
		Larval instars										Pupa			
		i		ii		iii		iv							
Food	No.*	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range		
							Males								
B. campestris															
R500	2	6.0 ± 0.0	6-6	5.5 ± 0.5	5-6	5.5 ± 0.5	5-6	17.0 ± 0.5	16-18	19.0 ± 0.5	18-20	53.0 ± 0.5	52-54		
Torch	39	6.0 ± 0.4	5-6	5.2 ± 0.5	5-7	5.8 ± 0.6	5-7	17.5 ± 1.2	15-19	18.4 ± 1.1	16-20	52.9 ± 2.2	49-57		
Candle	23	5.7 ± 0.5	5-7	5.5 ± 0.5	5-6	5.8 ± 0.6	5-7	17.9 ± 0.8	16-18	18.6 ± 0.7	18-20	53.5 ± 0.9	51-54		
B. napus															
Target	3	7.0 ± 0.0	7-7	5.3 ± 0.5	5-6	6.0 ± 0.0	6-6	17.7 ± 0.6	17-18	17.0 ± 0.5	16-18	53.0 ± 0.6	52-54		
Midas	26	6.1 ± 1.3	5-10	5.2 ± 0.7	4-6	5.8 ± 0.6	5-7	17.4 ± 1.0	15-19	18.1 ± 1.2	16-20	52.6 ± 2.8	48-59		
Tower	8	6.9 ± 0.4	6-8	5.3 ± 0.5	5-6	5.6 ± 0.5	5-6	16.8 ± 0.7	15-17	18.5 ± 0.5	18-19	53.1 ± 0.9	50-56		
							Females								
B. campestris															
R500	9	6.2 ± 0.7	6-8	5.2 ± 0.4	5-6	5.7 ± 0.5	5-6	17.2 ± 1.2	14-18	18.6 ± 0.9	18-20	52.9 ± 1.3	50-55		
Torch	17	6.0 ± 0.4	5-7	5.2 ± 0.5	4-6	5.9 ± 0.5	5-7	17.9 ± 1.3	15-20	17.7 ± 0.9	17-19	52.7 ± 1.2	49-54		
Candle	29	5.9 ± 0.4	5-7	5.3 ± 0.5	5-6	5.9 ± 0.5	5-7	17.7 ± 1.1	15-20	18.2 ± 0.8	17-20	53.0 ± 1.4	50-56		
B. napus															
Target	4	7.0 ± 0.8	6-8	5.3 ± 0.5	5-6	6.3 ± 0.5	6-7	17.3 ± 0.5	17-18	17.8 ± 0.5	17-18	53.7 ± 1.1	51-55		
Midas	36	6.2 ± 0.7	5-7	5.0 ± 0.7	4-6	6.0 ± 0.7	5-8	17.1 ± 0.9	14-19	18.1 ± 1.1	16-20	52.4 ± 1.4	48-54		
Tower	6	6.8 ± 0.8	6-8	5.2 ± 0.4	5-6	6.2 ± 0.4	6-7	17.2 ± 0.8	15-17	18.7 ± 0.5	18-19	54.1 ± 0.9	53-56		

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to the F-Test and Duncan's multiple range test.

At each stage of plant growth, the mean weights of the adults at emergence were not significantly different among the cultivars (Tables IX, X). However, the adults from R500 and Target were consistently lighter than those from the other four cultivars, but these differences were not significant statistically because of the small numbers of adults obtained from R500 and Target and the high variation in the weights for each cultivar. On all the cultivars, adults from the larvae fed the cotyledons were significantly heavier than those fed the first true leaves.

Table IX. Experiment I: Mean weight (mg ± SD) of Entomoscelis americana at the start of each stage when reared on the cotyledons of three cultivars of Brassica campestris and three cultivars of B. napus.

Food	No.	Larval instars i $\bar{X}$±SD**	i Range	ii $\bar{X}$±SD**	ii Range	iii $\bar{X}$±SD**	iii Range	iv $\bar{X}$±SD**	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Adult $\bar{X}$ ± SD**	Adult Range
Males													
B. campestris													
R500	4	0.28±0.02	0.25-0.31	1.77±0.29	1.36-2.12	6.06±0.86	5.65-6.91	18.43±3.79	15.86-24.00	54.32±5.78	42.34-58.90	47.08±5.60	36.43-54.67
Torch	42	0.30±0.04	0.23-0.34	2.02±0.39	1.34-2.87	6.41±1.28	4.09-8.74	20.35±4.13	13.38-33.19	58.62±7.01	45.62-69.14	53.27±6.80	41.52-67.19
Candle	33	0.30±0.03	0.24-0.33	1.97±0.35	1.32-2.84	6.66±1.57	4.16-9.84	19.66±3.67	11.51-29.21	57.32±5.78	37.08-62.86	52.74±6.81	33.89-60.95
B. napus													
Target	3	0.03±0.02	0.28-0.34	1.79±0.50	1.30-2.30	6.09±1.34	3.98-7.50	15.48±1.79	13.71-16.29	54.53±8.86	34.06-59.12	46.19±10.12	29.86-50.32
Midas	49	0.29±0.04	0.23-0.35	1.91±0.41	1.15-2.86	6.37±1.32	4.00-9.00	21.13±4.53	13.76-33.10	58.56±6.70	39.89-70.41	52.88±7.04	33.35-59.97
Tower	38	0.29±0.04	0.23-0.35	1.93±0.39	1.12-2.74	7.11±1.11	4.64-9.39	20.20±3.37	13.75-31.76	60.04±4.91	47.88-69.16	53.67±6.35	39.37-62.94
Females													
B. campestris													
R500	4	0.30±0.05	0.23-0.33	1.67±0.44	1.26-2.00	6.16±0.63	4.36-7.96	19.31±3.86	15.88-24.34	63.64±11.24	52.54-70.31	58.96±9.08	42.76-67.57
Torch	36	0.29±0.02	0.25-0.35	1.97±0.41	1.25-2.61	6.22±1.08	4.19-8.34	23.04±3.67	16.66-29.00	69.82±8.16	53.12-83.74	65.14±9.23	48.00-80.56
Candle	37	0.29±0.03	0.26-0.33	1.98±0.38	1.28-2.89	7.00±1.61	4.00-9.94	22.41±3.51	17.41-32.00	69.91±7.77	46.71-84.63	63.75±8.66	40.19-81.92
B. napus													
Target	6	0.29±0.04	0.25-0.33	1.79±0.19	1.50-2.00	6.77±1.52	5.29-9.65	20.65±4.90	14.70-26.37	64.42±9.21	53.75-72.61	59.87±6.33	45.00-65.23
Midas	31	0.30±0.03	0.24-0.35	2.01±0.47	1.25-2.92	6.75±1.50	4.28-9.84	23.30±4.58	15.72-32.19	69.91±7.02	58.04-83.87	63.52±7.14	49.91-72.37
Tower	21	0.29±0.04	0.23-0.34	2.03±0.34	1.35-2.55	7.67±1.37	5.39-10.75	22.78±4.81	14.56-32.86	70.65±5.67	61.00-79.71	66.23±7.50	50.52-77.86

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

Table X. Experiment I: Mean weight (mg ± SD) of Entomoscelis americana at the start of each stage when reared on the first true leaves of three cultivars of Brassica campestris and three cultivars of B. napus.

Food	No.	Larval instars i $\bar{X}$±SD**	i Range	ii $\bar{X}$±SD**	ii Range	iii $\bar{X}$±SD**	iii Range	iv $\bar{X}$±SD**	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Adult $\bar{X}$ ±SD**	Adult Range
Males													
B. campestris													
R500	2	0.31±0.00	0.31-0.31	1.83±0.83	1.34-2.32	3.87±0.50	3.51-4.22	15.33±4.39	12.22-18.43	45.11±6.07	40.09-56.22	38.45±5.60	32.12-50.78
Torch	39	0.29±0.03	0.24-0.36	1.76±0.34	1.19-2.54	5.68±0.83	4.09-7.26	16.54±3.50	14.83-25-91	49.51±4.60	38.51-60.69	40.29±5.32	32.76-51.19
Candle	23	0.32±0.04	0.23-0.36	1.83±0.36	1.29-2.53	5.91±1.18	4.48-8.71	17.14±2.38	13.65-21.10	50.53±5.58	46.54-65.48	42.28±8.41	40.62-47.87
B. napus													
Target	3	0.28±0.02	0.26-0.30	1.72±0.14	1.57-1.84	4.69±0.48	4.25-5.20	15.28±2.88	15.82-21.10	46.32±6.07	35.76-56.86	39.41±6.10	31.59-48.68
Midas	26	0.30±0.03	0.24-0.37	1.75±0.35	1.17-2.59	5.60±1.37	3.47-8.83	16.46±2.99	11.21-23.93	48.21±5.16	39.83-62.30	40.92±4.92	35.08-55.15
Tower	8	0.29±0.03	0.22-0.32	1.78±0.34	1.37-2.32	5.21±0.89	4.00-6.04	16.45±2.10	13.12-19.94	50.19±2.94	48.74-58.66	44.42±3.44	45.24-49.77
Females													
B. campestris													
R500	9	0.30±0.04	0.24-0.36	1.61±0.33	1.76-2.88	5.29±1.00	3.61-6.68	18.11±4.48	14.92-27.19	54.23±6.05	50.22-70.24	52.19±5.36	46.10-62.28
Torch	17	0.28±0.03	0.25-0.32	1.88±0.47	1.04-2.59	5.94±1.14	4.36-9.66	19.45±3.37	15.18-27.89	58.61±6.45	53.00-76.39	53.70±5.12	48.26-66.11
Candle	29	0.29±0.02	0.23-0.35	1.92±0.37	1.26-2.81	6.25±1.26	4.40-9.30	19.97±3.73	13.88-28.93	60.29±7.35	54.00-77.01	55.74±6.72	52.13-76.49
B. napus													
Target	4	0.27±0.04	0.22-0.32	1.78±0.34	1.62-2.39	5.32±0.80	4.52-6.26	18.12±1.99	19.00-23.69	56.87±2.58	48.29-68.83	51.89±2.79	41.24-64.49
Midas	36	0.28±0.03	0.24-0.35	1.83±0.35	1.22-2.72	6.16±1.26	3.57-9.75	19.43±3.77	15.34-30.92	58.75±9.10	36.52-76.09	54.67±8.23	30.45-67.12
Tower	6	0.31±0.04	0.24-0.37	1.98±0.31	1.50-2.25	6.32±1.41	3.30-6.66	19.98±2.17	17.15-23.24	60.21±4.87	59.00-70.56	56.28±4.74	50.81-65.18

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

The percentage of malformed adults was less than 4% among the cultivars at both the cotyledon and the first true leaf stages (Table VI). The only morphological abnormality observed was crinkled elytra (Fig. 6). Such adults probably would survive to lay eggs.

On the cotyledons and the first true leaves, the larval growth rate indices were significantly different among the cultivars (Table XI). For both stages of plant growth, larvae reared on the cultivars which are either low in erucic acid and normal in glucosinolates (Midas and Torch) or low in both erucic acid and glucosinolates (Candle and Tower) had significantly larger growth rate indices than those reared on the cultivars which are either high or normal in erucic acid and normal in glucosinolates (R500 and Target). The differences in the larval growth rate indices among larvae reared on Midas, Torch, Candle and Tower and between those reared on R500 and Target were not significant. On all the cultivars, the larval growth rate indices for the larvae reared on the cotyledons were significantly larger than those for the larvae reared on the first true leaves.

On the cotyledon and the first true leaf stages, the nutritional indices for larvae reared on the cultivars which are low in erucic acid and normal in glucosinolates (Midas and Torch) were 7 to 11 times larger than those for larvae reared on the cultivars which are either high

or normal in erucic acid and normal in glucosinolates (R500 and Target) (Table XI). At the cotyledon stage, the nutritional indices for larvae reared on Midas and Torch were 1.17 to 1.30 times larger than those for larvae reared on the cultivars low in both erucic acid and glucosinolates (Candle and Tower). However, on the first leaves, the nutritional indices for larvae reared on Midas, Torch and Candle were of similar magnitude, whereas that of Tower was about one-ninth the size of the other three. The nutritional indices for larvae reared on the cotyledons of Candle and Tower were 7.7 to 9.5 times larger than those for larvae reared on R500 and Target. At the first true leaf stage, the nutritional indices for larvae reared on Candle and Tower were larger than those for larvae reared on R500 and Target (5.8-8.3 times and 1.5-2.2 times respectively). On all the cultivars, the nutritional indices for larvae reared on the cotyledons were 1.5 to 5 times larger than those for larvae reared on the first true leaves, except in R500 and Target where survival was low on both stages of plant growth.

Table XI. Experiment I: Larval growth rate indices and nutritional indices on the cotyledons and the first true leaves of three cultivars of Brassica campestris and three cultivars of B. napus.

Food	Larval growth rate index*		Nutritional index	
	Cotyledons	1st true leaves	Cotyledons	1st true leaves
B. campestris				
R500	1.61b	1.45c	7.63	8.56
Torch	1.83a	1.55b	86.32	50.74
Candle	1.77a	1.59b	72.68	49.70
B. napus				
Target	1.62b	1.44c	8.57	5.99
Midas	1.78a	1.55b	81.78	56.45
Tower	1.86a	1.58b	66.37	13.15

*Means within the rows and columns followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

4.3.2 Experiment II

Since the first experiment showed that there were significant differences in survival among larvae reared on cultivars containing different levels of erucic acid in their seed, a second experiment was set up to investigate this possibility. The cultivars of B. campestris used were Torch, Echo and R500 and the cultivars of B. napus used were Tower and Target. Tower and Torch are low in erucic acid; Target and Echo (normal in glucosinolates) are normal in erucic acid; R500 is high in erucic acid (Appendix 4). The cultivars were tested at the cotyledon stage. Torch and Tower were also tested at the first true leaf stage. The other cultivars were not tested at the first true leaf stage because of a shortage of seeds and larvae. The eggs were from the 1977 stock colony kept out-of-doors during the winter. See Experiment I, Section 4.3.1, for the remainder of the materials and methods.

On the cotyledons, there were significant differences in survival among the cultivars (Table XII). Survival was the highest on the cultivars low in erucic acid (Torch and Tower) and the lowest on the cultivar high in erucic acid (R500). The differences in survival between these two groups were significant ($P<0.05$). Survival on the cultivars normal in erucic acid (Echo and Target) was intermediate between the survival rates in the other two groups, but was not significantly different from the survival rates for either of these groups. Significantly

more larvae reached the adult stage on the cotyledons of Torch and Tower than on the first true leaves of these two cultivars.

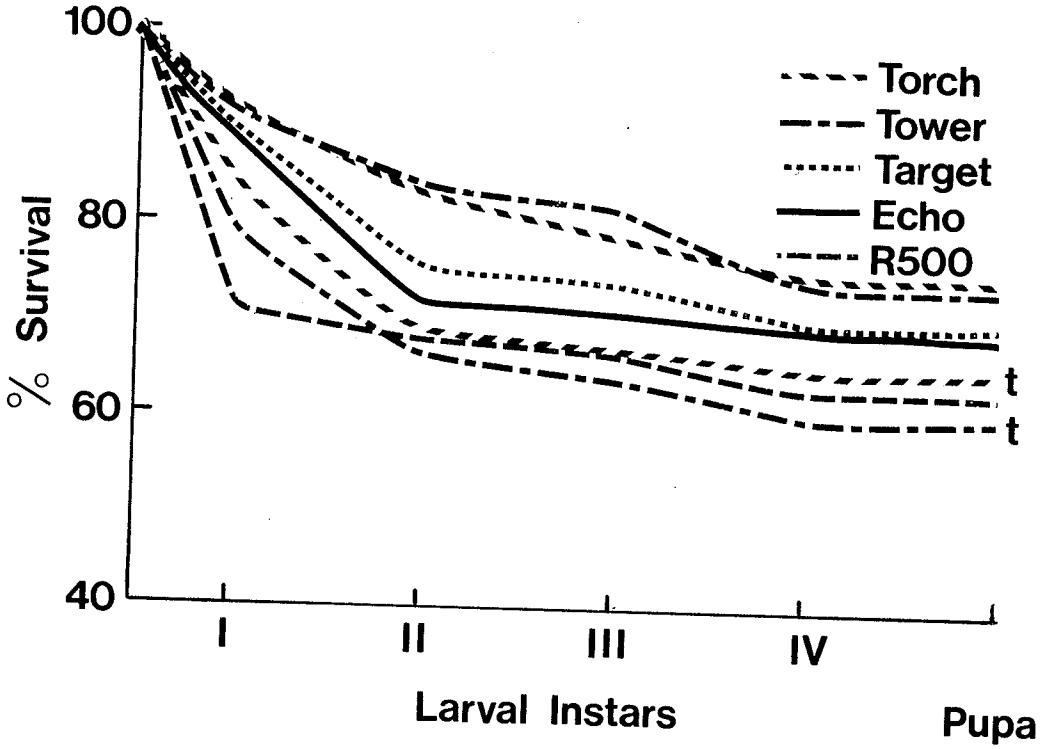
On the cotyledons and the first true leaves, mortality was the highest in the first and second instars on all of the cultivars (Fig. 9). On the cotyledons, mortality in the first instar was the highest (28%) on the cultivar high in erucic acid (R500) and the lowest (9%) on the cultivars low in erucic acid (Torch and Tower). Mortality in the first instar on the cultivars normal in erucic acid (Target and Echo) (11%) was similar to those on Torch and Tower. Mortality in the first instar on Torch and Tower at the cotyledon stage was lower than that at the first true leaf stage (9% vs 20-16%). In the second instar, mortality was similar to that in the first instar on Torch, Tower, Target and the first true leaves of Torch, but on R500, Echo and the first true leaves of Tower it was lower in the second instar than in the first instar. On the cotyledons, mortality in the second instar was the highest on Target and Echo (13-17%) and the lowest on R500 (3%). Mortality on Torch and Tower was also low (7%). Mortality in the second instar on the first true leaves of Torch and Tower was similar (14-16%), but was higher than that on the cotyledons of both cultivars. In each of the last two larval instars and in the pupa, mortality on all the cultivars for both the cotyledons and the first true leaves was less than 3%.

Table XII. Experiment II: Percent survival to the adult stage and % deformed adults when larvae of Entomoscelis americana were reared on the cotyledons of three cultivars of Brassica campestris and two cultivars of B. napus and on the first true leaves of Torch cultivar of B. campestris and Tower cultivar of B. napus; 100 larvae were used for each cultivar.

	% Survival*	% Deformed adults
B. campestris		
R500	63bc	1
Echo	69abc	1
Torch	75a	0
Torch (true leaves)	65bc	0
B. napus		
Target	70ab	0
Tower	74a	2
Tower (true leaves)	60c	0

*The percentages followed by the same letter are not significantly different at the 5% level according to Chi-squared test (2x2 contingency table).

Fig. 9. Experiment II: Survival of Entomoscelis americana at the end of each larval instar and at the end of the pupal stage when reared on the cotyledons of Torch, Echo and R500 cultivars of Brassica campestris and Tower and Target cultivars of B. napus; and on the the first true leaves of Torch cultivar of B. campestris and Tower cultivar of B. napus. t, first true leaves.


100
80
60
40
% Survival
Torch
Tower
Target
Echo
R500
t
t
I
II
III
IV
Larval Instars
Pupa

The following are the differences between the survival rates for this experiment and those for Experiment I. The survival rates in larvae reared on Torch cotyledons were similar in both experiments, but the survival rate on Torch first true leaves in Experiment II was 1.12 times higher than that on Torch first true leaves in Experiment I. On Tower, survival in Experiment II was higher than that in Experiment I for the cotyledons and the first true leaves (1.2 times and 4.3 times, respectively). On R500 and Target, survival in Experiment II was 8 times higher than that in Experiment I.

Mortality was the highest in the first and second instars in this experiment and in Experiment I regardless of the type of food. Mortality in the last two larval instars and in the pupa generally was low in both experiments. In the first instar, mortality was higher in Experiment I than in this experiment on all of the cultivars except Torch. Mortality in the first instar on Torch cotyledons was higher in this experiment than that in Experiment I, but on the first true leaves mortality was higher in Experiment I than that in Experiment II. In the second instar, mortality on R500 and Target was higher in Experiment I than in Experiment II. The mortality rates for the second instar on the cotyledons of Torch and Tower were the same for both experiments, but the mortality rates on the first true leaves of these two cultivars in Experiment II were higher than that in Experiment I. In the last two larval instars and in the pupa, mortality among the cultivars in this experiment was similar to that in Experiment I.

For the cotyledon and first true leaf stages, the developmental times were not significantly different among the cultivars (Table XIII). The mean developmental times ranged from 49.0 days in males given the first true leaves of the B. napus cultivar Tower, which is low in erucic acid, to 51.5 days in males given the cotyledons of the B. campestris cultivar R500, which is high in erucic acid. The developmental times for the larvae in this experiment were not significantly different from those in Experiment I.

At each stage of plant growth, the mean weights of the adults at emergence were not significantly different among the cultivars (Table XIV). Adults from the larvae fed on cotyledons of Torch and Tower were significantly heavier than those fed the first true leaves of these cultivars. For all of the cultivars and for both stages of plant growth, the weights of the adults at emergence in this experiment were similar to those in Experiment I.

Table XIII. Experiment II: Mean number of days ($\bar{X}$ ± SD) spent in each stage by larvae of Entomoscelis americana reared on the cotyledons of three cultivars of Brassica campestris and two cultivars of B. napus and on the first true leaves of Torch cultivar of B. campestris and Tower cultivar of B. napus.

		Number of days spent in each life stage										Total days to adult emergence	
		Larval instars											
		i		ii		iii		iv		Pupa			
Food	No.*	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range
Males													
B. campestris													
R500	36	6.3±0.6	6-8	5.7±0.7	4-7	5.6±0.7	4-7	16.6±1.4	14-20	17.3±0.9	15-18	51.5±3.0	49-61
Echo	37	6.7±0.9	6-9	5.2±0.8	4-7	5.5±0.6	5-7	16.5±1.2	15-20	16.5±1.0	15-20	50.4±4.4	46-60
Torch	36	6.5±0.7	6-9	5.0±0.9	4-7	5.6±0.7	4-7	15.7±1.3	14-19	16.6±1.0	15-18	49.4±3.9	44-55
Torch (true leaves)	30	6.6±0.7	6-8	5.3±0.8	4-7	5.4±0.5	5-6	17.1±0.9	15-19	16.6±1.5	14-19	51.0±2.9	44-51
B. napus													
Target	28	6.4±0.5	6-7	5.3±0.5	4-6	5.3±0.5	5-7	16.6±1.7	14-20	16.3±1.3	14-19	49.9±3.8	47-56
Tower	33	6.3±0.5	6-7	5.2±0.7	4-6	5.7±0.6	5-7	16.3±1.5	14-21	16.5±1.0	14-18	50.0±4.3	44-56
Tower (true leaves)	28	6.4±0.6	6-8	5.6±0.7	4-7	5.3±0.5	5-6	15.3±1.1	14-19	16.4±1.7	14-18	49.0±3.0	44-55
Females													
B. campestris													
R500	27	6.5±0.5	6-7	5.6±0.7	4-7	5.4±0.5	5-6	16.0±1.2	15-20	17.2±0.9	16-21	50.7±1.6	47-54
Echo	32	6.6±0.6	6-8	5.3±0.7	4-6	5.4±0.7	4-7	16.0±1.2	14-18	16.7±0.9	14-18	50.0±2.1	44-53
Torch	39	6.4±0.6	6-8	5.1±0.7	4-7	5.5±0.7	4-7	15.8±1.1	13-19	16.3±1.1	14-18	49.1±2.4	44-53
Torch (true leaves)	35	6.8±0.9	6-9	5.3±0.7	4-7	5.7±0.5	5-7	17.0±1.5	15-23	16.3±1.4	14-19	51.1±3.0	44-59
B. napus													
Target	42	6.6±0.5	6-7	5.1±0.6	4-6	5.3±0.6	4-6	16.6±1.3	14-20	16.5±1.1	15-19	50.1±2.0	47-56
Tower	41	6.6±0.8	6-9	5.5±0.7	4-7	5.5±0.6	5-7	16.0±1.3	13-18	16.2±1.3	14-18	49.8±2.1	46-54
Tower (true leaves)	32	6.5±0.6	6-8	5.7±0.7	5-7	5.4±0.5	5-6	15.9±1.1	14-18	16.5±1.3	15-18	50.0±2.8	46-58

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

Table XIV. Experiment II: Mean weight (mg ± SD) of Entomoscelis americana at the start of each stage when reared on the cotyledons of three cultivars of Brassica campestris and two cultivars of B. napus and on the first true leaves of Torch cultivar of B. campestris and Tower cultivar of B. napus.

Food	No.*	Larval instars: i $\bar{X}$±SD	i Range	ii $\bar{X}$±SD	ii Range	iii $\bar{X}$±SD	iii Range	iv $\bar{X}$±SD	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Adult $\bar{X}$ ± SD**	Adult Range
Males													
B. campestris													
R500	36	0.29±0.04	0.24-0.36	1.53±0.36	1.00-2.50	5.14±1.02	3.52-7.32	18.21±2.91	12.18-25.40	53.06±5.46	29.54-58.35	45.27±5.03cd	35.87-50.79
Echo	37	0.32±0.02	0.22-0.35	1.68±0.35	1.06-2.52	5.38±1.19	3.78-7.62	18.34±4.05	11.36-28.43	53.16±7.48	28.22-64.55	47.61±6.44cd	33.81-55.94
Torch	36	0.30±0.03	0.25-0.35	1.67±0.33	1.05-2.61	6.00±1.18	3.92-8.20	19.66±3.69	12.28-29.57	65.24±6.97	39.55-65.85	49.11±6.94c	33.63-56.64
Torch (true leaves)	30	0.30±0.02	0.24-0.34	1.68±0.36	1.00-2.46	5.15±0.95	3.76-7.00	17.68±2.80	13.22-23.41	47.59±5.42	38.27-57.19	43.16±4.91d	34.62-56.93
B. napus													
Target	28	0.31±0.04	0.24-0.37	1.59±0.33	1.00-2.36	5.68±0.96	3.62-8.21	18.89±3.20	13.16-26.44	53.68±6.18	33.83-64.78	47.80±5.76cd	28.86-55.11
Tower	33	0.30±0.03	0.25-0.34	1.72±0.33	1.02-2.59	5.94±0.86	3.36-7.49	19.64±3.27	13.00-28.89	55.82±5.99	44.23-63.64	48.62±6.29c	37.46-56.74
Tower (true leaves)	28	0.31±0.04	0.26-0.35	1.51±0.33	1.00-2.19	5.30±0.74	3.26-6.49	17.56±2.59	13.01-23.98	48.01±4.49	41.45-60.37	44.23±4.02d	37.54-58.28
Females													
B. campestris													
R500	27	0.29±0.03	0.24-0.36	1.60±0.28	1.07-2.12	5.93±1.07	3.72-7.61	20.74±3.19	15.38-28.43	63.83±4.72	53.87-70.19	57.83±4.65a	47.08-64.29
Echo	32	0.30±0.02	0.25-0.34	1.77±0.34	1.00-2.34	6.08±0.93	4.03-7.95	20.85±3.35	14.86-27.43	65.96±6.28	56.00-80.81	60.29±5.80a	48.66-72.50
Torch	39	0.28±0.03	0.25-0.35	1.83±0.29	1.23-2.40	6.63±1.02	4.69-9.00	21.56±3.79	17.14-33.34	67.19±6.70	56.89-81.13	61.83±6.55a	49.40-73.34
Torch (true leaves)	35	0.29±0.03	0.25-0.34	1.70±0.29	1.24-2.23	5.48±0.79	4.03-7.59	19.95±3.46	13.78-26.12	56.91±8.30	52.86-74.78	53.5±7.60b	48.23-70.42
B. napus													
Target	42	0.30±0.03	0.25-0.33	1.67±0.32	1.00-2.51	6.05±0.94	4.11-7.84	20.94±3.89	12.74-29.85	65.78±6.80	50.28-80.79	59.75±6.25a	43.03-71.20
Tower	41	0.31±0.04	0.25-0.34	1.82±0.36	0.94-2.54	6.92±1.01	3.92-7.42	21.67±3.61	15.44-26.00	66.38±6.00	57.00-84.46	61.43±6.20a	48.39-73.83
Tower (true leaves)	32	0.29±0.03	0.24-0.34	1.57±0.43	1.11-2.32	5.81±0.82	3.91-7.24	19.80±2.63	13.14-26.04	57.72±6.38	53.01-76.21	54.74±6.23b	47.64-72.19

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**Means followed by the same letter for each sex are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

The percentage of malformed adults was less than 3% among the cultivars for both the cotyledons and the first true leaves (Table XII). The deformed adults had crinkled elytra (Fig. 6). Such adults probably would survive and lay eggs. In both Experiments I and II, the percentages of malformed adults were similar and malformations were not restricted to a particular cultivar.

The larval growth rate indices differed significantly among the cultivars (Table XV). On the cotyledons, larvae reared on cultivars which are low in erucic acid (Torch and Tower) had significnatly larger indices than those reared on the cultivar high in erucic acid (R500). The larval growth rate indices for larvae reared on the cultivars normal in erucic acid (Echo and Target) were intermediate between those from the other two groups, but were not significantly different from the larval growth rate indices for either of these groups. On the first true leaves, the larval growth rate indices for Torch and Tower were not significantly different, but were significantly smaller than those for the larvae on the cotyledons of these cultivars. In Experiments I and II, the larval growth rate indices for Torch and Tower cotyledons and first true leaves were similar. For R500 and Target, the larval growth rate indices in Experiment II were significantly higher than those in Experiment I.

The nutritional indices were the largest for larvae reared on cultivars low in erucic acid (Torch and Tower) (Table XV). For the cotyledons of these two cultivars, the

nutritional indices were 1.31 to 1.40 times larger than that for the cultivar high in erucic acid (R500) and 1.10 to 1.16 times larger than those for the cultivars normal in erucic acid (Echo and Target). For the first true leaves, the nutritional indices for Torch and Tower were similar. Also in Torch and Tower, the nutritional indices for cotyledons were 1.37 to 1.41 times larger than those for the first true leaves. In Experiments I and II, the nutritional index for Torch first true leaves in Experiment II was 1.21 times larger than that in Experiment I. On Tower, the nutritional indices in Experiment II were 1.23 and 4.56 times larger for the cotyledons and first true leaves, respectively, than those in Experiment I. On R500 and Target, the nutritional indices in Experiment II were 7.31 and 12.57 times, respectively, larger than those in Experiment I.

Table XV. Experiment II: Larval growth rate indices and nutritional indices on the cotyledons of three cultivars of Brassica campestris and two cultivars of B. napus; and on the first true leaves of Torch cultivar of B. campestris and Tower cultivar of B. napus.

Food	Larval growth rate index*	Nutritional index
B. campestris		
R500	1.73c	62.55
Echo	1.77bc	73.08
Torch	1.88a	84.47
Torch (true leaves)	1.55d	61.56
B. napus		
Target	1.78bc	75.29
Tower	1.84ab	81.90
Tower (true leaves)	1.60d	59.99

*Means followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

4.4 Growth, development and survival on commercial mustards

Three types of commercial mustards belonging to B. juncea and B. hirta were evaluated as food for growth, development and survival of the red turnip beetle larvae. The commercial mustards were also compared with rape (B. campestris) to determine whether mustards or rape was more suitable as food for the larvae. The plants used were Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea, Gisilba (Yellow mustard) cultivar of B. hirta, and Torch cultivar of B. campestris. The cultivars of B. juncea and B. hirta were chosen, because they are the cultivars commonly used by growers. Torch was used as the control in the experiment. All plants were tested at the cotyledon stage. The eggs were from the 1977 stock colony and were kept out-of-doors during the winter. The larvae were weighed at the time the experiment was set up and just after each moult. Records were kept on the time of each moult, on the weights at the beginning and at each moult, on the number of deaths and when they occurred, and on the number of normal and malformed adults.

Survival from larval eclosion to adult emergence on Brown mustard and Oriental mustard was similar to that on Torch rape, but was higher than that on Yellow mustard (Table XVI). Survival on all of the commercial mustards was more than 60%, but was over 70% on Brown mustard and Oriental mustard and under 70% on Yellow mustard. There

were no significant differences between the survival rates on Brown mustard and Oriental mustard, but survival on Brown mustard was significantly higher than that on Yellow mustard and survival on Oriental mustard was not significnatly higher than that on Yellow mustard. However, these differences in survival rates between Brown mustard and Yellow mustard probably also were not significant, because the Chi-squared value for Brown mustard vs Yellow mustard (3.93) was only slightly above the 5% probability level (3.84). The Chi-squared value for Oriental mustard vs Yellow mustard (3.05) was just slightly below this 5% probability level.

Mortality was the highest in the first two larval instars regardless of the type of food (Fig. 10). In the first instar, mortality was the highest on Yellow mustard (21%) and the lowest on Torch rape (7%). Mortality on Brown mustard and Oriental mustard was the same and also low (10%). In the second instar, mortality was similar to that in the first instar on Torch, Brown mustard and Oriental mustard, but on Yellow mustard (13%) it was higher than that in the first instar and also higher than that on Torch, Brown mustard and Oriental mustard. In the last two larval instars and in the pupa, mortality was less than 4% in each of these stages and was similar on all of the plants.

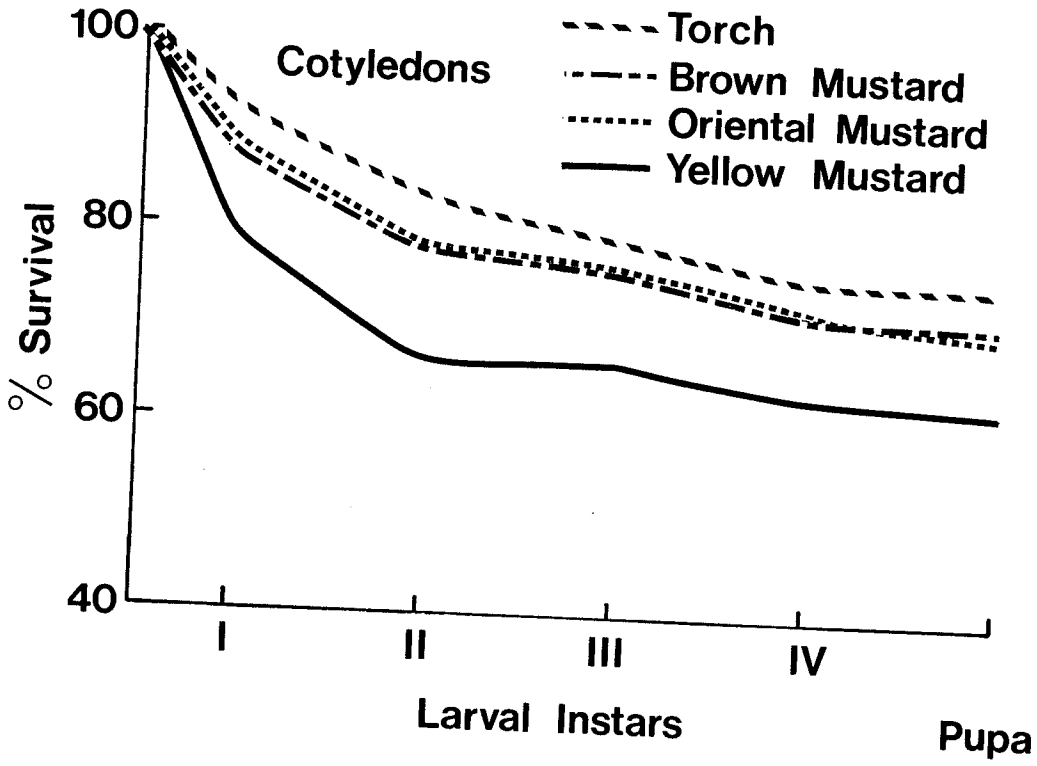
Table XVI. Percent survival to the adult stage and % deformed adults when larvae of Entomoscelis americana were reared on the cotyledons of two cultivars of Brassica juncea, one cultivar of B. hirta and Torch cultivar of B. campestris; 100 larvae were used for each cultivar.

Food*	% Survival**	% Deformed adults
B. juncea		
Brown mustard (Blaze)	71a	2
Oriental mustard (Lethbridge 22A)	70ab	1
B. hirta		
Yellow mustard (Gisilba)	62b	0
Control:		
B. campestris (Torch)	75a	0

*Names of cultivars are in parenthesis.

**The percentages followed by the same letter are not significantly different at the 5% level according to Chi-squared test (2x2 contingency tables).

Fig. 10. Survival of Entomoscelis americana at the end of each larval instar and at the end of the pupal stage when reared on the cotyledons of Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of Brassica juncea, Gisilba (Yellow mustard) cultivar of B. hirta, and Torch cultivar of B. campestris.


100
80
60
40
% Survival
Cotyledons
Torch
Brown Mustard
Oriental Mustard
Yellow Mustard
I
II
III
IV
Larval Instars
Pupa

The developmental times for the larvae reared on commercial mustards were not significantly different from those for larvae reared on Torch rape (Table XVII). The average length of developmental period from larval eclosion to adult emergence ranged from 49.1 days for females given Torch to 51.2 days for males given Oriental mustard.

The mean weights of adults at emergence were not significantly different among the commercial mustards and Torch rape (Table XVIII). However, the adults from commercial mustards were lighter than those from rape. These differences were not significant statistically because of the high variation in the weights for each plant.

Table XVII. Mean number of days ($\bar{X}$ ± SD) spent in each stage by larvae of Entomoscelis americana reared on the cotyledons of two cultivars of Brassica juneca, one cultivar of B. hirta and Torch cultivar of B. campestris.

		Number of days spent in each life stage											
		Larval instars										Total days to adult emergence	
		i		ii		iii		iv		Pupa			
Food	No.*	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range	$\bar{X}$ ± SD**	Range
Males													
B. juncea													
Brown mustard	40	6.3±0.7	6-8	5.2±0.8	4-7	5.5±0.6	5-7	17.4±1.9	15-22	16.0±1.3	13-18	50.4±3.2	44-56
Oriental mustard	32	7.0±2.0	6-10	5.3±0.7	5-8	5.5±0.9	5-9	17.0±1.5	15-23	16.4±1.1	13-18	51.2±2.8	47-58
B. hirta													
Yellow mustard	19	6.7±0.7	6-8	5.5±0.6	5-7	5.5±0.5	5-6	16.3±1.4	14-19	16.5±0.7	15-18	50.5±2.0	46-54
Control: B. campestris (Torch)	36	6.5±0.7	6-9	5.0±0.9	4-7	5.6±0.7	4-7	15.7±1.3	14-19	16.6±1.0	15-18	49.4±3.9	44-55
Females													
B. juncea													
Brown mustard	31	6.4±0.6	6-8	5.2±1.0	4-8	5.4±0.7	4-7	17.3±1.7	15-22	16.0±1.6	13-19	50.3±3.5	43-56
Oriental mustard	38	6.0±1.0	6-10	5.2±0.5	4-6	5.4±0.5	4-6	17.4±1.3	14-20	16.2±1.2	13-18	51.0±2.2	47-59
B. hirta													
Yellow mustard	43	6.9±0.7	6-9	5.3±0.6	4-6	5.6±0.5	5-6	16.4±1.7	14-20	16.2±0.7	15-18	50.4±2.3	46-57
Control: B. campestris (Torch)	39	6.4±0.6	6-8	5.1±0.7	4-7	5.5±0.7	4-7	15.8± 1.1	13-19	16.3±1.1	14-18	49.1±2.4	44-53

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant diference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

Table XVIII. Mean weight (mg ± SD) of Entomoscelis americana at the start of each stage when reared on the cotyledons of two cultivars of Brassica juncea, one cultivar of B. hirta and Torch cultivar of B. campestris.

Food	No.*	Larval instars i $\bar{X}$±SD**	i Range	ii $\bar{X}$±SD**	ii Range	iii $\bar{X}$±SD**	iii Range	iv $\bar{X}$±SD**	iv Range	Pupa $\bar{X}$ ± SD**	Pupa Range	Adult $\bar{X}$ ± SD**	Adult Range
						Males							
B. juncea													
Brown mustard	40	0.29±0.03	0.24-0.35	1.71±0.31	1.00-2.26	4.96±0.80	3.44-7.96	17.65±3.14	12.17-24.53	54.03±6.67	38.45-68.39	46.80±6.29	30.39-58.51
Oriental mustard	32	0.30±0.03	0.24-0.37	1.69±0.34	1.13-2.34	5.00±0.98	3.56-7.91	17.10±2.45	13.31-23.40	52.19±5.72	33.51-59.87	45.22±5.48	29.14-56.42
B. hirta													
Yellow mustard	19	0.30±0.02	0.26-0.24	1.53±0.31	1.00-2.15	4.74±1.02	3.48-7.84	17.98±3.70	14.71-30.83	53.03±4.90	39.27-57.85	46.98±5.28	33.52-54.57
Control: B. campestris (Torch)	36	0.30±0.03	0.25-0.35	1.67±0.33	1.05-2.61	6.00±1.18	3.92-8.20	19.66±3.69	12.28-29.57	56.24±6.97	39.55-65.85	49.11±6.94	33.63-58.64
						Females							
B. juncea													
Brown mustard	31	0.03±0.02	0.27-0.36	1.83±0.39	1.10-2.61	5.71±0.99	4.07-8.34	19.34±2.71	15.12-25.13	64.52±6.20	53.44-77.54	58.57±6.36	44.90-74.96
Oriental Mustard	38	0.03±0.02	0.23-0.35	1.82±0.33	1.21-2.49	5.95±0.88	4.62-7.87	19.44±3.09	15.26-28.45	63.48±6.58	49.13-76.75	58.27±6.65	42.42-72.37
B. hirta													
Yellow mustard	43	0.28±0.03	0.24-0.34	1.78±0.36	1.00-2.42	5.34±0.98	3.64-7.28	20.10±3.83	15.38-31.14	64.82±7.30	48.53-77.98	59.55±6.58	44.63-73.71
Control: B. campestris (Torch)	39	0.28±0.03	0.25-0.35	1.83±0.29	1.23-2.40	6.63±1.02	4.69-9.00	21.56±3.79	17.14-33.34	67.19±6.70	56.89-81.13	61.83±6.55	49.40-73.34

*Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each cultivar.

**No significant difference between means for each sex at the 5% level according to F-Test and Duncan's multiple range test.

The percentage of malformed adults on all the plants was less than 3% (Table XVI). Malformed adults occurred only on Brown mustard and Oriental mustard. The only morphological abnormality observed was crinkled elytra (Fig. 6). Such adults probably would survive to lay eggs.

The larval growth rate indices for the larvae reared on Torch rape were significantly larger than those for larvae reared on commercial mustards (Table XIX). Among Brown mustard, Oriental mustard and Yellow mustard, the differences in the larval growth rate indices were not significant. The nutritional indices for larvae on commercial mustards were high, but were 15-23% smaller than those for larvae on Torch.

Table XIX. Larval growth rate indices and nutritional indices on the cotyledons of two cultivars of Brassica juncea, one cultivar of B. hirta and Torch cultivar of B. campestris.

Food	Larval growth rate index*	Nutritional index
B. juncea		
Brown mustard (Blaze)	1.73b	72.21
Oriental mustard (Lethbridge 22A)	1.66b	69.88
B. hirta		
Yellow mustard (Gisilba)	1.73b	65.47
Control:		
B. campestris (Torch)	1.88a	84.47

*Means followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

4.5 Growth, development and survival on several cruciferous weeds

Seven species of cruciferous weeds were evaluated as food plants for larvae of the red turnip beetle. They were also compared with rape (B. campestris) to determine whether weeds or rape were more suitable for growth, development and survival of the larvae. The species of weeds tested were B. nigra, D. sophia, Sy. loeselii, S. arvensis, C. bursa-pastoris, Er. gallicum, and T. arvense (Table I). Torch cultivar of B. campestris was used as the control. D. sophia, S. arvense and Er. gallicum were selected, because adults of the red turnip beetle have been observed feeding on them in the field (Gerber, unpublished). C. bursa-pastoris, T. arvense and Sy. loeselii were chosen, because they are found in growers' fields, although the latter weed is less common than the other two. However, the red turnip beetle has not been observed to feed on these three weeds. B. nigra was selected, because it has been reported to be an attractive and acceptable food plant to adults of two other oligophagous chrysomelids, the flea beetle, Phyllotreta cruciferae (Goeze), and the stripe flea beetle, Py. striolata (F.) (Feeny et al. 1970). All plants were tested at the first true leaf stage.

The eggs were from the 1977 stock colony and were kept out-of-doors during the winter. Weights were taken only at pupation and at adult emergence. Records were kept on the time of pupation and adult emergence, on the weights

of the pupae and adults, and on the number of normal and malformed adults.

Survival from larval eclosion to adult emergence differed significantly among the weeds (Table XX). Survival was the highest on B. nigra (61%) and S. arvensis (60%) and the lowest on T. arvense (0%). The survival rate in the first two species was the same as that in Torch rape (65%). None of the larvae on T. arvense survived beyond the first instar. More than 40% of the larvae survived to the adult stage on D. sophia, Sy. loeselii, C. bursa-pastoris and Er. gallicum, but the survival rates for these four species were significantly lower than that for Torch.

Table XX. Percent survival to the adult stage and % deformed adults when larvae of Entomoscelis americana were reared on the first true leaves of seven species of weeds in the family Cruciferae and Torch cultivar of Brassica campestris; 100 larvae were used for each species.

Food	% Survival*	% Deformed adults*
Brassica nigra	61ab	33a
Descurainia sophia	45d	4c
Sisymbrium loeselii	48cd	10b
Sinapis arvensis	60ab	4c
Capsella bursa-pastoris	53bcd	2c
Erucastrum gallicum	55bc	3c
Thlaspi arvense	0e	—
Control:		
B. campestris (Cult. Torch)	65a	1c

*The percentages within columns followed by the same letter are not significantly different at the 5% level according to Chi-squared test (2x2 contingency tables).

The developmental times for the larvae were significantly different among the weeds (Table XXI). The mean developmental times for both sexes were the shortest in larvae reared on Er. gallicum (46-47 days) and the longest in those on D. sophia (55-56 days). These developmental times for the larvae on Er. gallicum were significantly shorter and those for larvae on D. sophia were significantly longer than those on Torch rape, B. nigra, Sy. loeselii, S. arvensis and C. bursa-pastoris. Developmental times on the latter four species were not significantly different from those on Torch. However, the developmental times for larvae reared on C. bursa-pastoris were significantly shorter than those on B. nigra and Sy. loeselii, but the differences among the latter two species and S. arvensis were not significant.

The weeds can be divided into two groups on the basis of the adult weights (Table XXII). The weights of the adults from larvae reared on the species of the first group (S. arvensis, C. bursa-pastoris and Er. gallicum) were not significantly different from those from Torch rape. The adults from the second group (B. nigra, D. sophia and Sy. loeselii) were significantly lighter ($P<0.01$) than those of the first group and those from Torch.

Table XXI. Mean number of days ($\bar{X}$ ± SD) spent by larvae of Entomoscelis americana on the first true leaves of seven species of weeds in the family Cruciferae and Torch cultivar of Brassica campestris.

Food	No.**	Larval period		Pupal period		Total days to adult emergence	
		$\bar{X}$ ± SD	Range	$\bar{X}$ ± SD	Range	$\bar{X}$ ± SD***	Range
				Males			
Brassica nigra	28	37.1±2.7	31-46	16.4±2.5	14-27	53.5±2.8b	49-62
Descurainia sophia	20	38.7±3.5	34-48	17.0±1.7	14-20	55.7±3.9a	49-60
Sisymbrium loeselii	27	35.9±2.1	32-41	16.6±1.2	15-21	52.5±3.0b	47-62
Sinapis arvensis	25	34.3±2.4	29-41	16.8±1.0	15-18	51.1±1.5bc	49-54
Capsella bursa-pastoris	28	34.0±2.8	30-41	16.3±1.4	13-19	50.3±3.6c	44-59
Erucastrum gallicum	25	31.8±1.1	30-34	15.3±1.6	13-18	47.1±2.1d	44-51
Thlaspi arvense*	0	-	-	-	-	-	-
Control:							
B. campestris (Cult. Torch)	30	34.4±2.7	28-40	16.6±1.5	14-19	51.0±2.9bc	45-56
				Females			
Brassica nigra	33	37.2±3.1	31-43	16.2±0.9	15-18	53.4±2.9b	47-58
Descurainia sophia	25	38.6±2.6	33-44	16.4±1.0	15-18	55.0±3.2a	47-59
Sisymbrium loeselii	21	36.4±2.4	32-42	16.5±1.3	15-20	52.9±3.3b	47-60
Sinapis arvensis	35	34.4±2.2	31-40	16.0±1.2	15-18	50.4±1.4bc	49-54
Capsella bursa-pastoris	25	33.7±3.0	30-42	15.7±1.1	14-17	49.4±3.7c	44-59
Erucastrum gallicum	30	31.6±1.2	30-34	14.8±1.4	13-18	46.4±2.0d	44-51
Thlaspi arvense*	0	-	-	-	-	-	-
Control:							
B. campestris (Cult. Torch)	35	34.8±2.1	30-40	16.3±1.4	14-19	51.1±3.0bc	44-59

*All larvae on T. arvense died in the first larval instar.

**Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment for each species.

***Means for each sex followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

Table XXII. Mean pupal and adult weights (mg ± SD) of Entomoscelis americana reared on the first true leaves of seven species of weeds in the family Cruciferae and Torch cultivar of Brassica campestris.

Food	No.**	Pupal Weight $\bar{X}$ ± SD	Pupal Weight Range	Adult weight $\bar{X}$ ± SD***	Adult weight Range
		Males			
Brassica nigra	28	45.24±9.74	27.00-56.62	34.04±7.88b	20.89-50.85
Descurainia sophia	20	42.43±5.42	31.84-52.00	34.17±5.53b	23.20-44.72
Sisymbrium loeselii	27	42.86±8.72	25.02-57.05	35.08±7.75b	21.15-50.74
Sinapis arvensis	25	52.37±4.17	43.36-64.46	42.11±5.64a	33.05-53.96
Capsella bursa-pastoris	28	50.63±6.79	39.62-61.11	42.62±6.40a	33.26-54.78
Erucastrum gallicum	25	50.32±7.20	36.54-67.19	43.31±7.20a	28.64-57.73
Thlaspi arvense*	0	-	-	-	-
Control:					
B. campestris (Cult. Torch)	30	47.59±5.42	38.27-60.49	43.16±4.91a	34.62-56.93
		Females			
Brassica nigra	33	54.47±7.73	44.38-63.83	46.37±8.56b	30.45-62.68
Descurainia sophia	25	57.14±6.68	44.70-67.82	46.04±5.95b	37.66-56.40
Sisymbrium loeselii	21	54.15±6.79	41.18-62.47	45.89±6.60b	32.73-55.14
Sinapis arvensis	35	68.53±7.62	57.82-89.43	57.98±7.06a	49.00-76.32
Capsella bursa-pastoris	25	67.05±8.72	51.24-81.05	58.35±8.63a	43.31-72.38
Erucastrum gallicum	30	65.93±9.80	46.00-80.78	58.80±9.17a	42.83-73.32
Thlaspi arvense*	0	-	-	-	-
Control:					
B. campestris (Cult. Torch)	35	56.91±8.30	52.86-74.78	53.54±7.60a	48.23-70.42

*All larvae on T. arvense died in the first larval instar.

**Number of larvae that survived to the adult stage for each sex out of a total of 100 larvae at the start of the experiment.

***Means for each sex followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

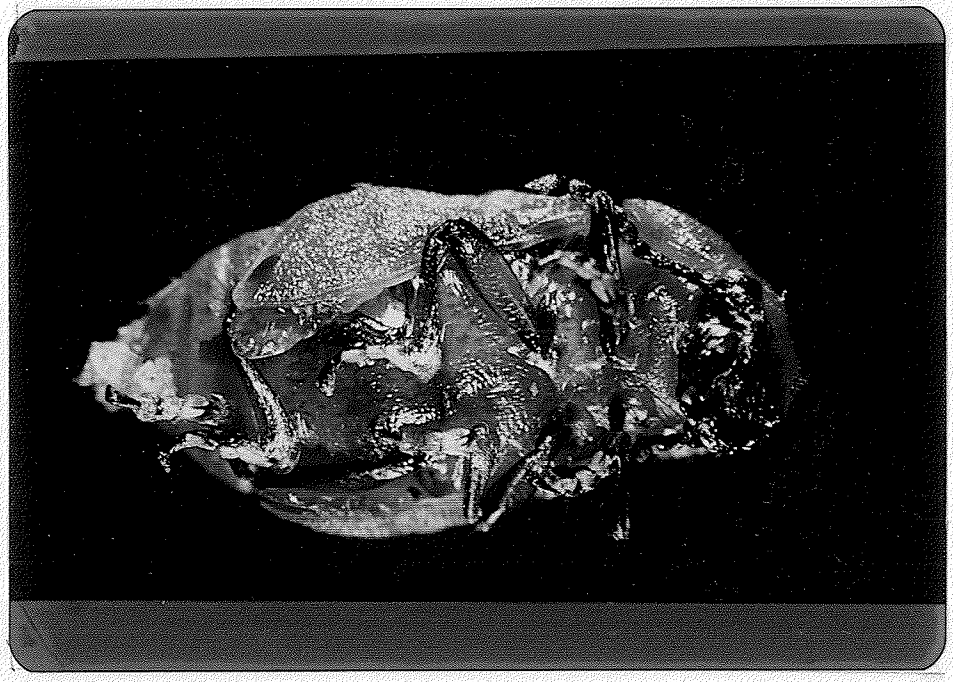
The percentage of malformed adults were significantly different among the weeds (Table XX). More adults were deformed on B. nigra than on Torch rape, Sy. loeselii, D. sophia, S. arvensis, C. bursa-pastoris, and Er. gallicum ($P<0.01$). The percentage of malformed adults from S. loeselii was significantly higher than those from D. sophia, S. arvensis, C. bursa-pastoris, Er. gallicum and Torch, but the differences between Torch and the latter four weeds were not significant. The types of malformations in the adults from Sy. loeselii, D. sophia, S. arvensis, C. bursa-pastoria, and Er. gallicum were the same as those from Torch (Fig. 6); they only had crinkled elytra. These adults probably would survive to lay eggs.

Several morphological abnormalities occurred in the adults from B. nigra (Fig. 11A). These adults had characteristics of both the pupal and adult stages. The anatomy and colour of the head, thorax and legs were characteristic of normal adults, but the rest of the body was similar in appearance to that of pupae (Fig. 2F,G). The elytra were not fully developed, were crinkled, and lacked the red colouration and black stripes typically found in adults. In some instances (Fig. 11B), the legs remained stuck to the abdomen; this prevented the adults from walking. The malformed adults from B. nigra probably would not survive.

Fig. 11. A malformed adult of Entomoscelis americana from a larva reared on the first true leaves of B. nigra:

(A) Dorsal view showing the incompletely developed elytra and abdomen (x12).

(B) Ventral view showing the legs stuck to the abdomen (x12).



The larval growth rate indices for the larvae differed significantly among the weeds (Table XXIII). The larvae reared on S. arvensis, C. bursa-pastoris and Er. gallicum had significantly larger larval growth rate indices than those on Torch rape, B. nigra, D. sophia and Sy. loeselii. The larval growth rate indices for the latter three weeds were significantly smaller than that for Torch.

The nutritional index for larvae on Torch rape was 6-15% higher than those for larvae on S. arvensis, C. bursa-pastoris and Er. gallicum (Table XXIII). The nutritional indices for these three weeds were about twice as large as those for B. nigra, D. sophia and Sy. loeselii.

Table XXIII. Larval growth rate indices and nutritional indices on the first true leaves of seven species of weeds in the family Cruciferae and Torch cultivar of Brassica campestris.

Food	Larval growth rate index**	Nutritional Index
Brassica nigra	1.35d	21.04
Descurainia sophia	1.29d	29.68
Sisymbrium loeselii	1.34d	29.20
Sinapis arvensis	1.77ab	55.17
Capsella bursa-pastoris	1.74b	51.60
Erucastrum gallicum	1.84a	56.73
Thlaspi arvense*	—	—
Control:		
B. campestris (Cult. Torch)	1.55c	60.62

*All larvae on T. arvense died in the first larval instar.

**Means followed by the same letter are not significantly different at the 5% level according to F-Test and Duncan's multiple range test.

4.6 Food selection

Newly-hatched larvae discriminated between the various plants tested. Initially, the larvae wandered from one food source to another, but after a short time, they began to favour certain food plants. In some cases, they took small bites before choosing a plant. The larvae finally settled down on the chosen plant and began feeding.

4.6.1 Two-choice experiments

The plants tested were divided into four groups. The first group consisted of the cotyledons of Echo, Candle and R500 cultivars of B. campestris and were compared with the cotyledons of Torch cultivar of B. campestris to determine the B. campestris cultivar which the larvae selected most frequently. The second group, consisting of the cotyledons of Target, Midas and Tower cultivars of B. napus, were compared with the cotyledons of Torch to determine whether the larvae selected the cultivars of B. napus or Torch most often. The third group consisted of the cotyledons of the commercial mustards: Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea and Gisilba (Yellow mustard) cultivar of B. hirta. They were compared with the cotyledons of Torch to determine whether the larvae selected the cultivars of commercial mustard or Torch most often. In the fourth group, the first true leaves of Torch cultivar of B. campestris, B. nigra and

S. arvensis were compared with the cotyledons of Torch to determine the stage of plant growth which the larvae selected most frequently. The experiments within each group were run at the same time.

Among the plants in the first group, the larvae selected Torch more frequently than either Candle or R500, but were evenly distributed on Torch and Echo (Fig. 12). The number of larvae on Torch was 1.5 and 3.5 times greater than that on Candle and R500, respectively.

In the second group, the number of larvae on Torch was significantly greater than that on each of Midas, Target and Tower (Fig. 13). The larvae selected Midas, Target and Tower at about the same frequency in the three experiments.

In the third group, Torch was selected by a significantly greater number of larvae than Brown mustard, Oriental mustard and Yellow mustard (Fig. 14). There were more than twice the number of larvae on Torch than on each of the three mustards. In the three experiments, Yellow mustard had the fewest number of larvae on it, and Brown and Oriental mustards were selected at about the same frequency.

Among plants in the fourth group, the larvae were on Torch cotyledons in significantly greater numbers than on the first true leaves of each of Torch, B. nigra and S. arvensis (Fig. 15). The number of larvae on the cotyledons of Torch was 2.2 to 5.3 times greater than those on the first true leaves of Torch, S. arvensis and B. nigra. B. nigra had the smallest number of larvae on it.

Fig. 12. Food selection by newly-hatched larvae of Entomoscelis americana in a two-choice experiment between the cotyledons of Torch cultivar of Brassica campestris and the cotyledons of each of Candle, Echo and R500 cultivars of B. campestris. TO, Torch; CA, Candle; EC, Echo; R5, R500. The line above the bars indicates no significant difference between the cultivars ($P>0.05$).

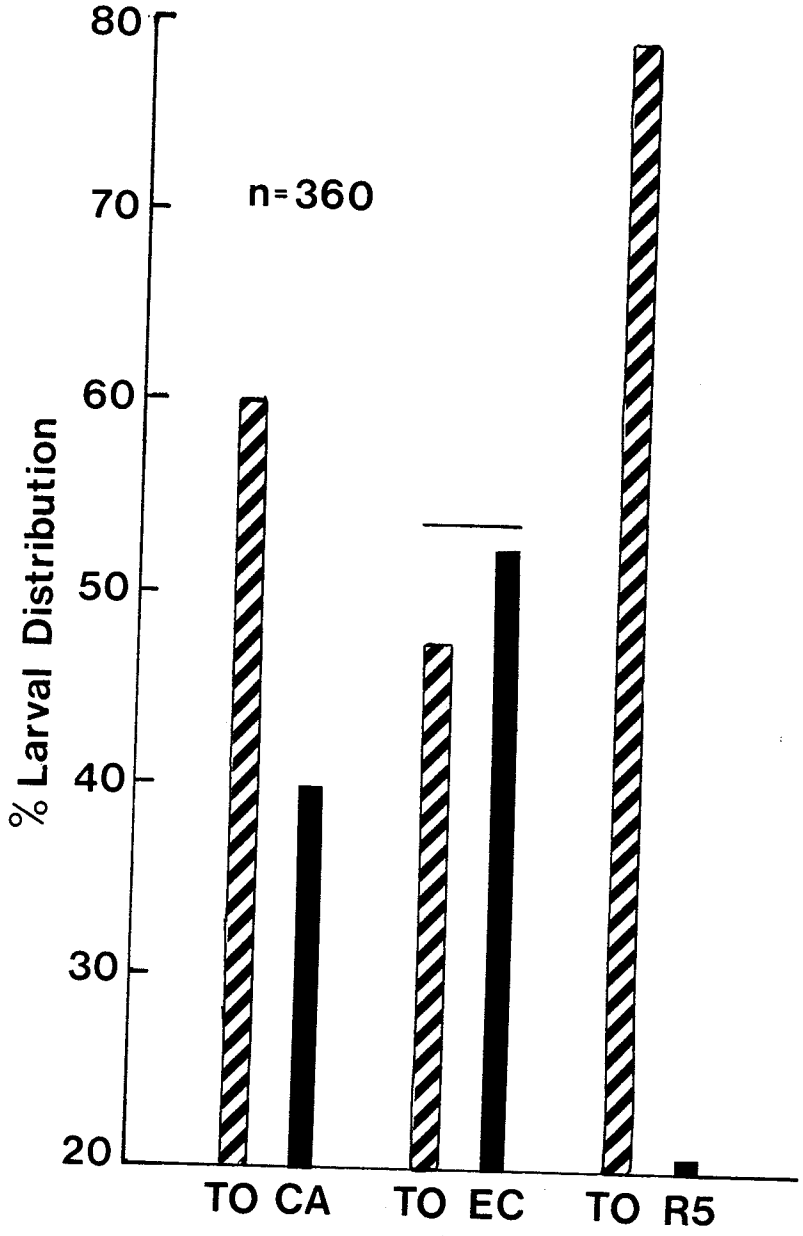

80
70
60
50
40
30
20
n=360
% Larval Distribution
TO CA
TO EC
TO R5

Fig. 13. Food selection by newly-hatched larvae of Entomoscelis americana in a two-choice experiment between the cotyledons of Torch cultivar of B. campestris and the cotyledons of each of Midas, Target and Tower cultivars of B. napus. TO, Torch; MI, Midas; TG, Target; TW, Tower. For each pair, the distributions were significantly different ($P<0.05$).

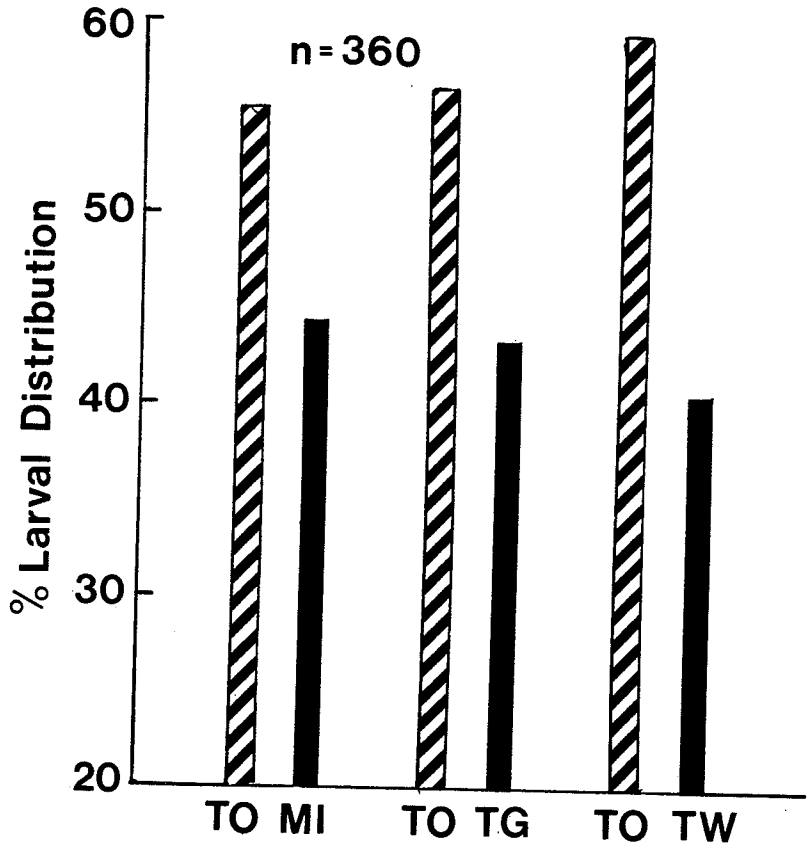

60
50
40
30
20
n = 360
% Larval Distribution
TO MI
TO TG
TO TW

Fig. 14. Food selection by newly-hatched larvae of Entomoscelis americana in a two-choice experiment between the cotyledons of Torch cultivar of Brassica campestris and the cotyledons of each of Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea, and Gisilba (Yellow mustard) cultivar of B. hirta. TO, Torch; BR, Brown mustard; OR, Oriental mustard; YW, Yellow mustard. For each pair, the distributions were significantly different ($P<0.05$).

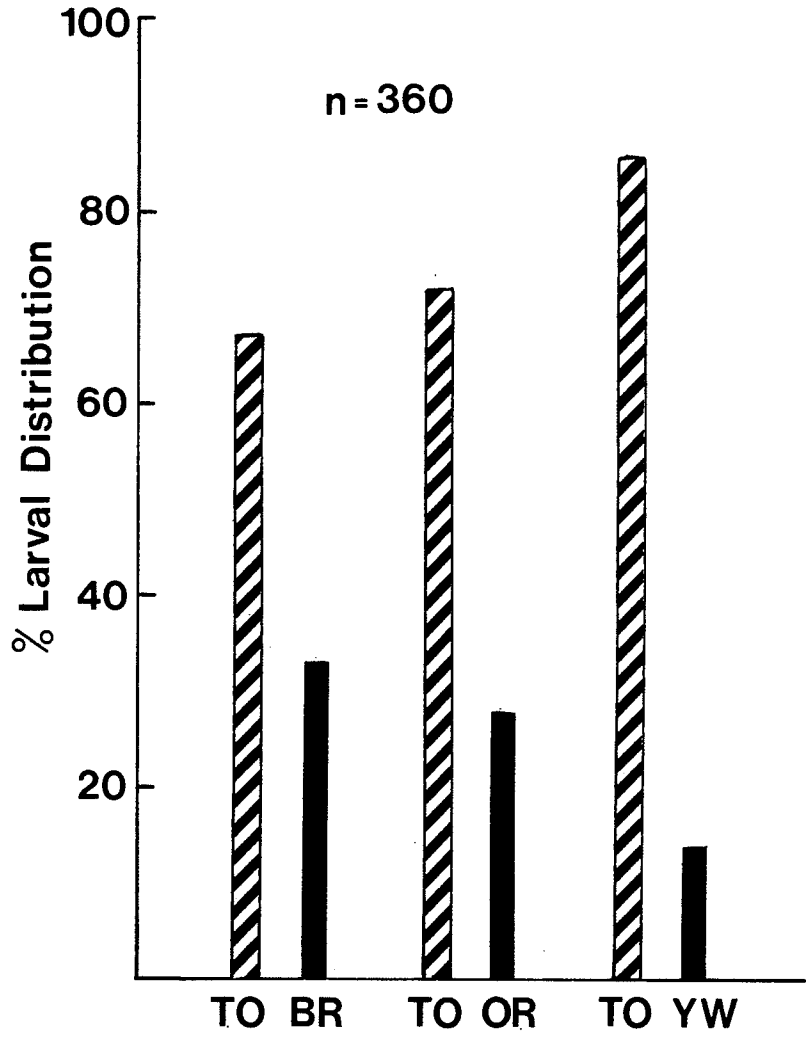
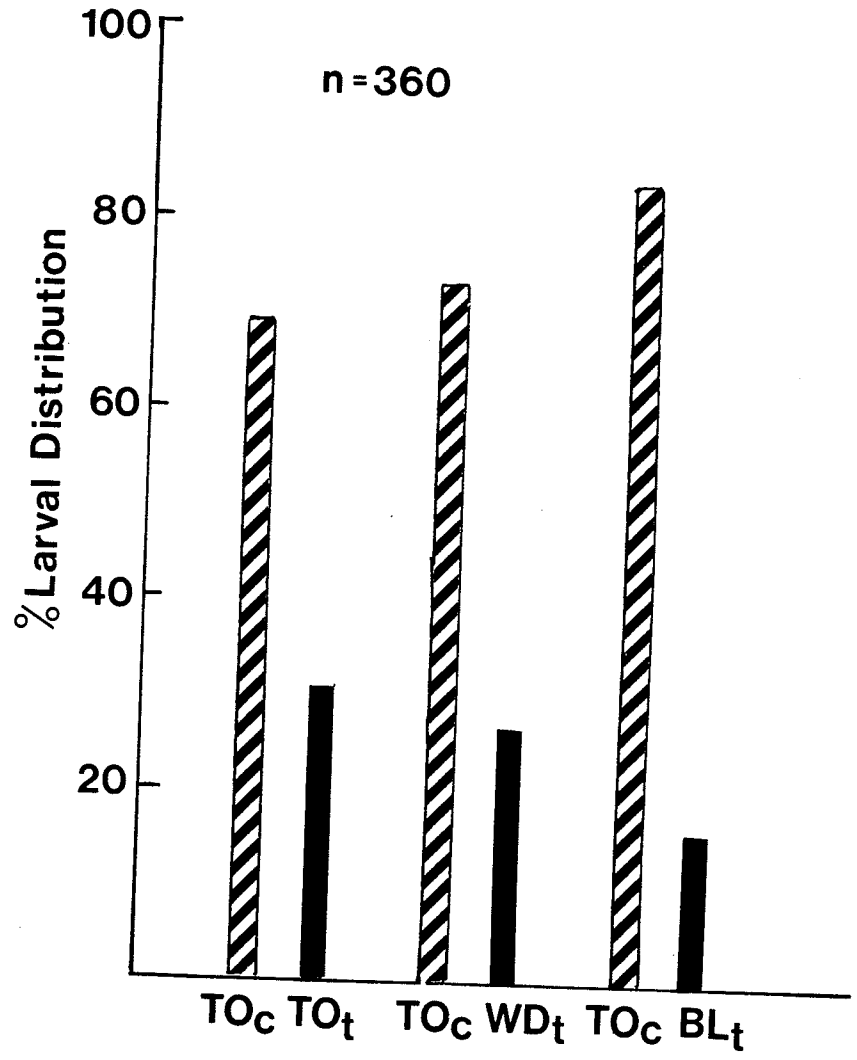

100
80
60
40
20
% Larval Distribution
n = 360
TO BR
TO OR
TO YW

Fig. 15. Food selection by newly-hatched larvae of Entomoscelis americana in a two-choice experiment between the cotyledons of Torch cultivar of Brassica campestris and the first true leaves of each of Torch, Sinapis arvensis (Wild mustard) and B. nigra (Black mustard). TO, Torch; WD, S. arvensis; BL, B. nigra; c, cotyledons, t, first true leaves. For each pair, the distributions were significantly different ($P<0.05$).


100
80
60
40
20
n=360
% Larval Distribution
TOc TOt TOc WDt TOc BLt

4.6.2 Four-choice experiments

The plants tested in the four-choice experiments were divided into six groups. The first group consisted of the cotyledons of four cultivars of B. campestris (Echo, Torch, Candle and R500). The second group consisted of the cotyledons of four cultivars of B. napus (Target, Midas, Regent and Tower). The cultivars in these two groups were tested to determine the cultivar in each species which was selected most frequently by the larvae.

In the third group, the cotyledons of the three commercial mustards, Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea and Gisilba (Yellow mustard) cultivar of B. hirta, were compared with the cotyledons of Torch cultivar of B. campestris to determine whether the larvae selected rape or commercial mustards most often. In the fourth group, the cotyledons of the three commercial mustards were tested with the cotyledons of S. arvensis to determine the type of mustard which the larvae selected most frequently.

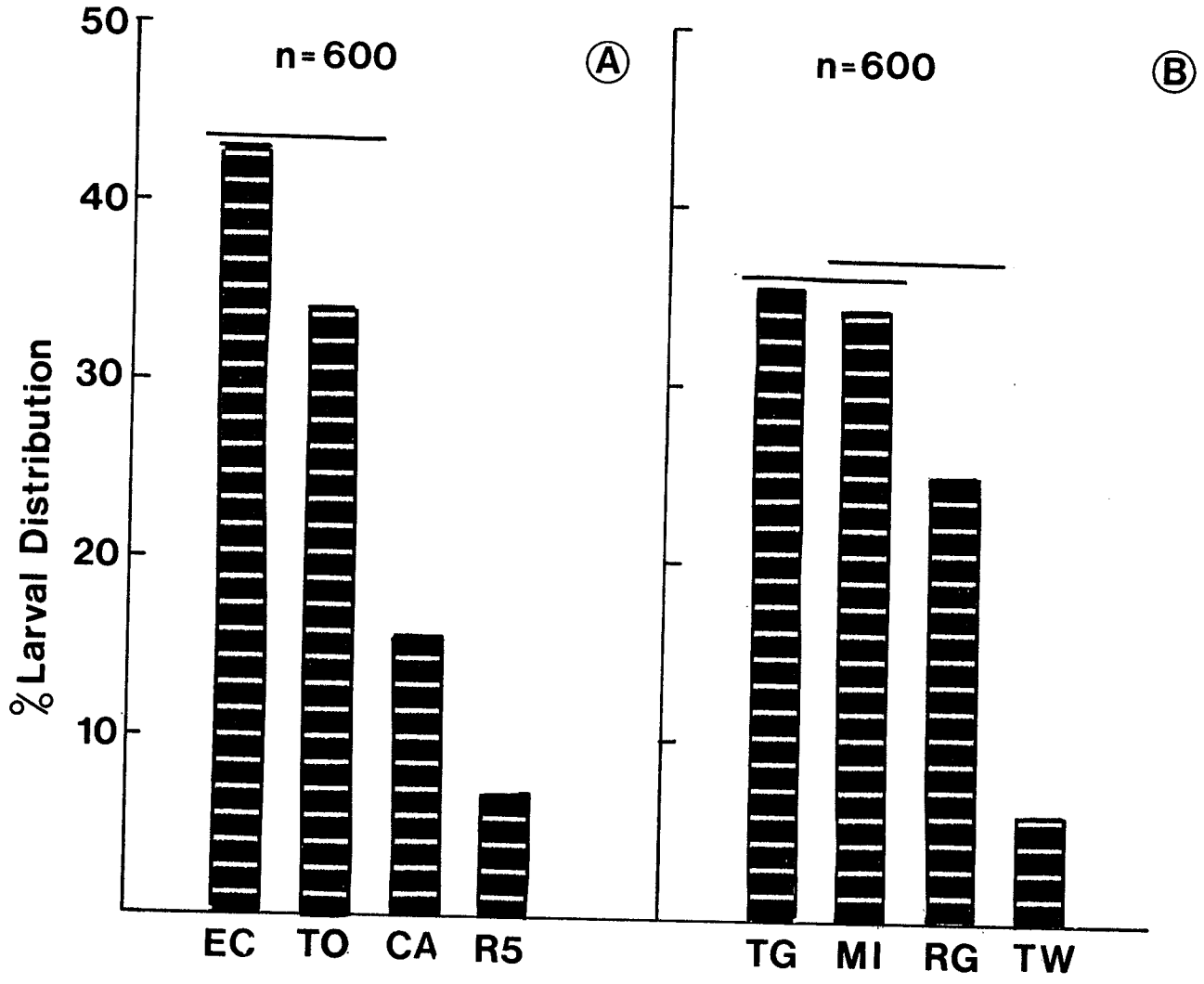
In the fifth group, the first true leaves of three rape cultivars (Torch, Midas and Tower) were compared with the cotyledons of Torch cultivar of B. campestris to determine the stage of plant growth selected most frequently by the larvae. In the sixth group, the first true leaves of two cultivars of B. campestris (Torch and Candle) and

of two cultivars of B. napus (Midas and Tower) were compared to determine the species of rape which the larvae selected the most.

In the first group, the numbers of larvae on the four cultivars of B. campestris differed significantly (Fig. 16A). R500 was selected the least and Echo was selected the most. Torch had fewer larvae on it than Echo, but the differences were not significant. Candle had significantly smaller numbers of larvae on it than Echo and Torch, and had significantly larger numbers on it than R500.

Among the four cultivars of B. napus in the second group, Tower was selected the least and Target and Midas were selected the most (Fig. 16B). Target and Midas had similar numbers of larvae. Target attracted significantly more larvae than Regent, whereas Midas did not attract significantly more larvae than Regent. Tower had significantly smaller numbers of larvae on it than Regent.

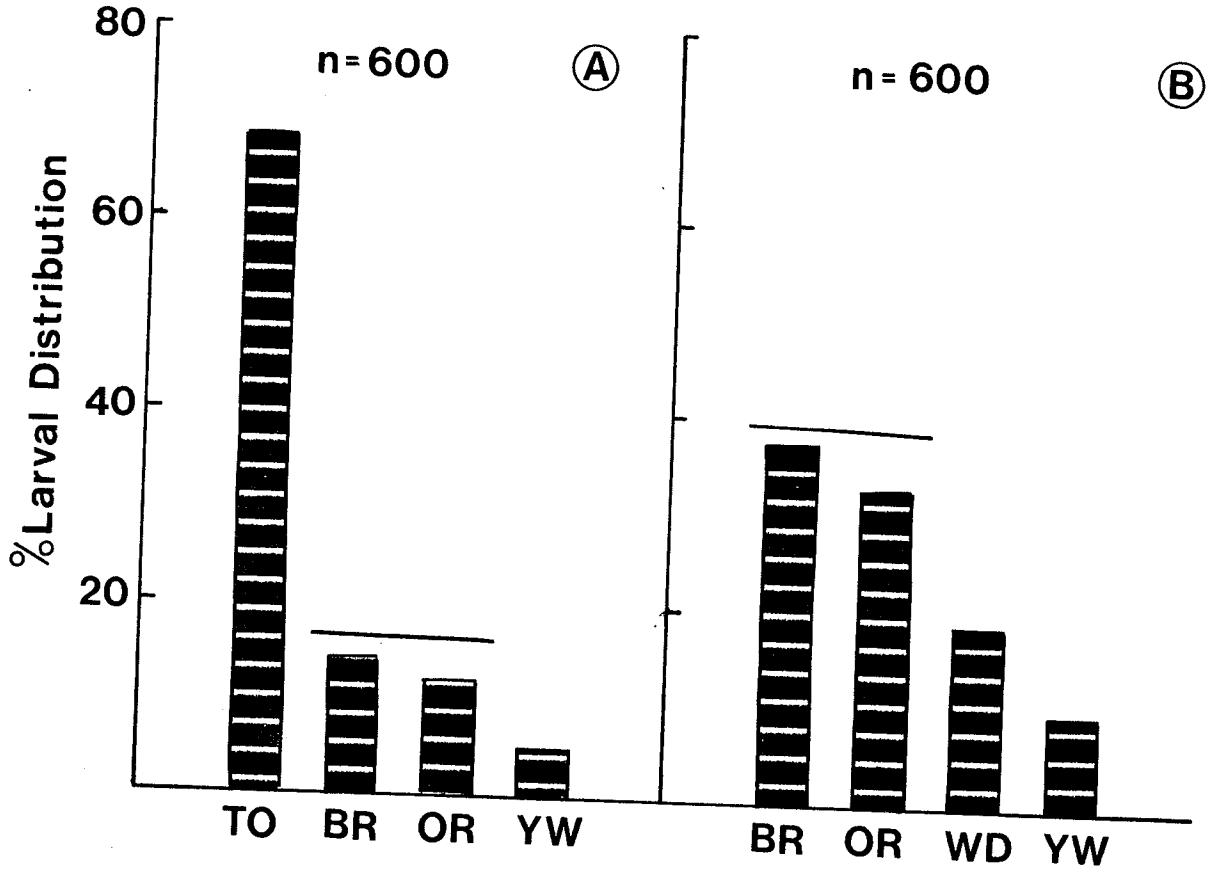
Fig. 16. Food selection by newly-hatched larvae of Entomoscelis americana in a four-choice experiment among (A) the cotyledons of Echo, Torch, Candle and R500 cultivars of Brassica campestris, and among (B) the cotyledons of Target, Midas, Regent and Tower cultivars of B. napus. EC, Echo; TO, Torch; CA, Candle; R5, R500; TG, Target; MI, Midas; RG, Regent; TW, Tower. The lines above the bars indicate no significant differences between the cultivars ($P>0.05$).


50
40
30
20
10
% Larval Distribution
n=600
A
n=600
B
EC
TO
CA
R5
TG
MI
RG
TW

In the third group, Torch attracted significantly more larvae than Brown mustard, Oriental mustard and Yellow mustard (Fig. 17A). The number of larvae on Torch was 4.2 to 14.2 times greater than those on the commercial mustards. There was no significant difference between the number of larvae on Brown mustard and that on Oriental mustard, but they attracted significantly more larvae than Yellow mustard.

Among Brown mustard, Oriental mustard, Yellow mustard and S. arvensis in the fourth group, Brown and Oriental mustards had significantly more larvae on them than on the other two mustards (Fig. 17B). The number of larvae on Brown and Oriental mustards were not significantly different from each other. S. arvensis attracted significantly more larvae than Yellow mustard.

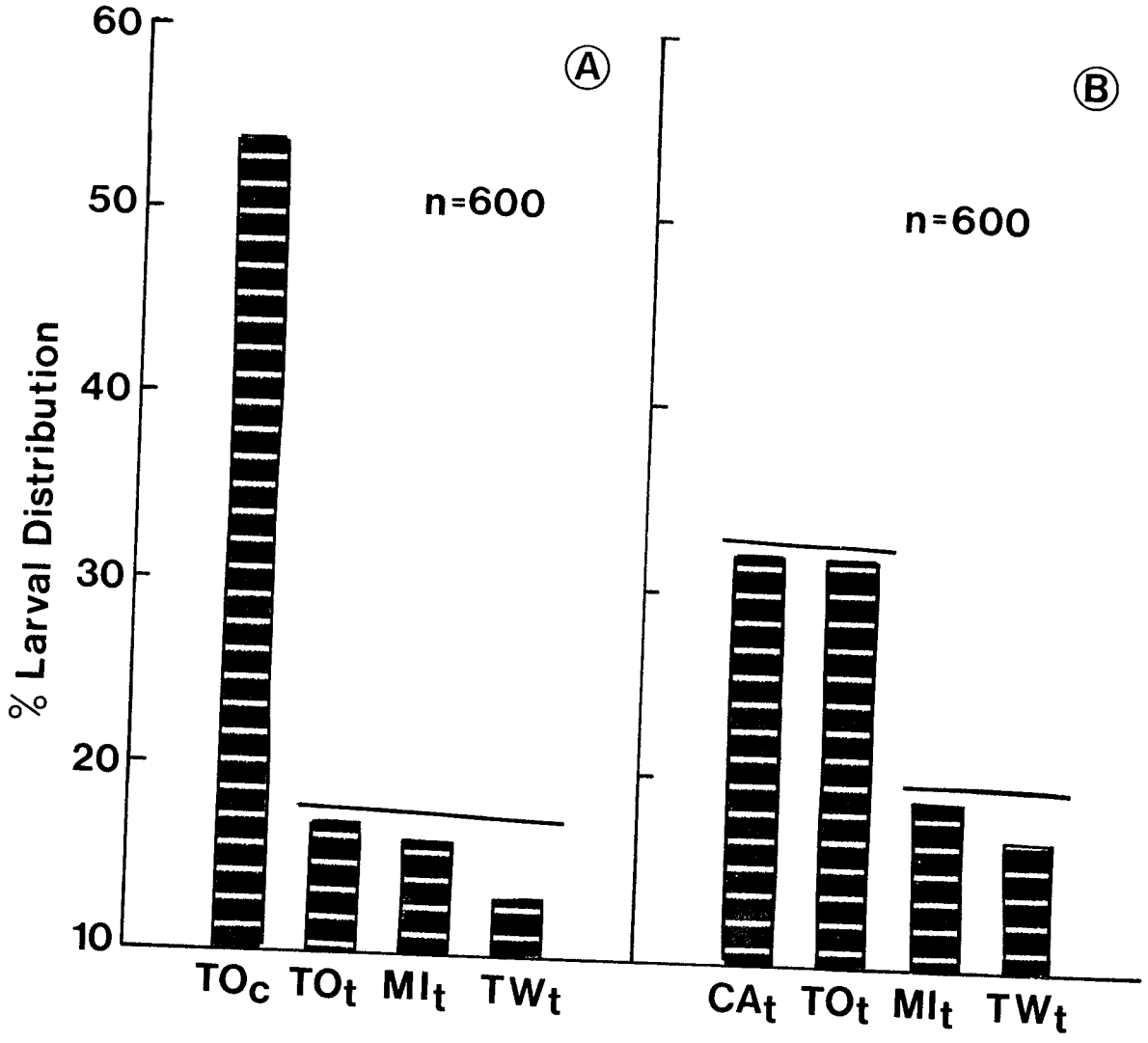
Fig. 17. Food selection by newly-hatched larvae of Entomoscelis americana in a four-choice experiment among (A) the cotyledons of Torch cultivar of Brassica campestris, of Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea, and of Gisilba (Yellow mustard) cultivar of B. hirta, and among (B) the cotyledons of Blaze (Brown mustard) and Lethbridge 22A (Oriental mustard) cultivars of B. juncea, of Gisilba (Yellow mustard) cultivar of B. hirta, and of S. arvensis (Wild mustard). TO, Torch; BR, Brown mustard; OR, Oriental mustard; YW, Yellow mustard; WD, S. arvensis. The lines above the bars indicate no significant differences between the cultivars ($P>0.05$).


80
60
40
20
%Larval Distribution
n=600
A
n=600
B
TO
BR
OR
YW
BR
OR
WD
YW

In the fifth group, Torch cotyledons attracted significantly more larvae than the first true leaves of Torch, Midas and Tower (Fig. 18A). The number of larvae on Torch cotyledons was 3.2 to 4.2 times greater than those on the first true leaves of Torch, Midas and Tower. The numbers of larvae on the first true leaves of Torch, Midas and Tower were not significantly different from each other.

Among the first true leaves of Candle and Torch cultivars of B. campestris and of Midas and Tower cultivars of B. napus in the sixth group (Fig. 18B), Candle and Torch had significantly more larvae on them than Midas and Tower. The numbers of larvae on the B. campestris cultivars were twice as great as those on the B. napus cultivars. Similar numbers of larvae were on Candle and Torch and on Midas and Tower.

Fig. 18. Food selection by newly-hatched larvae of Entomoscelis americana in a four-choice experiment among (A) the cotyledons and the first true leaves of Torch cultivar of Brassica campestris, and of the first true leaves of Midas and Tower cultivars of B. napus, and among (B) the first true leaves of Candle and Torch cultivars of B. campestris and the first true leaves of Midas and Tower cultivars of B. napus. TO, Torch; MI, Midas; TW, Tower; CA, Candle; c, cotyledons; t, first true leaves. The lines above the bars indicate no significant differences among the cultivars ($P>0.05$).


60
50
40
30
20
10
% Larval Distribution
A
B
n=600
n=600
TOc TOt MIt TWt
CAt TOt MIt TWt

5. DISCUSSION

The number of larval instars in E. americana obtained in this study by counting the number of moults supports the findings of Hanford (1932), who reported four larval instars from head capsule measurements. Manolache (1941) also reported four larval instars for a closely related Eurasian species, E. adonidis Pallas. However, the results are not in agreement with Stewart (1973), who reported five larval instars for E. americana; he also used head capsule measurements as the basis for his findings. Stewart might have counted the non-feeding phase of the fourth instar (pre-pupa) as another larval instar. Literature records of the number of larval instars among the Chrysomelidae show that most species within the family have four larval instars, although some have three instars and others have five instars (Weiss and Dickerson 1917; Gibson et al. 1925; Kogan and Goeden 1970; Lindquist and Davis 1971; Piper 1975).

The present study showed that the plants tested varied in their suitability as food for the larvae of the red turnip beetle. Six criteria were used to evaluate the suitability of the plants as food for the larvae. These were: the percent survival to adult emergence; the length of the developmental period from larval eclosion to adult emergence; the weights of the adults at emergence; the percentage of malformed adults and the severity of the malformations; the larval growth rate indices; and the

nutritional indices. In nutritional studies, the first three criteria are the ones commonly used to evaluate the suitability and adequacy of diets for insects (Pickford 1962; Wilson and Shade 1966; Kugelberg 1973; Wiklund 1973; Phillips 1977; MacFarlane and Thorsteinson 1977). Of these three criteria, the percent survival to adult emergence is the most important one. The suitability of the various food plants tested for growth, development and survival of red turnip beetle larvae is discussed below. In addition, the results from the food selection studies are evaluated in relation to the other studies.

5.1 Rape cultivars

The present experiments showed that cultivars of both species of rape, B. campestris and B. napus, are suitable food plants for the larvae of the red turnip beetle. The significant differences in the survival rates and in the larval growth rate indices, and the differences in the nutritional indices showed that the cultivars differed in their suitability. The differences showed up in both stages of plant growth and in both experiments. The results from Experiment I suggested that there were large differences in suitability among the cultivars, and the results from Experiment II suggested the opposite. However, the hatch rate of eggs and the viability of the larvae in Experiment I were poor compared to those for Experiment II. Because of the problems associated with Experiment I, more emphasis is placed on the results from Experiment II than on those from Experiment I in the remainder of the Discussion. Since the length of the developmental period, the weights of the adults at emergence and the percentage of malformed adults were not significantly different among the cultivars in both experiments, and since the survival rates of the larvae among the cultivars in Experiment II were high and similar, it is obvious that the differences in suitability among the cultivars were small. A comparison of the data for the seven cultivars indicated that Midas, Torch, Candle, Tower, Target and Echo are equal in suitability and are slightly superior to R500.

Several factors were considered to account for the small

differences in suitability among the rape cultivars. Firstly, it seemed possible that the differences were related to species differences. This was rejected, because the cultivars of the two species were of equal suitability. A second possibility is that glucosinolates were involved in the differences. This was rejected, because cultivars low in glucosinolates (Candle and Tower) were as suitable as cultivars normal in glucosinolates (Midas, Torch, Target and Echo). This conclusion is in agreement with some of the findings reported in the literature. Blau et al. (1978) found that high concentrations of the glucosinolate, sinigrin, was not toxic to larvae of Pieris rapae L., a Cruciferae-feeder. Similarly, Slansky and Feeny (1977) reported that larval growth of P. rapae was not affected by variations in the glucosinolate content, but was affected by nitrogen levels in the crucifers tested. In contrast, Van Emden (1972) found that Brevicoryne brassicae (L.) (a Cruciferae-feeder) and Myzus persicae (Sulzer) (a generalist but feeds on crucifers) were sensitive to concentrations of both glucosinolates and amino acids in the leaves. Similarly, Davis (1974) found a negative correlation between the gains in weight of the larvae of Tenebrio molitor L. (a generalist feeder) and the isothiocyanate content of the rapeseed and Yellow mustard seed tested. Thirdly, the data suggested that erucic acid was involved in the differences. Nevertheless, this is unlikely, since erucic acid usually is not present in rape leaves (Shorland 1963). There is only one report in the

literature which indicates that there can be erucic acid in the leaves of rape; it occurs in small amounts (0.5%) in the leaves of Gulle cultivar of B. napus which has high concentrations of erucic acid in the seed (Appelqvist 1976). Lastly, it is probable that some other primary or secondary plant chemicals are responsible for the differences. However, this possibility has not yet been investigated.

The cotyledon stage of plant growth is more suitable than the first true leaf stage as food for red turnip beetle larvae. Survival usually was higher, the weights of the adults at emergence were heavier, and the larval growth rate indices and the nutritional indices were larger in larvae reared on the cotyledons than those on the first true leaves. However, the length of the developmental period and the percentage of malformed adults were not affected by the stage of plant growth. Similar results were reported for larvae of Leptinotarsa decemlineata (Say) when reared on potato leaves(Cibula et al. 1967). Larvae fed young leaves had higher survival, developed faster and had heavier adults than those fed old leaves. The young leaves were found to contain higher amounts of amino acids than the old leaves. Taylor and Bardner (1968) also found that larvae of two Cruciferae-feeders, Plutella maculipennis (Curtis) and Phaedon cochleariae Fabricus, fed young leaves of turnips and radishes developed faster and had heavier pupae than those fed old leaves. The young leaves were found to contain more protein than the old leaves. It is probable that the cotyledons of rape also contain higher concentrations of primary chemicals, such as

proteins or amino acids, than the first true leaves and consequently are more nutritious than the first true leaves. This conclusion is further supported by the fact that cotyledons were selected over the first true leaves in both the two-choice and four-choice experiments.

In most insects, the highest mortality occurs in the early stages of development, in particular in the first instar (Painter 1951; Van Emden and Way 1973). Mortality in the early stages may be related to the quality of the larvae and (or) several plant factors. The plant factors include the morphology, digestibility, deficiencies of primary chemicals, and the presence of toxic substances in the plants. Mortality in the later stages of development often results from deficiencies in the primary chemicals. In the present study, mortality also was the highest in the first two larval instars for both the cotyledons and the first true leaves of rape. Mortality in the early instars on the cotyledons probably was mainly caused by poor quality larvae. The higher mortality in the early instars on the first true leaves when compared with cotyledons probably was caused by poor quality larvae and by deficiencies in the primary chemicals, because the adults obtained from the first true leaves were significantly lighter in weight than those from the cotyledons.

The results from the food selection studies were not in complete agreement with those from the growth, development and survival studies. In the two-choice experiments, the cotyledons of Torch attracted more larvae than those of Candle,

Target, Midas, Tower and R500, but there were similar numbers of larvae on Torch and Echo. Similarly, in the four-choice experiments, Candle and R500 cotyledons had fewer larvae on them than Torch and Echo cotyledons. Also, in the four-choice experiments, the cotyledons of Target and Midas attracted more larvae than those of Tower, and the first true leaves of Torch and Candle had more larvae on them than the first true leaves of Midas and Tower.

Four possible factors were considered to explain the differences among the food selection and the growth, development and survival studies. Firstly, it seemed possible that food selection was influenced by the nutritional quality of the plants, since insects usually select nutritionally superior foods over less nutritious ones (House 1969). However, this probably was not the case in the present studies, because all the rape cultivars were suitable food plants and R500 appeared to be only marginally inferior to the other cultivars. A second possibility is that feeding inhibitors may have been involved in the differences. This factor was rejected, because all the rape cultivars were suitable food plants. Thirdly, the concentration of glucosinolates in the cultivars may have influenced food selection. Glucosinolates are powerful attractants and feeding stimulants for Cruciferae-feeders (Schoonhoven 1972). With increasing concentrations of glucosinolates, the plants usually become more attractive to Cruciferae-feeders and Cruciferae-feeders generally are stimulated to increase their feeding on the diets (Thorsteinson

1958; David and Gardiner 1966; Hicks 1974; Feeny 1976). This may explain why Candle and Tower attracted fewer larvae than Torch, Echo, Target and Midas, but does not seem to account for the other discrepancies. The seeds of Candle and Tower contain only small quantities of glucosinolates, while the seeds of the other four have normal levels of glucosinolates (Appendix 4). Nevertheless, it is not known whether there are close relationships among the concentrations of glucosinolates in the seeds, cotyledons and leaves of rape. A fourth possibility is that the types of glucosinolates which predominate in B. campestris and B. napus affected food selection. Both species contain the same types of glucosinolates (8 types) (Josefsson 1970), but in the seeds, progoitrin is present in the highest concentration in B. napus and gluconapin predominates in B. campestris (Downey et al. 1975). It is not known, nonetheless, whether these also are the predominant glucosinolates in the cotyledons and leaves. For Pieris brassica L., Pl. maculipennis and Py. cruciferae, it has been shown that glucosinolates differ in their attractiveness and that the relative effectiveness of the glucosinolates as attractants depends on the insect species being studied (Nayar and Thorsteinson 1963; David and Gardiner 1966; Hicks 1974; Hicks and Tahvanainen 1974). Until the chemical composition of rape leaves and cotyledons is known, it is not possible to conclude whether glucosinolates are involved in the differences among the present studies.

5.2 Commercial mustards

The commercial mustards (Brown mustard, Oriental mustard and Yellow mustard) are suitable food plants for red turnip beetle larvae. The percent survival to adult emergence was relatively high and the percentage of malformed adults was low in all three mustards. Since the survival rates and the nutritional indices were similar and the length of developmental period, the weights of the adults, and the larval growth rate indices were not significantly different among these mustards, they probably are of equal suitability. A comparison of the data for the commercial mustards and Torch rape indicated that Torch was slightly superior to, at most, only one of the mustards (Yellow mustard). The nutritional index was higher and the survival rate and larval growth rate index were significantly higher for Torch than for Yellow mustard, but only the larval growth rate indices and the nutritional indices were different when Torch was compared with Brown and Oriental mustards. The differences among Torch and Brown and Oriental mustards did not seem to be sufficiently great to conclude that Torch is a more suitable host plant than these mustards.

Among the three commercial mustards, mortality was the highest in the first two instars. As on the rape cultivars, mortality in the early instars on the mustards probably was mainly due to poor quality larvae.

The results from the food selection studies were not in complete agreement with those from the growth, development

and survival studies. In the selection studies, Torch rape attracted more larvae than each of the three mustards and Yellow mustard had the fewest number on it. Brown and Oriental mustards attracted similar numbers of larvae. Since Brown, Oriental and Yellow mustards appeared to be of equal suitability and Torch seemed to be better than only Yellow mustard as a food plant, four possible factors were considered to explain the differences between the studies. Firstly, it seemed possible that food selection was influenced by the nutritional quality of the plants (House 1969). However, this probably was not the case in the present studies, because the three mustards and Torch were all suitable plants and Torch appeared to be only slightly better than Yellow mustard. A second possibility is that feeding inhibitors may have been involved in the differences. This factor was rejected, because all the mustards were suitable food plants. Thirdly, the concentration of glucosinolates in these plants might have been involved in the differences (Thorsteinson 1953; David and Gardiner 1966; Hicks 1974; Feeny 1976). This probably was not the case, since the concentration of glucosinolates in the seeds in Yellow mustard is higher than those of Brown mustard, Oriental mustard and Torch (Canada Committee on Grain Quality 1976, 1977; F.W. Hougen pers. comm.). The concentration of glucosinolates in the seeds of Brown and Oriental mustards are slightly higher than that in Torch. A fourth possibility is that the different types of glucosinolates found in the three species of the present experiments affected food selection. Progoitrin, one of the

major glucosinolates in the seeds of Torch, was a more effective feeding stimulant for Pl. maculipennis than sinigrin, the most prominent glucosinolate in the seeds of Brown and Oriental mustards (Nayar and Thorsteinson 1963; Downey et al. 1975). Nielsen (1978) found that sinigrin was a more effective feeding stimulant for Phyllotreta undulata Kutsch. than sinalbin one of the major glucosinolates in the seeds of Yellow mustard, but observed that sinigrin and sinalbin were about equal in their ability to stimulate feeding in Phyllotreta nemorum L., Phyllotreta tetrastigma Corn. and Ph. cochleariae. However, until the chemical composition of mustard and rape cotyledons and true leaves has been investigated, it is not possible to conclude that this last possibility is the main factor involved in the differences among the present studies.

5.3 Cruciferous weeds

The seven cruciferous weeds, Er. gallicum, C. bursa-pastoris, S. arvensis, B. nigra, D. sophia, Sy. loeselii, and T. arvense, differ in their suitability as food for the larvae of the red turnip beetle. These weeds can be classified into three groups on the basis of their suitability as food plants for this beetle.

The first group, consisting of Er. gallicum, C. bursa-pastoris and S. arvensis, was the most suitable of the three groups. On these three weeds, the percent survival to adult emergence was relatively high, the length of the development period was the shortest, the weight of adults at emergence was the heaviest, the percentage of malformed adults was low, and the larval growth rate indices and the nutritional indices were the largest. These data indicated that these three weeds are nutritionally superior to the other weeds and that they contain sufficient essential nutrients for growth and development of red turnip beetle larvae. Among these three species, the length of the developmental period for larvae on Er. gallicum was significantly shorter than for those on the other two. Also, the larval growth rate index for C. bursa-pastoris was significantly smaller than that for Er. gallicum. The differences among these three species probably are not sufficiently great to conclude that any one of them is a more suitable host plant than the others.

C. bursa-pastoris contains alkaloids (Hegnauer 1964).

In some insects, alkaloids have been shown to be toxic (Schmeltz 1971). In others, alkaloids inhibit growth and development (Harley and Thorsteinson 1967; Hsiao and Fraenkel 1968). Since growth, development and survival of the red turnip beetle on C. bursa-pastoris was good, it is obvious that this beetle can either tolerate or detoxify the alkaloids in this plant. Manolache (1941) and Brovdiy (1976) had observed both the larvae and adults of E. adonidis feeding on C. bursa-pastoris, but the effects of this plant on the growth, development and survival of the larvae of this insect were not reported.

The second group consisted of three species which were less suitable than those of the first group. The plants in this group include B. nigra, D. sophia and Sy. loeselii. The survival was lower, except on B. nigra; the length of the developmental period was longer; the adults were lighter in weight; the percentage of malformed adults was higher, except on D. sophia; and the larval growth rate indices and the nutritional indices were smaller on these weeds than on those of the first group. In addition, the severity of the malformations on B. nigra was much greater than those on the first group and those on D. sophia and Sy. loeselii. Within this group, D. sophia and Sy. loeselii probably are equal in suitability and are better than B. nigra. The poor performance of the red turnip beetle larvae on the weeds of this group indicated that these plants are nutritionally deficient and probably should be considered as marginal host plants for red

turnip beetle larvae. In insects, nutritional deficiencies may affect the moulting process, increase the developmental times, increase the incidence of malformations, or cause a decrease in weight gain (Evans 1938; House 1963; Chapman 1969; Wigglesworth 1972; Slansky and Feeny 1977).

The only cruciferous weed in the third group, T. arvense, can be considered as a nonhost plant of red turnip beetle larvae, because none of the larvae survived beyond the first instar. Death on T. arvense probably resulted from toxic substances. When the tissues of T. arvense are damaged, the glucosinolates are hydrolyzed giving rise to organic thiocyanates and cyanides, which are toxic to herbivores (Brown 1951; Gmelin and Virtanen 1959; Slansky and Feeny 1977). T. arvense has also been shown to be toxic to two other Cruciferae-feeders, Pieris napi macdunnoughii Remington and P. occidentalis Reakirt (Chew 1975).

A comparison of the data for the seven cruciferous weeds and Torch rape indicated that the three weeds in the first group, Er. gallicum, C. bursa-pastoris and S. arvensis, are as adequate nutritionally as Torch rape as food for red turnip beetle larvae. The values for the six criteria used for judging the plants were generally similar among these three weeds and Torch rape. On the other hand, the weeds of the second and third groups are nutritionally inferior to Torch rape as food for red turnip beetle larvae, because the values for the six criteria were lower than those for Torch rape in almost all cases.

5.4 Suitability of plants vs. taxonomic relationship

In the present study, no correlation was found between the suitability of the crucifers tested as food for red turnip beetle larvae and the taxonomic positions of these plants. Eleven species belonging to three tribes were tested (Appendix 1): Lepidieae, Sisymbrieae and Brassiceae. In Lipidieae, C. bursa-pastoris is a suitable food plant, while T. arvense is a nonhost plant. The two species of plants tested in the tribe Sisymbrieae, D. sophia and Sy. loeselii, are both marginally suitable. Of the seven species of Brassica (Brassiceae) tested, six are suitable hosts for the larvae. B. nigra is marginally suitable.

5.5 Application in pest management

In pest management systems for insects, a knowledge of the factors which influence their population dynamics is essential (National Academy of Sciences 1969). In phytophagous insects, the distribution and abundance of the host plants are two of the factors which affect population density. Gerber (1975) reported that red turnip beetle infestations usually arise in uncultivated fields which contain cruciferous weeds and volunteer rape and commercial mustards. The present studies showed that rape, the three commercial mustards, and three cruciferous weeds, Er. gallicum, S. arvensis and C. bursa-pastoris, are suitable host plants for red turnip beetle larvae and confirmed Gerber's observations on the importance of these plants in supporting field populations of this beetle. Since some of the larvae developed successfully on D. sophia, Sy. loeselii and B. nigra, it is obvious that these three cruciferous weeds also could be sources of food for the red turnip beetle, especially when suitable hosts are absent or in low supply.

In the Prairie Provinces, the eggs of the red turnip beetle hatch in late April and early May, usually before the growers have planted rape and commercial mustards (Gerber 1974, 1975, unpublished). It is clear, therefore, that an important element of the pest management system for the red turnip beetle should be the elimination of cruciferous weeds and of volunteer rape and commercial mustards by cultivation or with chemical herbicides. Since the larvae can travel only

relatively short distances, the cruciferous weeds and volunteer rape and commercial mustards should be eliminated early in the season in order to prevent population buildup and to eliminate the possibility of larvae and (or) new adults invading new rape and mustard fields.

One of the major objectives of the rapeseed breeding program has been the development of cultivars low in glucosinolates in the seeds (Stefansson 1975; Downey et al. 1975). Since the present studies showed that the rape cultivars which are low in glucosinolates are not nutritionally superior as food for red turnip beetle larvae than those which are normal in glucosinolates, larger numbers of larvae of this beetle should not be expected to survive on the new low glucosinolate cultivars (Candle, Tower, Regent and Altex) than on the cultivars grown previously (Midas, Torch, Target, Echo, etc.).

6. CONCLUSIONS

The principal findings of the present studies are as follows:

1. The red turnip beetle has four larval instars, a pupal stage and an adult stage. The growth curve for the larval stage is S-shaped.

2. B. campestris and B. napus are suitable host plants for red turnip beetle larvae.

3. In B. campestris and B. napus, the cotyledon stage is nutritionally superior to the first true leaves for larvae of the red turnip beetle.

4. B. juncea and B. hirta are suitable host plants for red turnip beetle larvae. B. juncea seems to be nutritionally as suitable as B. campestris, but B. hirta appears to be marginally inferior to B. campestris.

5. Er. gallicum, S. arvensis and C. bursa-pastoris are suitable host plants for red turnip beetle larvae and seem to be nutritionally as suitable as B. campestris.

6. D. sophia, Sy. loeselii and B. nigra are marginally suitable as food for red turnip beetle larvae.

7. T. arvense is a nonhost plant of the larvae of the red turnip beetle.

In the present studies, almost all the plants tested supported growth and development in red turnip beetle larvae. Since red turnip beetle infestations usually arise in uncultivated fields which contain cruciferous weeds and volunteer rape and commercial mustards, elimination of these

plants by cultivation or with chemical herbicides should be an important element of the pest management system for the beetle.

Since the present studies also showed that rape cultivars which are low in glucosinolates are not nutritionally superior as food for red turnip beetle larvae than those which are normal in glucosinolates, larger numbers of larvae of this beetle should not be expected to survive on the new low glucosinolate cultivars than on those grown previously.

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Appendix 1. Taxonomic relationship of the cruciferous plants used in the feeding experiments for the larvae of *Entomoscelis americana* (Hedge 1976).

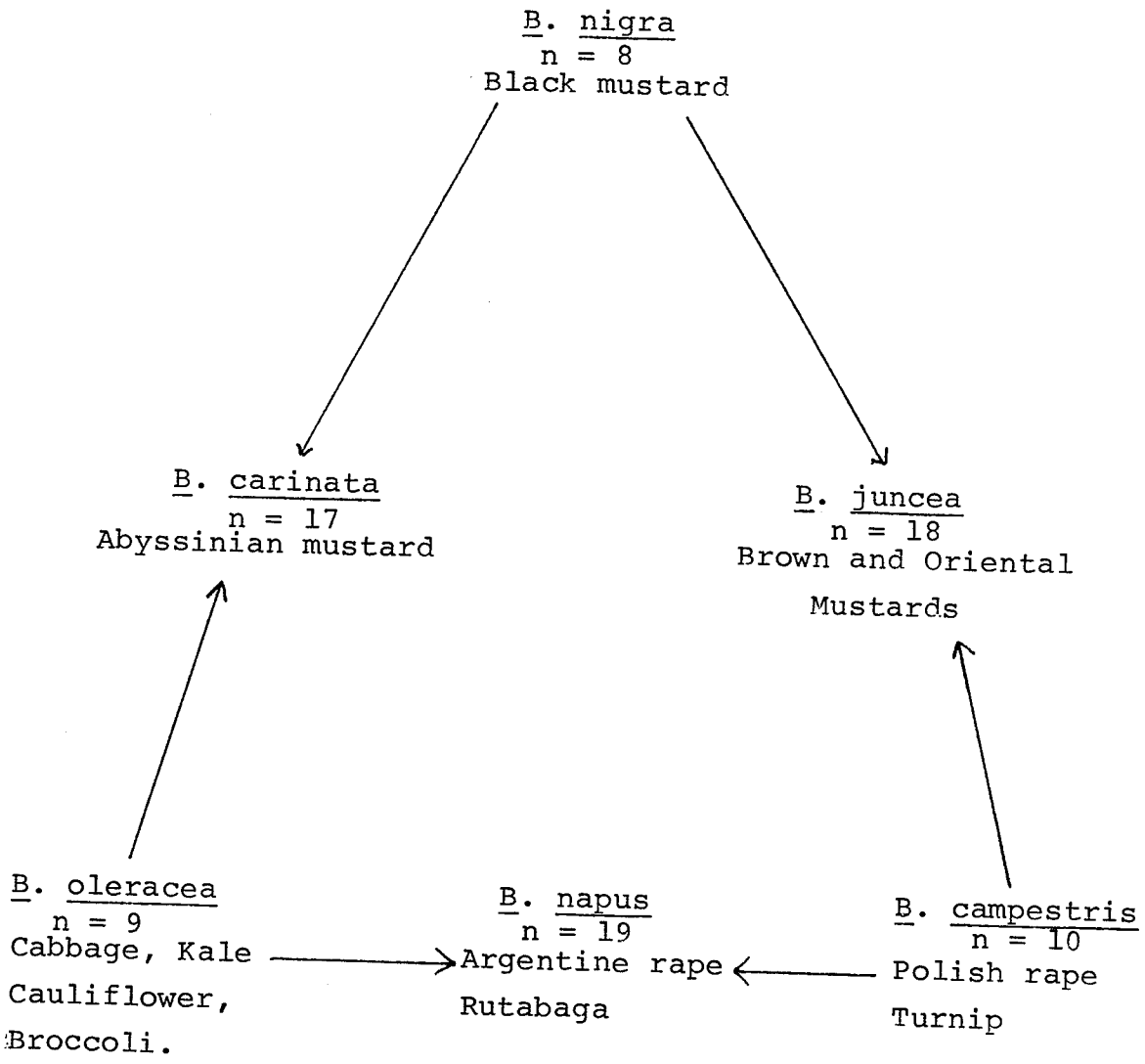
Species	Tribe	Subtribe	Common Name*
Sisymbrium loeselii	Sisymbrieae	Sisymbriinae	Tall hedge mustard
Descurainia sophia	Sisymbrieae	Descurainiinae	Flixweed
Capsella bursa-pastoris	Lepidieae	Capsellinae	Shepherd's purse
Thlaspi arvense	Lepidieae	Thlaspidinae	Stinkweed
Brassica campestris	Brassiceae	Brassicinae	Turnip rape (Echo, Torch, Candle, R500)
B. napus	Brassiceae	Brassicinae	Rape (Target, Midas, Tower Regent)
B. juncea	Brassiceae	Brassicinae	1. Brown mustard (Blaze) 2. Oriental mustard (Lethbridge 22A)

Appendix 1. (cont.)

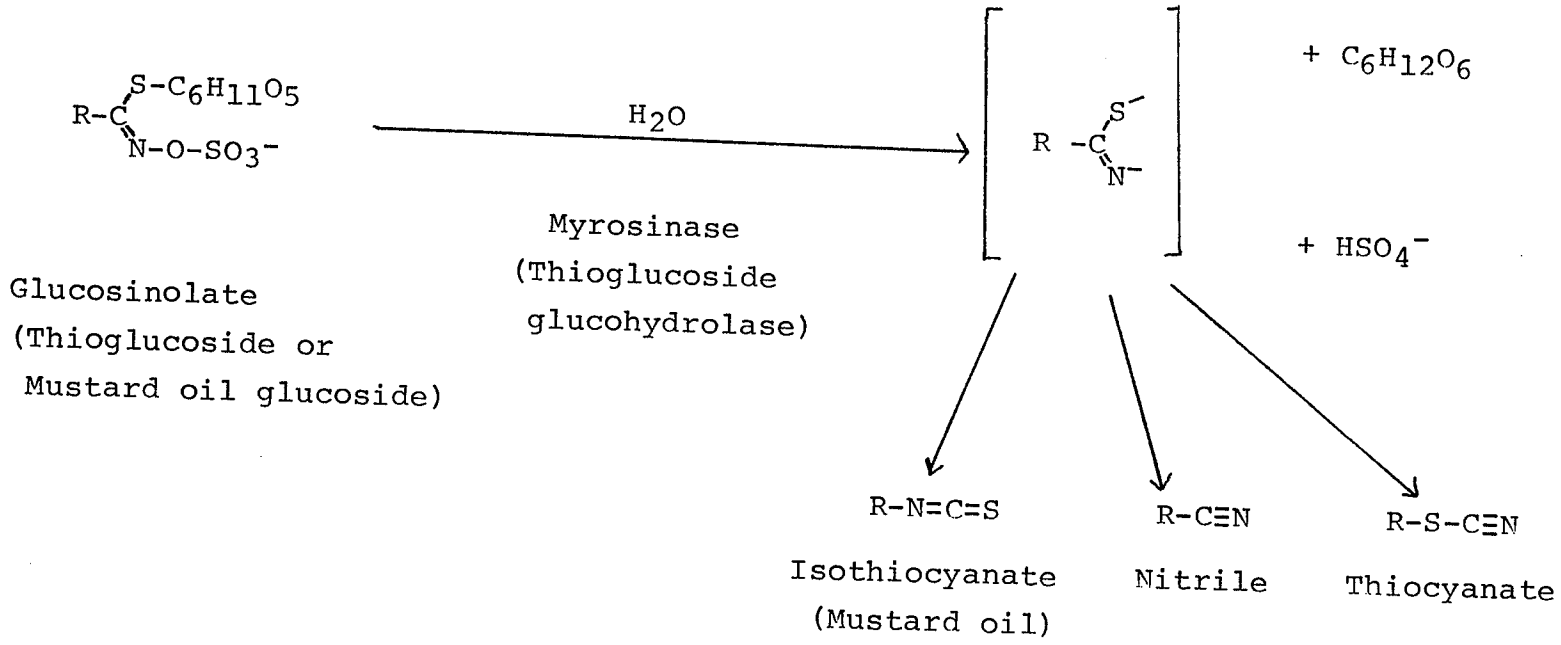
Species	Tribe	Subtribe	Common Name*
B. hirta	Brassiceae	Brassicinae	Yellow mustard (Gisilba)
B. nigra	Brassiceae	Brassicinae	Black mustard
Sinapis arvensis	Brassiceae	Brassicinae	Wild Mustard
Erucastrum gallicum	Brassiceae	Brassicinae	Dog mustard

*The names of the cultivars of each species are in parenthesis.

Appendix 2. Taxonomic relationship of the Brassica species used in the feeding experiments for the larvae of Entomoscelis americana (Downey et al. 1975).



Appendix 3. Structural formula and enzymatic hydrolysis products of glucosinolates (Ettlinger and Kjaer 1968).



Appendix 4. Total glucosinolate and erucic acid content in the seed of the cultivars of *Brassica napus* L., *B. campestris* L., *B. juncea* (L.) Coss. and, *B. hirta* Moench tested in the feeding experiments with larvae of *Entomoscelis americana* (Canada Committee on Grain Quality 1976, 1977).*

Cultivar	Total glucosinolate mg/gm of oil free meal**		Erucic acid (22:1) (%)	
	1976	1977	1976	1977
B. napus				
Target	12.5	11.4	43.1	36.5
Midas	14.1	11.5	0.8	0.5
Tower	2.1	1.1	0.9	0.5
Regent	2.3	1.3	1.9	0.5
B. campestris				
R500	11.8	9.5	55.8	58.6
Echo	8.8	7.1	21.7	20.9
Torch	8.1	7.0	1.2	4.8
Candle	0.5	0.8	1.5	3.2
B. juncea				
Blaze (Brown mustard)	9.3	10.0	22.8	25.6
Lethbridge (Oriental mustard)	9.9	10.5	23.7	24.0
B. hirta				
Gisilba (Yellow mustard)	-***	31.3	31.8	35.7

Appendix 4. (Cont.)

*Values represent averages of the data available.

**Total glucosinolate content in rapeseed is expressed as mg. of 3-butenylisothiocyanate per gm. of oil-free meal.

Total glucosinolate content in Brown and Oriental mustard is expressed as mg. of allylisothiocyanate per gm. of oil-free meal.

Total glucosinolate content in Yellow mustard is expressed as mg. of para-hydroxybenzylisothiocyanate per gm. of oil-free meal.

***No data available in 1976 for Yellow mustard. Only one datum available in 1977 for Yellow mustard.