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ORIGINAL ARTICLE

Suitability of Amaranthaceae and Polygonaceae species as food source for the sugar beet weevil *Asproparthenis punctiventris* Germar

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Abstract

This study explores the food plant spectrum of the sugar beet weevil (*Asproparthenis punctiventris* Germar; Coleoptera: Curculionidae), one of the most important pests of sugar beet (*Beta vulgaris* subsp. *vulgaris* Altissima group). It examines the potential of various weeds and other plants to maintain populations of *A. punctiventris* adults and larvae outside sugar beet fields. To this end, leaf consumption of females and males on twelve Amaranthaceae and six Polygonaceae species was compared over a 24-h period in a laboratory environment. Both sexes consumed the greatest amount of leaf mass from Beta spp. and on average about a third less from Atriplex spp., indicating that these plants have the highest nutritional value for *A. punctiventris*. Weevils consumed between 30 and 60% of the amount of *A. retroflexus* and Chenopodium spp. than they fed on sugar beet leaves. Like *Spinacia oleracea* (Amaranthaceae), plant species of the Polygonaceae family were hardly or not at all fed on. Mated females generally consumed more leaf mass than unmated, especially from Chenopodium spp. and *A. retroflexus*, i.e. plants with low feeding value. Experiments with potted plants revealed that the most and heaviest 4th instar larvae developed on sugar beet, while fewer individuals with lesser weight were found on *B. vulgaris* subsp. *maritima* and *A. hortensis*. Very few larvae were able to develop on *C. album*, and none on *A. retroflexus*. To prevent promotion of pest population, special attention should be paid to the control of weeds from the Amaranthaceae family in sugar beet growing areas.

Keywords *Bothynoderes punctiventris* · Host plant spectrum · Leaf consumption · Feeding rate · Larval development

Introduction

The sugar beet weevil (*Asproparthenis punctiventris* Germar; Coleoptera: Curculionidae) is a pest of sugar beet (*Beta vulgaris* subsp. *vulgaris* Altissima group). It is widely distributed in Eurasia (EPPO Global Database 2022), in south-eastern Europe and in Turkey (Eckstein 1936; Sivcev et al. 2006; Drmic 2016).

The main damage to sugar beet is caused by adult weevils, shortly after leaving their overwintering sites in the soil. During maturation feeding they feed on sugar beet seedlings or young plants, destroying them in the process. The economic threshold is 0.1–0.3 individuals/m^2 for seedlings (Camprag et al. 2006). Periodical outbreaks of this pest species have been described in Saxony-Anhalt in central Germany in the middle of the twentieth century (Eichler and Schrödter 1951; Tielecke 1952). In the sugar beet growing areas of eastern Austria, mass occurrences of the sugar beet weevil have been recorded between 2002 and 2005 (Haluschan and Bindreiter 2006) and again between 2017 and 2020, causing severe damage to sugar beet crops (Wechselberger 2020). In 2018, about a quarter of the total Austrian area under sugar beet was lost to this pest (Anonymus 2019). The region´s climate shows a marked trend towards perennial dry phases and high spring temperatures (Eitzinger et al. 2009), which favours the development of large

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populations of this pest (Haluschan and Bindreiter 2006) and its spread to Central Europe (Klukowski and Piszcek 2021).

At the same time, a lack of effective insecticides makes the control exceptionally difficult. Seed treatments with neonicotinoids used to give satisfactory protection due to their systemic activity during the most sensitive stages of sugar beet plant development, at least in years with low weevil population densities. Lately their use in the field was banned by the European Commission because of their risk to bees (Wechselberger 2020; Viric Gasparic et al. 2021). Drmic et al. (2017) tested the practicability of mass trapping with a pheromone-based attractant in traps. Although this approach succeeded in reducing pest populations, the authors concluded that trapping as an isolated measure is not efficient enough to replace chemical control of the sugar beet weevil. Other alternative measures such as the use of entomopathogenic nematodes as natural enemies for biological control of *A. punctiventris* have not yet been investigated sufficiently and are not available in practice (Sursuluk 2008; Drmic et al. 2020).

The sugar beet weevil is described as an insect with an oligophagous feeding pattern (Drmic 2016). Almost all plants on which, according to the literature, adult weevils feed, belong to the families Amaranthaceae and Polygonaceae. The list includes plant species closely related to sugar beet, but also many common weeds in sugar beet crops and various other species from related plant genera (Tielecke 1952; Müller 1957; Auersch 1961a; Brendler et al. 2008). The available information is partly contradictory, mainly based on observations and—with the exception of sugar beet—does not provide quantifying data on the feeding of the sugar beet weevil on these plants. The same applies to information about plants on which larval development is possible. There are reports of larvae found on roots of various weeds in sugar beet crops (Camprag 1984; Klapal et al. 2004; Bindreiter 2005), but no results from detailed investigations are available yet.

In this context, it is particularly important to identify plants and, especially weeds that can serve as an alternative food source for the sugar beet weevil. These plants could contribute to maintaining the pest population, especially during periods when sugar beet is not cultivated. Furthermore, according to Auersch (1961a), the availability of suitable plants as food sources from the very beginning of the maturation feeding has a crucial influence on the oviposition rate of *A. punctiventris* females. If feeding is delayed, the maturation period is prolonged and the total number of eggs laid decreases, leading to a reduction in the population. However, it is not known how much leaf mass the weevils consume from potential food plants during maturation feeding, and how much the females consume after mating during oviposition.

Therefore, the aim of the present study was (1) to directly compare the leaf consumption of *A. punctiventris* females and males on sugar beet with other potential food plants from the Amaranthaceae and Polygonaceae families, (2) to compare leaf consumption of unmated and mated females and (3) to investigate larval development on selected plants that are fed on by adults.

Materials and methods

Insects

In April and May 2020 and 2021, *A. punctiventris* adults were collected shortly after emergence from their overwintering sites in the soil of winter wheat fields (previous year´s sugar beet fields that had been infested with sugar beet weevils) from different locations in the Tullnerfeld region in Lower Austria. The insects were captured using pitfall traps (Csalomon®, Plant Protection Institute, Centre for Agricultural Research, HAS, Budapest, Hungary) baited with the aggregation attractant Grandlure III-IV (Bedoukian Research Inc., Danbury, CT, USA).

In the laboratory, the weevils were kept under artificial hibernation conditions at 5 ± 1 °C and of $80 \pm 5\%$ relative humidity in the dark. Twenty-four to 72 h prior to the experiments the individuals were sexed and females and males of mixed sizes were kept separately in plastic boxes with a bottom layer of coarse quartz sand in a climate chamber at 15 ± 1 °C, $78 \pm 5\%$ relative humidity and a 14:10 h (L:D) photoperiod. The weevils were fed with sugar beet leaves.

Plants

The plant species tested as food plants and for larval development of *A. punctiventris* are shown in Table 1.

All plants were raised from seeds and grown in pots of $6.5 \times 6.5 \times 9$ cm in a substrate mixture of peat: quartz sand: expanded clay in a proportion of 2:1:1. They were cultivated in a walk-in climate chamber or in the greenhouse, depending on their temperature requirements, and regularly watered with tap water without fertilizer.

Plants for testing the leaf consumption of the weevils were grown in groups to a weight (0.05–0.18 g, depending on the species) corresponding to a sugar beet leaf at BBCH 12-14. *Beta vulgaris* subsp. *vulgaris* Altissima group, *B.* subsp. *maritima, Atriplex hortensis, Chenopodium album and Amaranthus retroflexus* plants for the experiments on the larval development of *A. punctiventris* were pricked after germination and initial growth and potted singly in pots of $6.5 \times 6.5 \times 9$ cm filled with the substrate described above. Depending on the different germination times of the individual species, they were grown

Table 1 Amaranthaceae and Polygonaceae species tested as food plants of *A. punctiventris*

Plant family/species	Common name(s)/cultivar	Source/origin
Amaranthaceae		
Amaranthus retroflexus L	Common amaranth, redroot pigweed	Staphyt Austria GmbH, Austria
Atriplex hortensis L	Garden orache	Magic Garden Seeds GmbH, Germany
Atriplex patula L	Common orache	Field collection (Essling), Institute of Plant Protection, BOKU Vienna, Austria
Beta vulgaris L. subsp. *vulgaris* Altissima group	Sugar beet cv. Blandina	KWS Austria Saat GmbH, Austria
Beta vulgaris L. subsp. *vulgaris* Cicla group	Chard cv. Lucullus	Floraself, Hornbach Baumarkt AG, Germany
Beta vulgaris L. subsp. *vulgaris* Conditiva group	Red beetroot cv. Rote Kugel 2	Austrosaat, Österreichische Samenzucht- u. Handels-Aktiengesellschaft, Austria
Beta vulgaris L. subsp. *maritima*	Sea beet	Magic Garden Seeds GmbH, Germany
Chenopodium album L	Fat hen	Staphyt Austria GmbH, Austria
Chenopodium bonus-henricus L	Good king henry	Magic Garden Seeds GmbH, Germany
Chenopodium foliosum Asch	Strawberry blite	Austrosaat, Österreichische Samenzucht- u. Handels-Aktiengesellschaft, Austria
Chenopodium hybridum L	Maple-leaved goosefoot	Arbiotech, France
Spinacia oleracea L	Spinach	Austrosaat, Österreichische Samenzucht- u. Handels-Aktiengesellschaft, Austria
Polygonaceae		
Fagopyrum esculentum M	Buckwheat	Reinsaat KG, Austria
Fallopia convolvulus L	Black bindweed	Arbiotech, France
Persicaria lapathifolia L	Pale smartweed	Arbiotech, France
Persicaria maculosa Gray	Redshank	Appels wilde Samen GmbH, Germany
Polygonum aviculare L	Knotgrass	Arbiotech, France
Rumex obtusifolius L	Broad-leaved dock	Field collection (Irdning), Institut für Pflanzenbau und Kulturlandschaft, HBLFA Raumberg-Gumpenstein, Austria

for 10 to 24 weeks after sowing to develop sufficient leaf and root mass.

Leaf consumption of unmated sugar beet weevils

A leaf of a test plant was weighed and placed on slightly moistened filter paper in a glass Petri dish (9 cm diameter). A single unmated *A. punctiventris* male or female that had not previously starved was added. Petri dishes with leaves but without weevils served as controls. The Petri dishes were stored in a climate chamber at 20 ± 1 °C, 83,5 ± 5% relative humidity and a 14:10 h (L:D) photoperiod. After 24 h, the weevils were taken out and the leaves were weighed again. In order to take the water loss of the leaves into account, leaves of the respective test plant without weevils were placed in Petri dishes on moist filter paper for 24 h as a control. The bioassay was replicated with 31–55 females and males and with as many controls per test plant species. Leaf consumption was calculated using the formula according to Nagasawa and Matsuda (2005):

$$E = T - T'C/C'$$

E = leaf consumption, T = weight of the leaf in the beginning, T' = weight of the leaf after 24 h, C = average weight of the control leaves in the beginning, C' = average weight of the control leaves after 24 h.

Leaf consumption of mated females

About 200 female and male weevils were kept together in plastic boxes filled with a 2 cm layer of peat substrate in a climate chamber at 28 ± 2 °C, 58 ± 3% relative humidity and a photoperiod of 14:10 h (L: D). According to Steiner (1936), the pre-oviposition period of the females at about 28 °C lasts approximately 40 days. Therefore, the beetles were fed daily with sugar beet leaves for 5 to 6 weeks to ensure that all females had mated and were in the oviposition period. Leaf consumption of mated females on selected test plants was determined in the same way as described above. The bioassay was replicated with 33–50 mated females and with as many controls per plant species.

Larval development on potted plants

The mated *A. punctiventris* females laid their eggs in the peat substrate in the plastic boxes. They were transferred together with males into fresh plastic boxes with substrate 1 to 2 times a week and the substrate with the eggs was placed on wire mesh sieves (hole size 1.9 mm). The sieves were stored at room temperature for 2 weeks to allow the larvae to hatch. Due to their positive geotaxis (Auersch 1961b), the first instar larvae (L1) migrated downwards with the gravity stimulus, and could be collected from a tray below the sieves. Three L1 were placed with a brush on the substrate surface of each potted *B. vulgaris* subsp. *vulgaris* Altissima group, *B. vulgaris* subsp. *maritima*, *A. hortensis*, *C. album* or *A. retroflexus* plant. After the larvae had burrowed into the substrate, the plants were kept at 21 ± 2 °C, 46 ± 5% relative humidity and a 14:10 h (L: D) photoperiod in a climate chamber. All plants were regularly watered from above as needed. After 42 days, the roots were searched for larvae and all larvae found alive were weighed. According to Tielecke (1952) and preliminary experiments, the larvae on sugar beet roots are in the 4th instar after 42 days but have not yet pupated, which allows a comparison with the development of larvae on other plants. The bioassay was replicated with 20–25 plants per species. Plants that had died before the 42-day period had ended and all larvae found in the soil of these plants were excluded from the experiment.

Statistical analysis

Statistical analyses were conducted using the statistical software R (R Development Core Team 2021). The effects of weevil sex and plant species as well as the effects of mating status and plant species on leaf consumption were analysed separately for Amaranthaceae and Polygonaceae. Linear models containing main effects and interactions were analysed using the package for general factorial designs (GFD) (Friedrich et al. 2017) due to non-normal error terms and/or heteroscedastic variances, and the *p*-values generated from the permuted version of the Wald-type statistics (WTPS) were used. To detail plant species effects, the data were pairwise compared by Tukey contrast tests, where needed. These tests were performed using the nparcomp package (Konietschke et al. 2015). The figures were either created using SigmaPlot 14.0 (Systat Software GmbH, Palo Alto, California) or the R package lattice (Sarkar 2008).

Results

Overall analysis of the leaf consumption of *A. punctiventris* adults on Amaranthaceae species indicated significant main effects for plant species (nonparametric ANOVA, test statistic = 955,90, $df = 11$, p-value WTPS < 0.0001) and sex of the weevils (test statistic = 22,55, $df = 1$, p-value WTPS < 0.0001), and a significant interaction between plant species and sex of the weevils (test statistic = 37,32, $df = 11$, p-value WTPS < 0.0001) (Fig. 1).

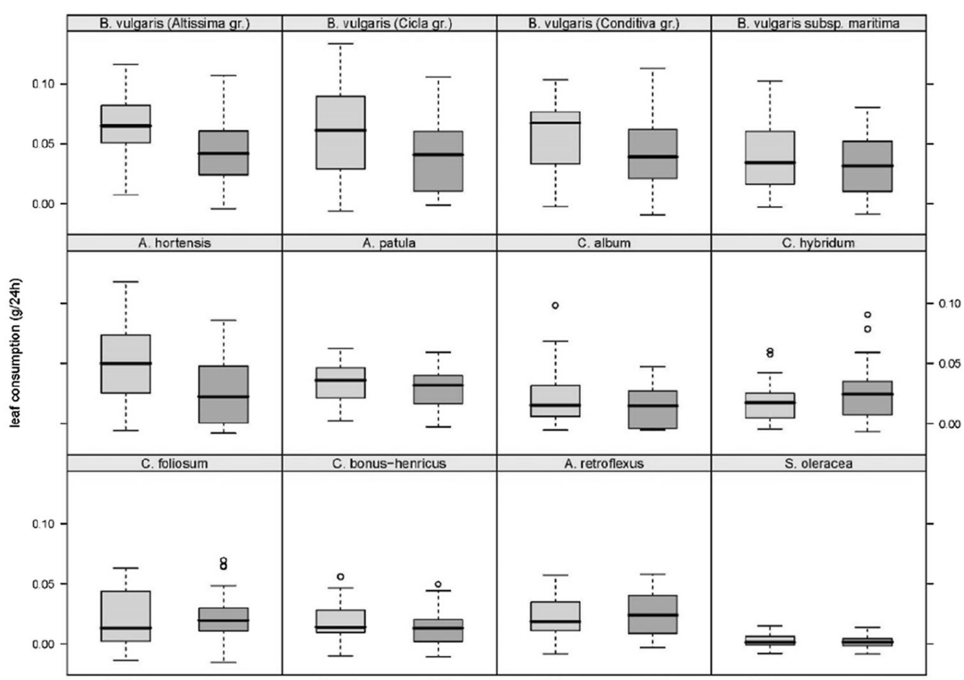


Fig. 1 Boxplots comparing the leaf consumption (in g) of unmated female and male sugar beet weevils of different plant species from the Amaranthaceae family in 24 h. In all panels the line within the box shows the median, while the boxes and the whiskers represent the percentiles 10, 25, 75 and 90 of the data

In general, both females and males consumed the greatest amount of leaf mass from sugar beet (*B. vulgaris* subsp. *vulgaris* Altissima group) compared to all other plants tested. Irrespective of sex, the consumption of leaves of Beta and Atriplex species was higher than that of Chenopodium species, *A. retroflexus* or *S. oleracea*.

In all Beta and Atriplex species, females consumed greater amounts of leaf tissue than males, while the pattern was inconsistent in Chenopodium species, *A. retroflexus* and *S. oleracea*. Consumption of leaves of *C. foliosum*, *C. hybridum*, and *A. retroflexus* tended to be slightly higher in males than in females.

The Polygonaceae species, but not the sex influenced the leaf consumption of the weevils (nonparametric ANOVA; factor plant species: test statistic = 24,09, $df = 5$, p-value WTPS = 0.0007; factor sex: test statistic = 0,63, $df = 1$, p-value WTPS = 0,43; interaction: test statistic = 1,73, $df = 5$, p-value WTPS = 0,89) (Fig. 2). Pooled over sex, a Tukey post-hoc analysis revealed that adult weevils fed significantly more on the leaves of *F. convolvulus*, *R. obtusifolius*, *P. lapathifolia* and *P. aviculare* than on the leaves of *P. maculosa*. There was no significant difference in leaf mass fed between *F. esculentum* and *P. maculosa*.

The plant species, the mating status and their interaction influenced the leaf consumption of female weevils (nonparametric ANOVA; factor plant species: test statistic = 1669,84, $df = 8$, p-value WTPS < 0.0001; factor mating status: test statistic = 57,29, $df = 1$, p-value WTPS < 0.0001; interaction: test statistic = 69,88, $df = 8$, p-value WTPS < 0.0001) (Fig. 3). Mated females tended to consume more leaf mass from Amaranthaceae species than unmated females (Figs. 1, 3). Irrespective of mating status, female weevils fed least on *P. maculosa*.

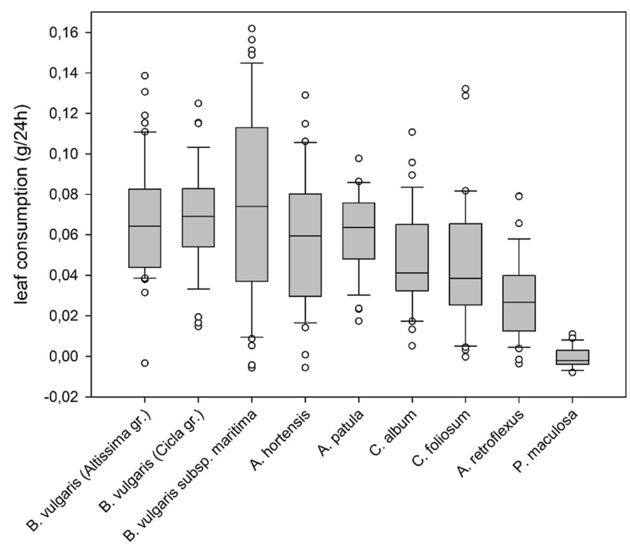
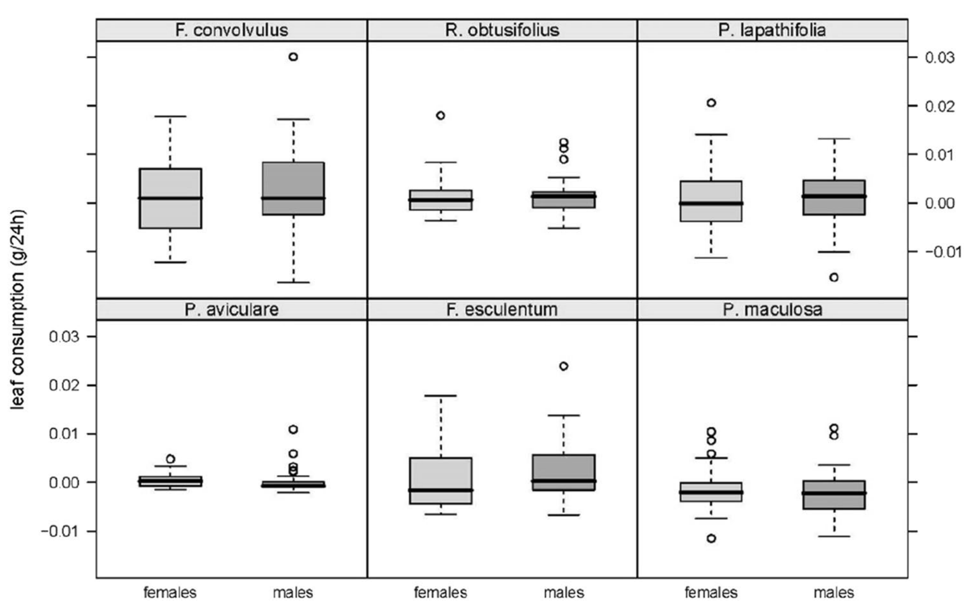


Fig. 3 Boxplots comparing the leaf consumption (in g) of mated female sugar beet weevils on different plant species in 24 h. The line within the box shows the median, while the boxes and the whiskers represent the percentiles 10, 25, 75 and 90 of the data

The plant species on which the *A. punctiventris* larvae had developed to the 4th instar significantly affected their weight (one-way ANOVA; $F = 4{,}69$, $df = 3, 58$, $p = 0{,}0054$) (Fig. 4). While not a single larva had developed to the 4^{th} instar on *A. retroflexus*, 27 larvae developed on sugar beet, 16 on *B. vulgaris* subsp. *maritima*, 12 on *A. hortensis* and 7 on *C. album*. The larvae on sugar beet and *B. vulgaris* subsp. *maritima* had significantly more weight than those that developed on *C. album*. There was no significant

Fig. 2 Boxplots comparing the leaf consumption (in g) of unmated female and male sugar beet weevil of different plant species from the Polygonaceae family in 24 h. In all panels the line within the box shows the median, while the boxes and the whiskers represent the percentiles 10, 25, 75 and 90 of the data



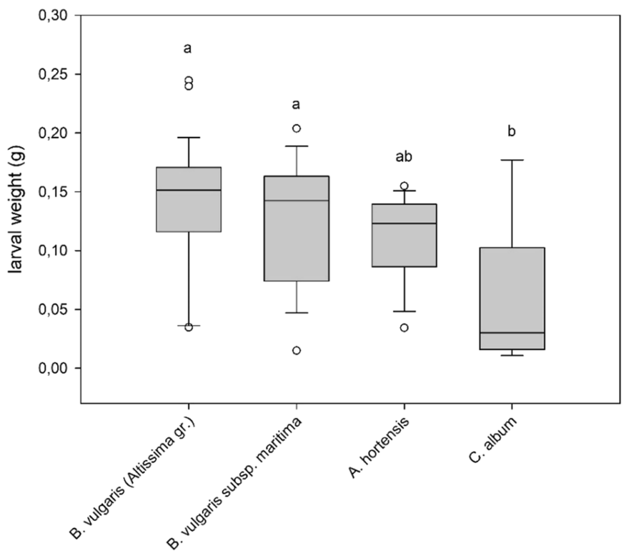


Fig. 4 Boxplots comparing the larval weight of *A. punctiventris* larvae (in g) after 42 days development on different plant species. Number of larvae found on *B. vulgaris* subsp. *vulgaris*, $n=27$; number of larvae found on *B. vulgaris* subsp. *maritima*, $n=16$; number of larvae found on *A. hortensis*, $n=12$; number of larvae found on *C. album*, $n=7$. The line within the box shows the median, while the boxes and the whiskers represent the percentiles 10, 25, 75 and 90 of the data. The small letters indicate the differences in the plant species

difference in weight between the larvae of *A. hortensis* and all other plants tested.

Discussion

This study focuses on the leaf consumption and larval development of *A. punctiventris* on sugar beet, drawing for the first time direct comparisons with plant species from the Amaranthaceae and the Polygonaceae family that have been described as food sources in the literature. We found that the adult weevils consumed the largest amounts of leaf mass from *B. vulgaris* subsp. *vulgaris*, with no difference between sugar beet, chard, and beetroot. Sea beet (*B. vulgaris* subsp. *maritima*) is very closely related to these plant species but was fed on somewhat less, confirming Auersch's (1961a) observations. Atriplex species are described as plants with a high feeding value (Auersch 1961a). This is largely consistent with our findings that sugar beet weevils consumed on average about 30% less leaf mass from *A. hortensis* or *A. patula* than from sugar beet. Similarly, the most and heaviest 4th instar larvae developed on sugar beet, while fewer and somewhat lighter individuals were found on *B. vulgaris* subsp. *maritima* and *A. hortensis*. To our knowledge, this is the first report that the sugar beet weevil can also develop on *B. vulgaris* subsp. *maritima* and *A. hortensis*.

Atriplex patula, but also *C. album*, *C. hybridum* as well as *A. retroflexus* are among the most widespread weeds in sugar beet cultivation. These weeds are difficult to control, occurring in high densities, not only in sugar beet but also in other crops (e.g. Holzner 1981; Holzner and Glauninger 2005; Brendler 2008; Cioni und Maines 2010; Leithner and Glauninger 2013; Stöckl 2018; Bhadra 2020). Chenopodium spp. and *A. retroflexus* have been described as food plants for *A. punctiventris* (e.g. Tielecke 1952; Auersch 1961a). In the present study, a leaf consumption comparison revealed that both sexes of unmated sugar beet weevils consume between 30 and 60% of the amount of Chenopodium spp. and *A. retroflexus* than they feed on sugar beet leaves. Even though these plants have a lower feeding value (Auersch 1961a), they could be part of a mixed diet. Drmic (2016) suggested that a diet of sugar beet and Chenopodium species leads to higher oviposition rate in females than a diet of sugar beet leaves only. Taranuha (1956) observed that female sugar beet weevils laid about the same amount of eggs when fed with sugar beet or *C. album*, but fewer eggs when fed only *A. retroflexus*. According to observations made by Klapal et al. (2004) and Bindreiter (2005) larvae feed on the roots of *A. retroflexus* in sugar beet fields. While a few light-weight larvae had developed on *C. album*, not a single larva developed to the 4th instar on our potted *A. retroflexus* plants. In the field, larvae of Curculionid species on plant roots can be difficult to distinguish, as Klapal et al. (2004) also noted that the larvae found could not be identified more precisely. Identifying the immature stages of soil-living Curculionidae requires knowledge and experience (Gosik et al. 2016; Skuhrovec et al. 2019). However, sugar beet weevil larvae can orientate themselves by chemotactic stimuli of the root exudates and actively migrate to the plant roots (Auersch 1961b). In a weed-infested sugar beet field, the larvae could therefore also be found on the roots of weeds.

Spinacia oleracea is described as another food plant for *A. punctiventris* (Tielecke 1952), and was suggested to be utilized as trap crop in the field (Bindreiter 2005). In our experiments, adult weevils did hardly accept spinach for feeding, which could be due to phytoecdysteroids contained in spinach leaves. Spinach is among the plants with the highest content of these substances (Grebenok et al. 1994; Al Naggar et al. 2017), which have previously been found to deter feeding of several Coleopteran species (Jurenka et al. 2017).

The present study found other plants on which female and male weevils fed little or not at all in the Polygonaceae plant family. This contradicts descriptions of Tielecke (1952) and Müller (1957), which mentioned *P. aviculare* as a food plant of *A. punctiventris.* Also Auersch (1961a) did not observe any feeding on this plant in the laboratory and suggested that the information on the suitability of Polyonaceae and *S. oleracea* as food plants might be due to confusion with related weevil species (e.g. *Cleonis pigra* or *Tanymecus palliatus*). However, Polygonaceous plants such as *F. convolvulus*, *P. lapathifolia*, *P. maculosa* and *P. aviculare* often occur as competitive weeds in sugar beet, requiring immediate control measures (e.g. Brendler et al. 2008; Cioni und Maines 2010; Bhadra 2020). Recently, also Rumex spp. and *F. esculentum* were found in weedy sugar beet fields (Geyer and Kempl 2019). Since unmated female or male *A. punctiventris* did not accept one of these plants as food, it seems unlikely that larvae can develop on their roots. Our experiments with mated females and *P. maculosa* further contribute to this assumption.

We investigated for the first time differences in leaf consumption patterns between unmated females during maturation feeding and mated females during their egg-laying period. Mated females generally consumed more leaf mass than unmated, especially from Chenopodium species and *A. retroflexus*, i.e. plants with a lower feeding value than Beta spp. and Atriplex species (Auersch 1961a), especially when no alternative was available. Berner et al. (2005) discussed this phenomenon for the grasshopper species *Omocestus viridulus* L. that consume more leaf mass from low quality grass to compensate their needs for water and nutrition. Another explanation might be that a mixed diet could lead to higher egg production, as described in Drmic (2016) for the sugar beet weevil, in Mody et al. (2007) for the specialist herbivorous caterpillar of the moth *Chrysopsyche imparilis* Aurivillius and in Unsicker et al. (2008) for the generalist grasshopper *Chorthippus parallelus* Zetterstedt. In any case, the energy requirements of females during oviposition may be increased, as has been shown for *Callosobruchus chinensis* L. (Yanagi and Miyatake 2003).

A comparison of leaf consumption of unmated females and unmated males during maturation feeding shows that females consumed more than males only of Beta and Atriplex species, but not of low nutritional value plants such as *P. maculosa*. Gromova (1965) also found that *A. punctiventris* females consume 25% more sugar beet leaf mass than males.

In summary, the present study shows that widespread weeds such as *A. patula* and *C. album*, which occur in high densities in sugar beet and other crops, can serve as alternative food source for *A. punctiventris* in the absence of sugar beet. Whether, and to what extent, they promote female fertility and reproduction as a sole food source or in a mixed diet—as Camprag (1984) and Drmic (2016) suggested—presents a topic for further research. Larvae can also develop on some weeds of the plant family Amaranthaceae, although to a lesser extent than on sugar beet. Therefore, as they can contribute to the maintenance of *A. punctiventris* populations outside sugar beet fields, special attention should be paid to the control of these weeds in sugar beet growing areas.

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Declarations

Conflict of interest The authors declare that they disclose financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Ethics approval All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

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