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Review

Topographical Based Significance of Sap-Sucking Heteropteran in European Wheat Cultivations: A Systematic Review

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Abstract: Sap sucking heteropteran cereal bugs—members of the *Eurygaster* and *Aelia* genus—are serious pests of wheat. Moreover, they feed on a variety of gramineous plant species, including rye, barley, oat, maize, and millet. They are widely distributed in the European continent. The purpose of this review paper is two-fold; it summarizes the currently available data on the biological characteristics, the inflicted damage, and their European distribution and, in addition, we aimed to determine their economic importance, based on data available in the current literature. For the most important cereal bug species, we have collected data on their occurrence in Europe to provide a comprehensive picture of their distribution, and characterized them according to their temperature requirements at different life stages. We have also determined the degree of their attachment to wheat as their host plant, examining the synchronization between the pests and the life cycle of the plant. Finally, we compared their migration characteristics. All the above-mentioned characteristics were merged, in order to assess and rank the damage potential of each species.

Keywords: cereal bugs; damage; distribution; Hemiptera; ranking of damage potential

Citation: Gibicsár, S.; Keszthelyi, S. Topographical Based Significance of Sap-Sucking Heteropteran in European Wheat Cultivations: A Systematic Review. *Diversity* **2023**, *15*, 109. https://doi.org/10.3390/d15010109

Academic Editor: Michael Wink

Received: 2 December 2022
Revised: 6 January 2023
Accepted: 10 January 2023
Published: 13 January 2023

1. Introduction

Cereals are the edible seeds of grains of the Poaceae family. Wheat is one of the most important crops of the world's cereal production, and as a staple food it is an important source of nutrients in both developed and developing countries. Cereals were termed the most important sources of food as they are the major source of energy, protein, vitamins and minerals on a daily basis [1].

Heteroptera (true bugs) is a large sub-order of the Hemiptera order, having over 45,000 species in almost 90 families. It is considered one of the largest groups of non-holometabolous insects. The heteropterans can be found in various habitats, including aquatic, marine, and terrestrial ones. Their feeding preferences vary; phytophagous, zoophagous, and hematophagous species may also be found [2]. Heteropteran cereal bugs are dangerous pests of wheat, widely distributed in the European continent [3–5], and capable of causing significant yield loss in wheat and other cereals [6,7]. These damages may not only manifest in the reductions of actual yields, but in germination capacity as well [4]. During feeding, the enzymes of the sap-sucking heteropterans' salvia predigest endosperm and destroy gluten [8–10], leading to decreased baking quality [11,12].

Only a few studies and summary articles have been published on this subject in the last 20 years. The vast majority of these articles report yield losses and damage potential based on data related to *Eurygaster integriceps* (Puton, 1881), while the number of publications related to *Eurygaster austriaca* (Schrank, 1778) and *Aelia* species is particularly low.

The relevant literature is inconsistent in terms of biological characteristics and damage, with substantial differences in the reported values. The present communication plans to fill this gap in the literature, allowing a better understanding of their damage potentials. In this context, the aim of the present work was to study the significance of sap-sucking heteropteran pests based on the referred bibliographical sources. In addition, the objectives of our review study were to provide summarizing data in connection with determinative cereal pests, highlighting the morphological, physiological and topographical properties and economic significance, and to develop an objective system for comparing and evaluating species.

This may help to improve plant protection techniques, even reducing the volume of chemical insecticide controls, with proper timing, or possibly replacing them partly with biological control measures.

2. Methodology

Seasonal observation records of the examined *Eurygaster* and *Aeila* species based on the works of Benedek [13,14] and Kapustkina [15] were transformed to relative abundance. These data were illustrated by a flight phenological diagram, and these trends were compared with green mass formation tendencies of winter wheat. For this analysis, we used the development-dependent LAI (leaf area index) of winter wheat [16].

The grouping of these species was analyzed as a function of their specific temperature-dependent biological life constants and activities (temperature values regarding embryonic threshold, migration, host colonization, and mass oviposition).

The ranking, based on damage potential, was established from the collected data. We used a five-point scale to rank the main cereal pest species for each of the considered characteristics. A lower value indicated a higher potential for damage. We assigned a value to represent the size of the potential area of damage (obtained by summing up the areas of wheat cultivated in 2020 within the distribution area of the given pest). We evaluated the species according to the presence of migration, rating their colonization temperature, the degree of attachment to the crop, and the number of publications related to their damage. The scores obtained for all these traits were then summed to obtain a final ranking, characterizing the economic significance of the main Palearctic sap-sucking heteropterans.

3. Evaluation of Heteropteran Pests Harmful to Cereal Cultivation in Europe

3.1. Main Qualitative and Quantitative Properties of Wheat Cultivation in the European Continent

Winter wheat, *Triticum aestivum* L. (Poaceae), is grown on 219 million hectares throughout the world, yielding 760 million metric tons of wheat in 2020 [17]; with its significant annual production and growing harvest area, it is one of the most important field crops in the world. In Europe, about 255 million metric tons of wheat was produced in 2020. The harvested area was 61,643,400 hectares; Europe has a 33.5% share in the world's wheat production, preceded only by Asia. Leading producers of wheat in Europe are Russia, France, Ukraine, and Germany. Other important producers are the United Kingdom, Poland, Romania, Spain, and Italy [17,18].

Wheat is the basic ingredient of bread, other bakery products, and pastas, owing to the ability of its seed to be ground into flour. Due to this fact, wheat is one of the main sources of nutrition for most of the population. Furthermore, with its high protein content and high energy value, wheat is an important forage in animal feed. Moreover, its gluten content makes wheat suitable to use as a pelleting aid, as well [19].

Differences in quality within the dominant species of common wheat are highly important in wheat production. Protein content is the most important factor used to assess wheat quality in global trade. A distinction is made between bread wheat (higher protein content), biscuit wheat, and feed wheat (lower protein content). High quality wheat is often added to other varieties to improve their overall quality. There has been a long history of using specific measurements to evaluate the harvested wheat and the flour. Examples of the important characteristics of harvested wheat are moisture content and hectoliter weight. The main factors of the flour's technological performance are complex. These factors are made up of physical and chemical parameters (e.g., ash content, protein content, wet gluten content, gluten index), as well as a range of characteristics concerning the flour's behaviour in the gel or dough stage (e.g., falling number, amylografic viscosity) [20,21]. Some instruments are used to measure the rheological parameters of flour, such as alveographs and pharynographs. Several studies have shown that the parameter mostly determining bread volume is the protein content of wheat [22–24].

3.2. Taxonomic Order and General Distribution of Heteropteran Pests Registered in European Cereal Cultivation

The two families of the suborder Heteroptera comprise the five species included in this work, which have major importance in Europe. These families are the Scutelleridae and the Pentatomidae. The two genera that cover these pests are *Eurygaster* (Hemiptera: Heteroptera: Scutelleridae) and *Aelia* (Hemiptera: Heteroptera: Penntatomidae) [25].

Eurygaster integriceps is distributed in Eastern and South-eastern Europe, Western and Central Asia, and the Middle East. *Eurygaster maura* (Linnaeus, 1758) and *Eurygaster austriaca* have similar ranges, being found in Central and Southern Europe, Central Asia, Turkey, the Caucasus, and North Africa [26–28].

Aelia rostrata (Boheman, 1852) is found in Central and Southern Europe, in Central and Western Asia, and in Northern Africa. It is widespread in the former Soviet Union, in European Russia, the Caucasus, Western Siberia, Kazakhstan, Moldova, and Ukraine [28].

Aelia acuminata (Linnaeus, 1758) is widespread in Western, Central, and Eastern Europe, and Western and Central Asia. Populations can be found in the former Soviet Union; Ukraine, Transcaucasia, Western Siberia, Northern Ural, Kazakhstan, Moldova, and the Baltic States [28]. Details on other possible wheat pests from the Heteroptera suborder are discussed in Appendix A.

3.3. The Distribution of Main European Species of Heteropteran Registered as Cereals Pests

Cereal bugs are serious pests of wheat. Moreover, they feed on a variety of gramineous plant species including rye, barley, oat, maize, millet, and perennial cereal grasses. They are widely distributed in the European continent [3,4]. A figure was prepared (Figure 1, shown below) based on the work of de Jong [5] and Neimorovets [27] to illustrate the detailed distribution.

3.4. Species Ranking Based on Temperature Requirements

The results of data integration based on the fundamental works of Afonin [28], Kivan [29], and Konjevic [30] are illustrated in Figure 2. The examined sap-sucking heteropterans find their life conditions under different temperature criteria (Figure 2).

The most cold-tolerant species is *E. integriceps*, in which many biological activities will already begin slightly above ten degrees Celsius. In contrast to this dangerous bug, other scuttellerids and the *Aelia* genus have higher temperature requirements. These values are realized around twenty degrees Celsius in the case of *E. maura* and *A. acuminata*. Only *A. rostrata*'s temperature requirements are somewhat similar to that of *E. integriceps*. This species finds its optimal life condition at around 15 °C.

3.5. The Main Biological Characteristics of Wheat Bugs

E. integriceps is currently considered to be the most noxious pest among the cereal bugs; its developmental cycle is perfectly matched to the vegetation cycle of wheat [26]. It breeds and feeds in cereal fields from the spring; two and a half to three months are spent as an active pest on gramineous plants [4]. This period is for copulation, oviposition, nymphal development, and to build up fat reserves to prepare for migration [25]. Large outbreaks, which usually occur every 5–8 years, can cause significant yield losses [4]. The young adults migrate to diverse shelters. They spend the rest of the year in diapause with two phases: aestivation over the hot period of summer and autumn, and hibernation during winter. Hibernating places can be soil around the roots of grasses in highlands, and under litter and vegetations in valleys. In spring, when the temperature reaches 12–14 °C, they leave overwintering sites for cereal fields. *E. integriceps* lives for one year, it is univoltine, and it has five nymphal instars [28].

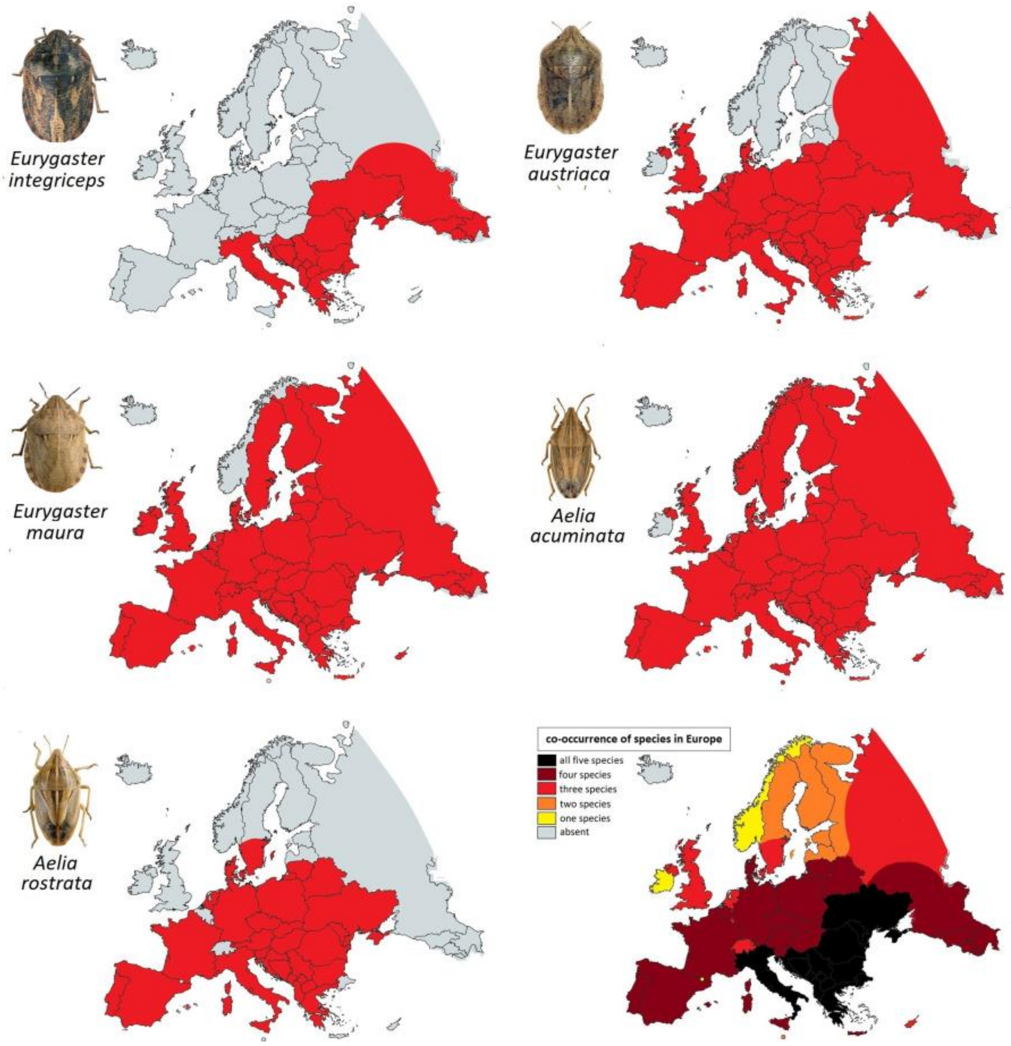

Figure 1. European distribution of main heteropteran cereal bugs.

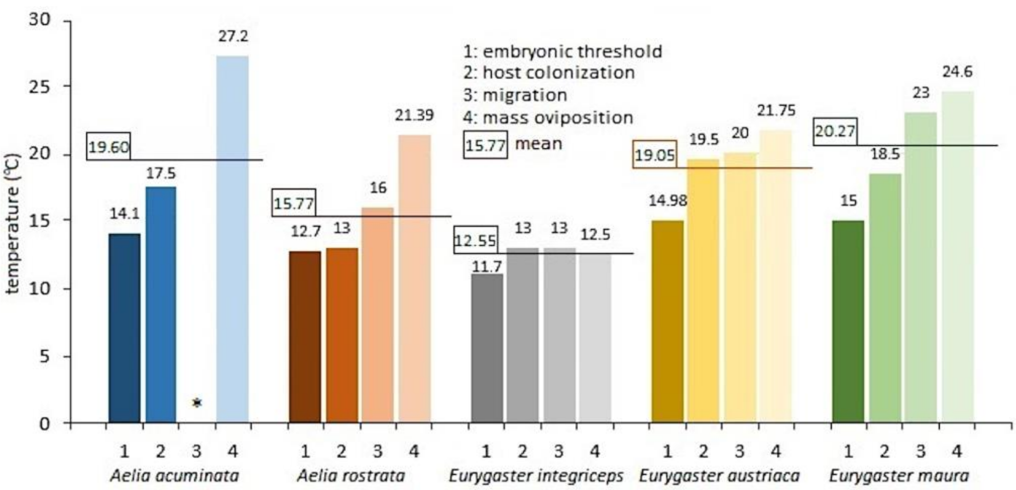

Figure 2. Distinction of sap-sucking heteropterans based on their temperature-depending biological characteristics. *: non-migrating species.

E. maura and *E. austriaca* have similar lifecycles and host plants as compared to *E. integriceps*. Notable differences are female fecundity (1.5 times fewer eggs/female) and awakening temperature (18–20 °C compared to 12–14 °C for *E. integriceps*). The above-mentioned *Eurygaster* species are also univoltine [28].

A. acuminata can also cause significant yield loss in cereal fields. Overwintering takes place under fallen leaves in forests, in plant remnants on cereal fields, or on wild cereal grasses. Awakening is observed at a temperature of 5–10 °C [28]. The feeding begins on cereal grasses, then the bugs migrate to their main hosts. After additional feeding, they lay eggs, followed by five nymphal instars. This species is multivoltine. Their damage is similar to that of *Eurygaster* spp. After harvesting, they migrate to wild cereal grasses and later to overwintering areas, when the temperature starts to fall. *A. rostrata* has a higher awakening temperature (10–12 °C), so they appear on the grain fields later. Otherwise, their biology and lifecycle are very similar to that of *A. acuminata* [28,31].

Regarding the main ecological characteristics, the species of genus *Aelia* and *Eurygaster* are similar. Moreover, there are some important distinguishing characteristics between the species mentioned.

3.6. Voltinism and Diapause

A. acuminata and *A. rostrata* are multivoltine, while *E. integriceps*, *E. maura*, and *E. austriaca* are strictly univoltine [32]. There is a general pattern regarding the multivoltines' cycles, where one or more directly breeding generations are followed by the generation which go into winter diapause (hibernation). This general pattern can be modified by seasonal adaptations, such as migration and aestivation [33].

Diapause is a hormonally determined complex state of an organism, characterised by morphological, physiological, and behavioural traits. Diapause in insects may be obligate (in this case it is hereditary and present in all generations), as it can be observed in the three mentioned *Eurygaster* species [34,35]. Diapause can be facultative (not necessarily present in every generation and controlled only by external factors), as it occurs in the mentioned *Aelia* species. There are two main factors that may induce facultative diapause in the case of *A. rostrata* and *A. acuminata*: photoperiod and temperature [36]. Low temperature and day-length shortening are the signs of the approaching autumn. Temperature usually modifies the effect of the photoperiod; in warmer years, the winter diapause shifts to a later date. Both mentioned species overwinter as adults.

Aestivation, a state of animal dormancy, is similar to hibernation, and characterized by inactivity and a lowered metabolic rate. It occurs as a response to high temperature and arid environmental conditions, to synchronize the insect's life cycle with the most favourable periods within a particular season.

3.7. Migration

For some species, different areas are used for feeding, winter hibernation, and summer aestivation. Cereal bugs colonise the main host plant during the growing season, and this requires migration. The species of sap-sucking heteropterans are significantly different based on their migratory features. Certain species can be characterized by determinative migratory features in some parts of their distribution area, but not in others. There are non-migrating species as well.

E. integriceps is a typically migratory species. During summer migration, it ascends about 1000 m of altitude, and migrates 20–30 km on average, but may also migrate over 200 km [37]. This migration usually occurs at the end of spring. In that period, the surviving adults migrate down to the cereal fields. The migration lasts up to one month or more, since they do not all cease hibernation at the same time [4].

It is known that the migratory tendency of certain species can change as a function of its distribution area [38]. *E. maura* shows similar migratory features in the Near East to that of *E. integriceps*. In contrast, this species is hardly migratory in Morocco. *E. austriaca* shows opposite migratory features in the north-western African habitats, where this species is strongly migratory.

The migratory features of *A. rostrata* are similar to the vagility of *E. maura*. This species is a typical migrator in the middle areas of Turkey. It overwinters on mountains, at altitudes of about 1500–1800 m, and migrates down to cereals in spring, covering distances possibly up to about 30–50 km. According to the work of Dikyar, *A. rostrata* leaves its hibernating areas in April, and it begins its mass migration to main host areas in May [39]. *A. acuminata* is an exceptional member of this pest group, because it lacks the evidence of migratory behaviour within its distribution area [39].

3.8. Seasonal Activity as a Function of the Host Preferences

Feeding on host plants is restricted to a limited timeframe within the growing season; synchronisation between the consumer and the plant is one of the life-history strategies of herbivores [40]. The synchronisation between the cereal bugs and the phenology of the host plants shows differences.

LAI values, reflecting the winter wheat growth compared to the seasonal abundance of sap-sucking heteropterans can be seen in Figure 3a. A determinative break can be detected at the end of the vegetation cycle of winter wheat (and other cereals) in the flight diagrams, independently of the species' univoltine characteristic. Naturally, the life cycle of these univoltine species will not be finished by harvesting their main host; they will migrate to other vegetating gramineous plants (*Setaria* spp., *Echinochloa crus-galli*, *Panicum* spp., etc.) in the second part of the summer. The fundamental demands of these heteropterans will not be completely served by these hosts during this period, but these plants may help in maintaining their population, and preparing for the winter diapause.

The mass abundances of the species are synchronized with different host plants (Figure 3b). There are heteropteran pests in which the mass appearance is timed for the green biomass peak of winter wheat. This identifies winter wheat as the primary host, which was unequivocally confirmed by the results of the regression analysis of Leaf Area Index (LAI) values of different hosts and the accumulated observation records per unit time. The positive correlation with LAI points out that the individual number of a given phytophagous insect reflects the vegetative development of their primary host, the winter wheat. Examples of such species are *E. integriceps*, *E. austriaca*, and *A. rostrata* (in the order of the strength of attachment). Moreover, a negative correlation was found between the LAI of winter wheat and the observed numbers of *A. acuminata* and *E. maura*, showing that the populations of these bugs are influenced by the pace of development or the green biomass production of other gramineous plants.

However, one must note that the dependence between LAI and pest abundance does not necessarily represent the degree of the damage caused by sucking pests. In particular, *E. integriceps* is considered relatively harmful at the beginning of summer, even with a low LAI and small pest population. These imagoes are highly deleterious; the damaging of the central stalk of wheat may hinder or prevent ear formation. Milky and milky-wax ripeness periods are also highly sensitive to damage.

3.9. Morphological Feeding Characteristics of the Sap-Sucking (Hemiptera: Heteropetra) Insects

Herbivore heteropterans use their mandibular and maxillary stylets to obtain food by piercing plant tissues and sucking plant fluids [41]. There is a general design of the piercing–sucking mouthpart which consist of a rostrum that contains a central pair of stylets. These fine stylets form two tubes when they are pressed together. One canal is for depositing saliva, the other is for sucking sap; the canals are normally enclosed and protected by the mandibular stylets and the rostrum.

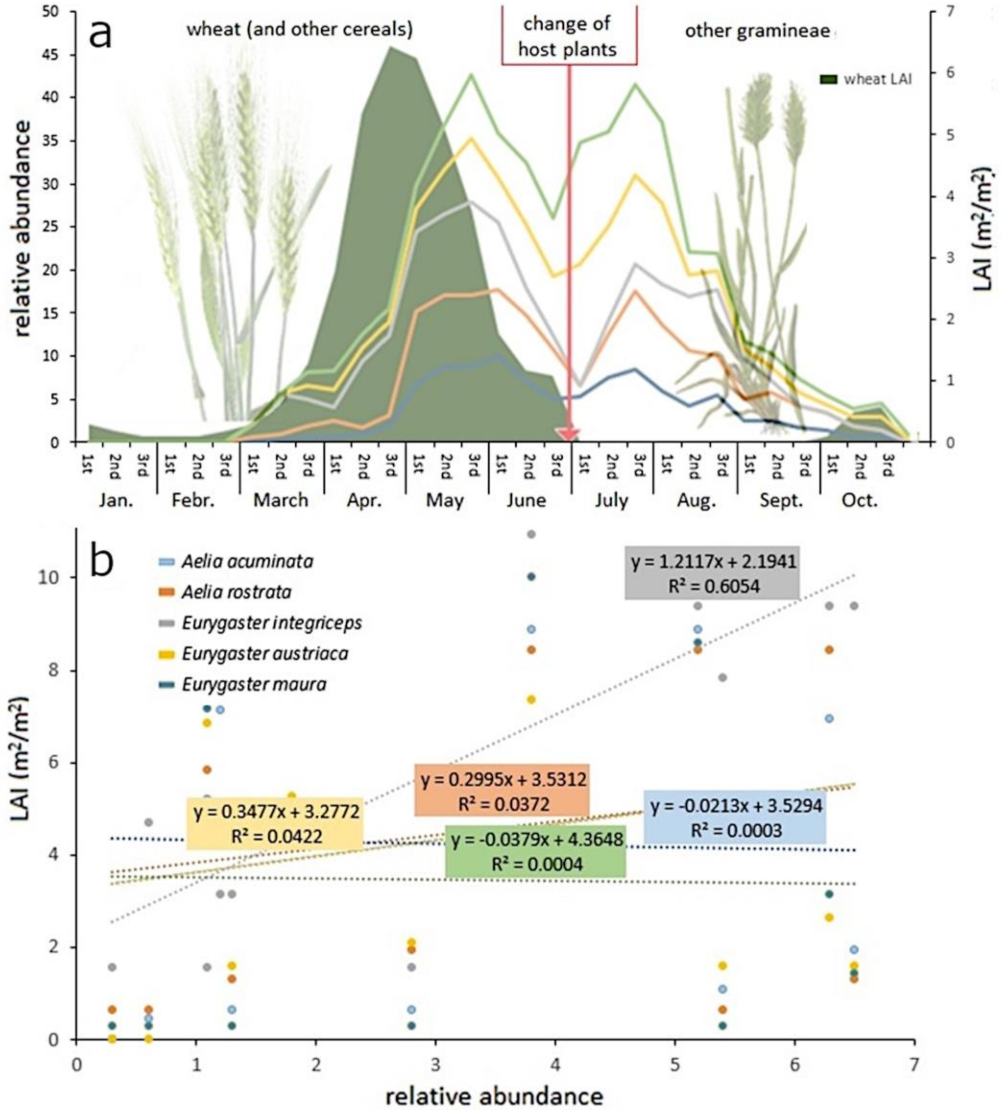

Figure 3. Observation-record-based relative abundance of cereal damaging heteropterans. Abundance characteristics of *Aelia* spp. [13], *Eurygaster* spp. [14,15] and the calculated LAI of *Triticum aestivum L.* are depicted on the upper panel (**a**), as a function of time. The bottom panel (**b**) shows the association between LAI and the relative abundance. LAI data of winter wheat are based on the work of Huang and colleagues [16].

The salivary glands consist of a pair of primary, bilobed principal and accessory glands [42,43]. The accessory glands produce watery saliva, which contains enzymes and other protein components. The other type of saliva is a gel-like secretum and the basis of the salivary sheath. This salivary sheath forms a hardened lining between the plant tissues and the penetrating stylet [44]. The functional role of the sheath is to prevent plant juice loss during feeding. This type of saliva hardens rapidly after being released through the salivary canal. It adheres to plant tissues but not the surface of the stylets. After feeding, the sheath remains in the plant tissue [42,44].

The function of the saliva is complex. The usual functions are moistening and mixing the food with enzymes before ingestion. Moreover, the saliva plays major role during the mechanical penetration of plant tissues by the stylet. Therefore, the chemical composition of saliva may vary during the feeding [45].

3.10. Registered Quantitative Damage in Wheat Caused by Different Cereal Bugs

Yield losses caused by certain cereal bugs can hardly be estimated, because the induced damage cannot be attributed to different species easily; moreover, the amount of damage can vary within a wide range. Crop loss can be more significant in outbreak years or in the absence of control measures; in addition, the pest population densities are affected by both cultural methods and natural enemies [30]. In case of heavy infestation, yield loss can be up to 100% in some areas.

A. rostrata was reported to cause a yield loss of 20–93% in wheat; however, in outbreak years, the induced damage may reach up to 100% [6,32,46]. There are no percentage data available for yield loss induced by *A. acuminata.* Yield losses caused by *E. integriceps* are estimated to be between 50% and 90% in wheat and 20% and 30% in barley [25,47–49], but may reach up to 100% in case of heavy infestation [7,50,51]. The observed yield losses of *E. maura* and *E. austriaca* are estimated at 50–90% in wheat and 20–30% in barley [48,52].

3.11. Physiological Consequences of Saliva Injected by Heteropteran Pests in Cereals

For phytophagous heteropterans, pre-oral digestion is important because they feed from various plant organs, including hard seeds covered by the cuticle. In addition, these seeds contain defensive chemicals, such as enzyme inhibitors and antifeedants [53]. It is necessary to liquefy the hard, soiled seed material to make it consumable [44]. Moreover, the heteropteran herbivores' saliva is of utmost importance during the penetration of plant tissues by the piercing-sucking mouthparts [45].

The damage can manifest in all parts of grain crops, since adults and nymphs feed by sucking from almost any plant organs, except the first instars, because they are in a nonfeeding stage. Adults and fifth instars may cause the most injury [41].

The early damage usually affects the stems of young plants, due to the adults' feeding. Early symptoms are slow plant growth, yellowing, leaf deformation, and wilting due to deprivation of nutrients [25]. During the growing period, bugs may feed at the base of the spike, causing white spikes without kernels [52]. These kinds of damage may manifest in pronounced reductions in the actual yield. A standard method of evaluating grain yield is the measurement of 1000-grain weight. The 1000-grain weight can be reduced to 78–92% in grains damaged by cereal bugs [4].

Later, adults and nymphs attack the kernels as well, influencing seed germination. No more than 88% germination is obtained where 14% of kernels are damaged [4]. If the grain is attacked in the milky stage, the damage may result in whole kernel destruction; in late maturity, it manifests in shrivelled kernels with a black pinpoint on the seed, surrounded by a discoloured halo (or patch). The maximum bug feeding related damage occurs at the late milk-ripe stage [54].

During feeding, the amylolytic and proteolytic saliva injected into the grain predigests endosperm and destroys gluten [8–10]. It leads to decreased baking quality; dough made from damaged grain has unsatisfactory consistency. The deteriorative effect on baking qualities is evident in the presence of only 3–5% damaged grain [11,12].

The injected secretions become active when flour is processed into dough. The enzymes are activated and degrade gluten due to the appropriate moisture and temperature. Therefore, the elasticity and the gas adsorption capacity of dough decreases; it has a negative effect on bread's crumb structure and texture, as well [12,55].

3.12. Comparison and Evaluation of Cereal Bugs According to Their Damage Potential

From the data collected, we have established a ranking of the cereal bug species according to their damage potentials (Table 1). Based on the available literature, we have identified indicators to characterize the damage in harvested crops, wheat quality, and germination. Our ranking is based on objective indicators, but it should be noted that it is impossible to collect and evaluate all factors influencing damage, due to their large number and the contradictory and widely scattered data in the literature.

Table 1. Ranking of cereal bugs according to their damage potential.

		Eurygaster integriceps	*Eurygaster austriaca*	*Eurygaster maura*	*Aelia acuminata*	*Aelia rostrata*
Harvest area of wheat within the distribution area in 2020	km^2	429,234.24	600,925.24	614,537.24	614,864.34	588,633.17
	ranking	5	3	2	1	4
Migratory inclination	1: yes, 0: no	1	1	1	0	1
	ranking	1	1	1	0	1
Colonization temperature	°C	13.0	19.5	18.5	17.5	13.0
	ranking	1	5	4	3	1
Number of related sources on damage since 2000	No.	35	7	16	2	4
	ranking	1	3	2	5	4
Degree of synchronization with host plants	No.	5	4	1	2	3
	ranking	1	2	5	4	3
Sum of rankings	total score	9	14	14	18	13
	dam.pot.	1	3	3	5	2

Species are ranked on a five-point scale, with smaller numbers indicating higher damage potential. dam.pot. = damage potential.

To calculate their actual distribution area, we used the data published by de Jong et al. [5] and Neimorovets [27]. We determined the area of wheat cultivation in the affected areas to obtain the area where their damage may occur [17]; source data are provided in Supplementary Table S1. The presence of migration may increase the damage potential of a species, so migratory species were considered as having higher damage potential. As our assessment covers European territories, we have only distinguished between migratory and non-migratory species in terms of whether the migratory behaviour is present in Europe or not. We are disregarding the fact that differences in this respect are described in some Middle Eastern and African areas, as described above. The colonization temperature is the threshold at which the species can colonize cereal fields. The time of damage (and its consequences) depends to a large extent on this characteristic. The lower the colonization temperature, the greater the potential damage. On this basis, we have prioritized species with lower colonization temperatures. The number of publications on the inflicted damage of a species is also a good indicator of damage potential. Therefore, we have also ranked species by the number of articles published after 2000. The degree of synchronization between the phenological phases of the crop and the life cycle of the pest insect also determines the extent of feeding-related damage that can occur in cereal fields. The better the synchronization between them, the greater the role of the host plant in the insect's feeding, so we have scored the pests on this basis too. After collecting and evaluating the data, a final ranking was established, which can be summarized as follows: *E. integriceps* was clearly found to have the highest damage potential. It is a highly potent pest, due to its low colonization temperature and high plant-pest life cycle synchronization. The number of publications on this species is a good indication of its importance, although it lags behind other species in terms of distribution area. It is followed by *A. rostrata*, a species that also has a very low colonization temperature and it is attached to the wheat as host plant. Close behind are *E. austriaca* and *E. maura*; they appear much later in wheat fields due to their higher colonization temperature.

A. acuminata proved to be the least potent species, although it probably has the largest distribution. Its position in the ranking can be explained by (i) the fact that it is not a migratory species, which reduces its potential for damage, and (ii) the fact that wheat as a food crop plays a minor role in the diet of this pest; moreover, (iii) it is a relatively late colonizer of cereal fields. Due to its minor importance, it also appears less frequently in the literature reviewed.

4. Conclusions

The main Palearctic wheat bug species with significant economic impact are *E. integriceps*, *E. austriaca*, *E. maura*, *A. rostrata*, and *A. acuminata*. Based on the summarized data of their distribution, it can be stated that in the European wheat-growing countries surveyed in this article, *E. maura* and *A. acuminata* are the most widespread pest species. These pests are present in 34 surveyed countries/areas, followed by *E. austriaca* in 29 and *A. rostrata* in 26 countries/areas. *E. integriceps*, which is considered in many ways the most dangerous pest among cereal pests, was recorded in only 13 surveyed countries/areas.

Temperature plays a significant role in the growth and development of cereal bugs, since they are cold-blooded animals. The most cold-tolerant species are *E. integriceps* and *A. rostrata*. Their temperature requirements are similar, although the temperature optimum of *A. rostrata* is a few degrees higher, around 16 °C. *E. maura*, *E. austriaca* and *A. acuminata* have higher temperature requirements, around 20 °C.

The positive correlation between LAI and population size of *E. integriceps*, *E. austriaca*, and *A. rostrata* has pointed out that their numbers reflect the vegetative development of the primary host, winter wheat. Moreover, the negative correlation between the LAI of winter wheat and the observed numbers of *A. acuminata* and *E. maura* implies that populations of these bugs are potentially influenced by the biomass production of other gramineous plants.

Crop loss in wheat is more prevalent in outbreak years; yield losses caused by *E. integriceps* are estimated between 50% and 100%. The observed yield losses of *E. maura* and *E. austriaca* are estimated at 50–90%, while *A. rostrata* was reported to cause yield loss of 20–100%.

E. integriceps was ranked first in terms of damage potential. It is a prominent and dangerous pest due to its low colonization temperature and high adaptation to the life cycle of wheat. This is also reflected in the high number of publications on this species, although its distribution is not as wide as that of the other cereal bugs discussed in this article. It is followed by *A. rostrata*, due to its low colonization temperature and its strong association with wheat as a food plant.

E. austriaca and *E. maura* are slightly behind, as they colonize wheat fields much later. *A. acuminata* has the lowest damage potential, colonizing wheat relatively late, showing weak attachment to the plant and being non-migratory (uniquely among the listed cereal bugs). Its minor importance is also confirmed by its lower abundance in the literature.

Yield losses may increase due to global warming, which may encourage certain cereal bugs to change their distribution area [56]. They may become more widespread in Northern Europe if the frequency of dry and warm years increases [56]. The knowledge of the distributional, morphological, physiological, and topographical properties of the cereal bugs may help to clarify their economic significance and potential damage capacity. A better understanding of their properties is necessary to improve the practical plant protection methods, in order to reduce the use of insecticides or to replace them with biological methods of control.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15010109/s1, Figure S1: The main morphological characters of adult cereal bugs. Table S1: Source data used to create Table 1.

Author Contributions: Conceptualization, S.K.; Funding acquisition, S.K.; Investigation, S.G.; Formal analysis, S.G. and S.K.; Writing—original draft, S.G.; Writing—review and editing, S.G. and S.K. All authors have read and agreed to the published version of the manuscript.

Funding: The work was supported by the EFOP-3.6.3-VEKOP-16-2017-00005 and the EFOP-3.6.3-VEKOP-16-2017-00008 projects. The project is co-financed by the European Union, the European Regional Development Fund, and the European Social Fund.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Other Possible Wheat Pests from the Heteroptera Suborder

The five species discussed above are usually considered as cereal bugs of economic importance in Europe. However, other species of the suborder Heteroptera may also be found on cereal fields as minor pests. One example is *Eurygaster testudinaria* (Geoffroy, 1785), a transpalaearctic species, whose range includes Europe, Central Asia, China, and Japan. It may be a significant cereal pest in some parts of its range and it is very difficult to distinguish from *Eurygaster maura* [57]. *Eurygaster dilaticollis* (Dohrn, 1860) is widespread in Central Europe, Turkey, Central Asia, and some parts of Siberia. No estimates of potential damage have been made to date [57]. *Dichelops melacanthus* (Dallas, 1851) has become one of the most important pests of wheat after changing conventional tillage system in Brazil [58]. *Nezara viridula* (Linnaeus, 1758), a polyphagous pest of African origin, can also damage wheat [59]. The *Aelia* genus also includes occasionally damaging species, such as *Aelia klugii* (Hahn, 1833) and *Aelia germari* (Küster, 1852) [60]. The widely distributed extremely polyphagous pest *Halyomorpha halys* (Ståhl, 1855) has more than 100 host plants. The species is native to Asia and, in the absence of any other more favourable food plants, wheat could possibly be a host [61].

Appendix B

Main Identifying Features of Heteropteran Adult Cereal Pests

The major wheat bug species in Europe are members of the families Scutelleridae and Pentatomidae (Hemiptera). The main morphological features of their imagoes correspond to the identification characters of these families. The heads of the scutellerid bugs are triangular, with a trapezoidal thorax and a convex lateral margin. Their shields are large and U-shaped, covering the entire body. Their colours show a great variance [62]. Some are entirely straw-coloured, and others are brownish or quite dark, with a longitudinal characteristic pattern of greyish-ground colours [57]. The pentatomid bugs are slightly smaller, with a more elongated body. Their body colour is similarly straw yellow or brownish yellow, with black or greyish spots on the edges. There is a light longitudinal stripe from the head to the shield. The legs are straw yellow [31,63].

In this appendix, we discuss the most important morphological characteristics to distinguish species (Figure S1). The scutellerid bugs differ in size. While *E. integriceps* and *E. austriaca* are essentially of the same size, *E. maura* is smaller and more convex. The most common identification marker is the relative shape of the clypeus and ganeas. In *E. austriaca*, the ganae enclose the clypeus anteriorly, whereas in *E. integriceps* they extend to the apex, whereas in *E. maura* they are rounded at the end [64,65]. The main distinguishing feature of *E. integriceps* is that the lateral edges of the prothorax are not straight but slightly curved [64]. *E. integriceps* has a penis with four horns, while *E. maura* has only two horns [66,67]. Compared to *A. acuminata*, *A. rostrata* is more elongated, and larger. Its markings are less expansive but more contoured. The light ribs from the clypeus are broader in the middle of the shield and then narrow, whereas in *A. acuminata* they are more continuous and elongated. In *A. acuminata*, the ganeas enclosed the clypeus well before the end, while in *A. rostrata* the clypeus segment extends to the tip. In *A. acuminata* there are two black spots in the middle of the femur segment, while in *A. rostrata* there is only one black spot [68,69].

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