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PHENOLOGY OF ELM SEED BUG (*Arocatus melanocephalus*) IN ALMATY CITY OF SOUTHEASTERN KAZAKHSTAN

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SUMMARY

The phenology of the elm seed bug (*Arocatus melanocephalus*) and the effects of environmental factors on its population dynamics were studied during the months of May and June from 2016 to 2019 in the Almaty region, Kazakhstan. The study comprised the sampling of 15 elm trees at 10 different selected sites. The insects were caught using entomological nets for population dynamics studies. The extent of leaf damage was determined by measuring the damaged square area using Blunk's formula. In the Almaty region, the elm seed bug laid eggs in mid-April, and the imago appeared in mid-June. The insect laid eggs on the regenerative organs of the elm trees and caused significant damage to the leaves, ranging from 60%–95%. However, the significant leaf damage was not caused by the said elm trees insect as what is common in other regions of the world. In the Almaty region, the elm tree foliar damage is notably made by bugs. A negative correlation was recorded between the insect population and rainfall during May. The elm seed bug reproduction and growth occurred, and population size grew during May and June, but, no correlation was found on temperature for these two months. The present results would help in understanding the phenology and population dynamics of the elm seed bug and design the strategies for its control.

Keywords: *Arocatus melanocephalus*, phenology, population dynamics, temperature, rainfall, environmental factors

Key findings: Long-term studies on the effect of environmental parameters on elm seed bug (*Arocatus melanocephalus*) development and population dynamics are vital to gain sufficient knowledge to forecast outbreaks of this pest, as well as, effectively manage its population.

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INTRODUCTION

The elm tree holds great importance in the urban landscapes of many countries. Yet, the Dutch elm disease (DED) has significantly decreased its population in different parts of the world. Still, the development of new DED-resistant varieties has led to an increase in the elm plantation. The tree has important aesthetic and ecological values as it adapts

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well to environmental stresses such as strong winds, frost, and poor soil quality and thrives well in urban environment (Smalley and Guries, 1993). In urban landscapes, the trees play an important role in combating environmental pollution, mostly caused by particulate matter (PM-2.5).

Some tree species are suitable for planting in urban areas to tackle pollutants such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate material. Specifically, the elm trees have been found to possess many desirable characteristics such as high PM-2.5 trap ability, resistance to urban pollution, and low emission of biogenic volatile organic compounds. For this reason, the elm trees are mainly used for city planting (Yang *et al.*, 2015). However, the elms are affected not only by the DED but also by the different pests such as butterflies, sawflies, beetles, and mites. The pest phenology study helps in the identification of the behavior and life cycle for the effective management of pests or a particular pest. Also, the understanding of the relationship between environmental factors and the pest population, migration, and feeding habits can be used for the prediction of pest outbreaks to minimize the damage on host plants.

Elm seed bug (*Arocatus melanocephalus*, Fabricius, 1798) is a major pest, damaging the elm trees of the Almaty region of Kazakhstan. It is a tree bug found in most European countries and recently found in many regions of North America and Asia (Gao *et al.*, 2013; Acheampong *et al.*, 2016). Apart from *Ulmus*, it is also a pest of the other genera i.e., *Populus* and *Platanus*, and causes a nuisance in summer when a large number of insects enter residential buildings and offices to avoid the environmental heat. The adult elm seed bug releases an intense unpleasant smell similar to that of bitter almonds (Davis, 2017).

Few studies on the foliar damage caused by the elm seed bug exist. It is well known that this insect completes its life cycle on elm trees, where the adults thrive over winter and mate in spring. The eggs are laid on the fruits of elm trees, where the nymphs go through five instars, and the adults begin to appear in late May to early June with a total post-embryonic period of four-six days (Pedrazzoli and Salvatori, 2009). Several reports have highlighted the problem of summer invasions by this insect in residential buildings. With the rising temperature caused by climate change, the number of insects invading buildings and cities where invasion has been reported increased (Maistrello *et al.*, 2006; Lestari *et al*., 2015; Davis, 2017).

The past studies also concluded that the increased incidences of insect invasion in indoor buildings might be due to an increased insect swarm caused by rising temperature, forcing insects to move inside cooler buildings instead of thriving on their normal habitats. The humidity was also found to affect the behavior of insect pests, with drier days favoring more intense invasions. The elm trees pruning has the greatest effect on the population size of elm seed bugs, and the chemical control may have unpredictable results (Ferracini and Alma, 2008). However, Martín *et al.* (2019) reported that the elm seed bug is considered to use elm trees mainly for reproduction and causes little damage to the host trees.

In light of the recent outbreaks of elm seed bugs and increased incidences and intensity of invasion on residential buildings in many countries, it is important to study the phenology and behavior of this insect. The study of the environmental parameters which affect the elm seed bugs population dynamics is vital to forecast outbreaks and prevent damages to the trees, as well as, lessen human discomfort. The extent of damage caused to the elm trees by this pest also needs to be studied. The elm trees are affected by many pests, however, the significant damage caused by the elm seed bug needs to be evaluated (Lawson and Dahlsten, 2003).

Based from previous literature research, the present study might be the first approach about the elm seed bug phenology, environmental effects on its population size, and the extent of damage caused by this pest to elm trees in the Almaty region of Kazakhstan.

MATERIALS AND METHODS

Study location and procedure

The study was conducted every months of May to June from 2016 to 2019 in the Almaty Region, Kazakhstan. The study sites were 10, and a total of 15 trees were included in the study from all the locations.

Study of phenology

The study of elm seed bug (*Arocatus melanocephalus*) phenology was done using the methodology described by Ellwood *et al.*

(2012). Briefly, the bug appearance and development data were recorded every 10 days and the data on weather conditions such as temperature and rainfall for the entire duration of the study were obtained from the website of Kazhydromet, Almaty, Kazakhstan. The effective temperature sum for the development of the elm seed bug for May and June in various years of study was calculated using the formula:

$$K= y\ (T - t_0),$$

where
K = accumulated thermal units (degree-days);
y = number of days used for the summation;
T = average daily temperature for the duration of the study;
t_0 = lower threshold temperature for the insect development, which in the absence of experimentally determined threshold temperature was taken as 10 °C.

The hydrothermal coefficient, HTC, was calculated for a particular month by applying the formula of Selyaninov (Evarte-Budere *et al.*, 2012).

$$HTC = \Sigma x / \Sigma t \times 10\ ^{o}C,$$

where
Σx = the sum of daily rainfall in the month,
Σt = the sum of temperatures in the month when the temperature was not below 10 °C.

Estimation of pest abundance and leaf damage

The insects were caught manually from parks, streets, squares, and avenues using an entomological net and stored in paper envelopes. At each study site, a branch of an elm tree was enclosed in the net and the branch was shaken to collect the insects. The damaged leaves were collected, dried, and preserved in a herbarium. The collected leaves were used to determine the type of leaf damage as per the method described before (IPPC, 2016) and the damaged square area was calculated using Pick's formula (Loughlin *et al.*, 2015),

$$S = M/2 + N - 1$$

where
M = the number of integer points on the border of the triangle (on the side and at the vertices);
N = is the number of integer points inside the triangle;
S = is the damaged square area of the leaf.

The damaged square area was expressed as a percentage of the total leaf area. A total of 100 leaves from different locations were used to calculate the damaged square area percent. The degree of damage caused to the trees was determined by visual inspection and expressed in percentage:

$$P = (n \times 100) / N$$

where
P = Damage;
n = Number of damaged trees;
N = Total number of trees in an area.

The damaged trees were categorized into three categories based on the degree of damage: a) insignificant damage with small harm to the trees, b) significant damage with noticeable damage to the tree but the tree survives, and c) severe damage with significant damage on the tree resulting in its death.

RESULTS AND DISCUSSION

Elm seed bug (*Arocatus melanocephalus*) phenology

It has been reported that elm seed bugs lay eggs in the fruits of elm trees. In the Almaty region of Kazakhstan, the bugs were found to lay eggs on the generative organs of elm trees and sometimes also on the leaves in mid-April and early May. The white eggs with a greenish-yellow tint are ellipsoid in shape. The length of the eggs is about 1.5 mm, and the first stage nymph hatches from the eggs in the first 10 days of May (Table 1). The length of the first stage nymph is about 6 mm and has walking legs with a red back, and a black head and chest. The first-age nymph also has black wing rudiments (Figure 1a). In the first 10 days of June, the first stage nymph matures to the second stage nymph, which unlike the first stage lymph has an elongated body and is brick-red in color.

The head and chest are black as in the first stage nymph and the wing rudiments are also retained (Figure 1b). The imago appears in the mid of June. The adult insect is brownish to dark brown. The length of the bug is around 8 mm and has an elongated, flat body shape, and the head is triangular but not flattened.

Table 1. Phenology of *Arocatus melanocephalus* (Elm seed bug).

April			May			June			July			August			September		
Days																	
I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
			N_1	N_1	N_1	N_2	N_2	N_2									
	E	E	E														
I	I	I					I	I	I	I	I	I	I	I	I	I	I

Notes: I: imago; E: egg; N1, N2: first and second age nymph; I: Day 1-10 of the month; II: Day 11-20 of the month; III: Day 21-30/31 of the month.

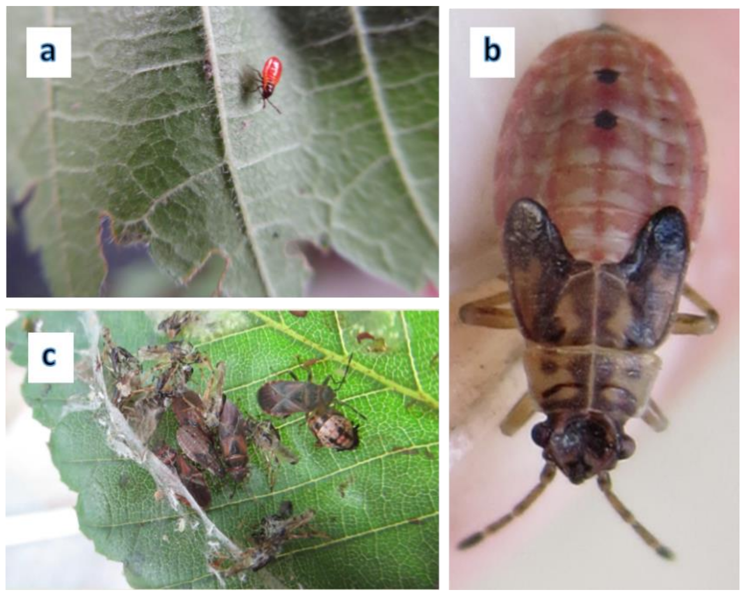

Figure 1. Life stages of *Arocatus melanocephalus*. a) First stage nymph, b) Second stage nymph, c) Imago hatching on elm leaf.

The antennae are long, located in the lateral part of the head on the supporting tubercles. Proboscis and antennae are four segmented, and the transverse groove is found on the front back. The antennae and legs are dark brown in color, and tibias are bent. The appendages are three-segmented and the oral apparatus is piercing-sucking type (Figure 1c).

The phenology of the elm seed bug has not been extensively studied. Maistrello *et al*. (2006) provided a brief description of the phenology of the said insect citing two reports published in the Italian language (Davis, 2017). In the Italian region, the nymph develops up to six weeks and matures into the imago insect in May which is about one month earlier than that seen in Almaty, Kazakhstan. This is probably due to relatively warmer weather in Italy compared with Almaty, Kazakhstan. As reported from other countries, the adult bug (*Arocatus melanocephalus*) hibernates under fallen leaves and the deciduous tree bark. The elm seed bug produces only one generation per year in Almaty, the same as its reproductive behavior in Europe and North America.

Elm seed bug damage to elm trees

The elm seed bug pierces the elm tree leaf blade and sucks out the sap by using its piercing-sucking type oral apparatus. The leaf damage may be in the form of holes, deformation, bending, and drying. The Russian elm (*Ulmus laevis* Pall.) was worst affected with greater than 95% damaged square area on leaves. The elm seed bug also significantly affected the leaves of the Androsov elm (*Ulmus androssowii* Litv.) and the Scotch elm (*Ulmus glabra* Huds.) with a damaged area of 90% and 80%, respectively, while the Chinese elm (*Ulmus parvifolia* Jacq.) is least affected with 60% damaged area on leaves. Thus, the elm seed bug causes significant damage to the

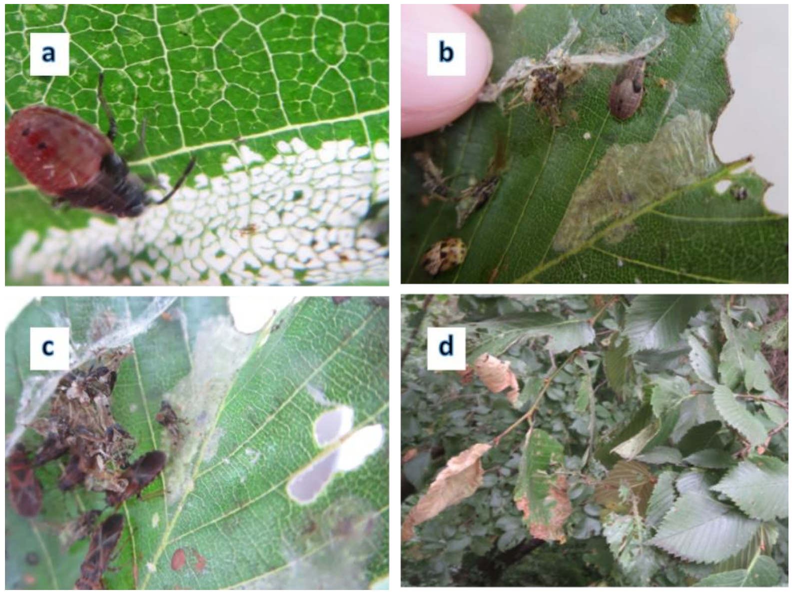

Figure 2. Damage caused to elm leaves by *Arocatus melanocephalus*. a-b) Discoloration, c) Holes, and d) Bending and drying.

leaves of the elm trees that may be categorized as 'significant damage' to 'severe damage'. This is in sharp contrast to reports on the feeding behavior of this insect obtained from other countries where it has not been found to cause significant damage to the elm tree leaves. More research is needed to find out the reason for this difference in the feeding behavior of this insect in different geographical areas. The type and extent of damage caused by the elm seed bug to the elm tree leaves are also shown in Figure 2. Various types of leaf damages such as holes, deformation, bending, and drying were observed.

Effects of environmental factors on the elm seed bug population

The present studies concluded that a behavioral response of elm seed bug to rising temperature increased fecundity of over-wintered adults, and greater survival of newly generated nymphs. Past studies also revealed a positive correlation between the intensity of elm seed bug outbreaks and the temperature (Maistrello *et al.*, 2006; Régnière *et al.*, 2012; Davis, 2017). Other previous studies have also mentioned the significant effect of different weather conditions on the population size of different insect species i.e., temperature (Overgaard and Sørensen, 2008; Hong-Xing *et al.*, 2017; Ali *et al.*, 2020), humidity (Chanthy *et al.*, 2012; Norhisham *et al.*, 2013), and rainfall (Norris *et al.*, 2002; Mutshinda *et al.*, 2011; Rahmathulla *et al.*, 2012). In the past four year (2016–2019) study period, the effect of temperature and rainfall on the population size of elm seed bugs was studied, and the insect population was expressed as the number of individuals caught in a particular season from all the study sites (Table 2). The average temperature, rainfall, temperature sums for the development of elm seed bugs, and hydrothermal coefficients for May and June during four years (2016–2019) of study are presented in Table 3.

The population size in each season and year (represented by the number of insects caught in the entomological nets per year) was plotted with the average temperatures and rainfall during May and June (where the eggs hatched and reproduction and growth of elm seed bug is completed) of each year and the trend was analyzed. The elm seed bug population showed no correlation with the average temperatures in May and June in the four years of study. However, a negative correlation between the rainfalls during May was observed for this period (Figure 3).

Although the rainfall affected the insect population, a greater population of insects was found during the four years of the studies, and significant damage was observed to the elm trees. The absence of a correlation between insect population and May and June temperatures during the four years study period is likely due to a less difference in average temperatures of these two months

Table 2. The number of elm seed bugs caught per year during 2016-2019.

Year	Total Number
2016	1500
2017	2000
2018	2000
2019	2500

Table 3. Climatic parameters in May and June during 2016-2019 in Almaty region, Kazakhstan.

Year	Months	Average temperature (°C)	Effective Temperature sum (°C)	Rainfall (mm)	Hydrothermal coefficient
2016	May	16.7	173.6	214	4.2
	June	23.1	350.0	132	1.9
2017	May	18.8	238.7	113	1.9
	June	22.4	339.0	51	0.8
2018	May	16.3	161.2	118	2.4
	June	22.3	336.0	24	0.4
2019	May	17.0	179.8	39	0.8
	June	22.3	336.0	72	1.6

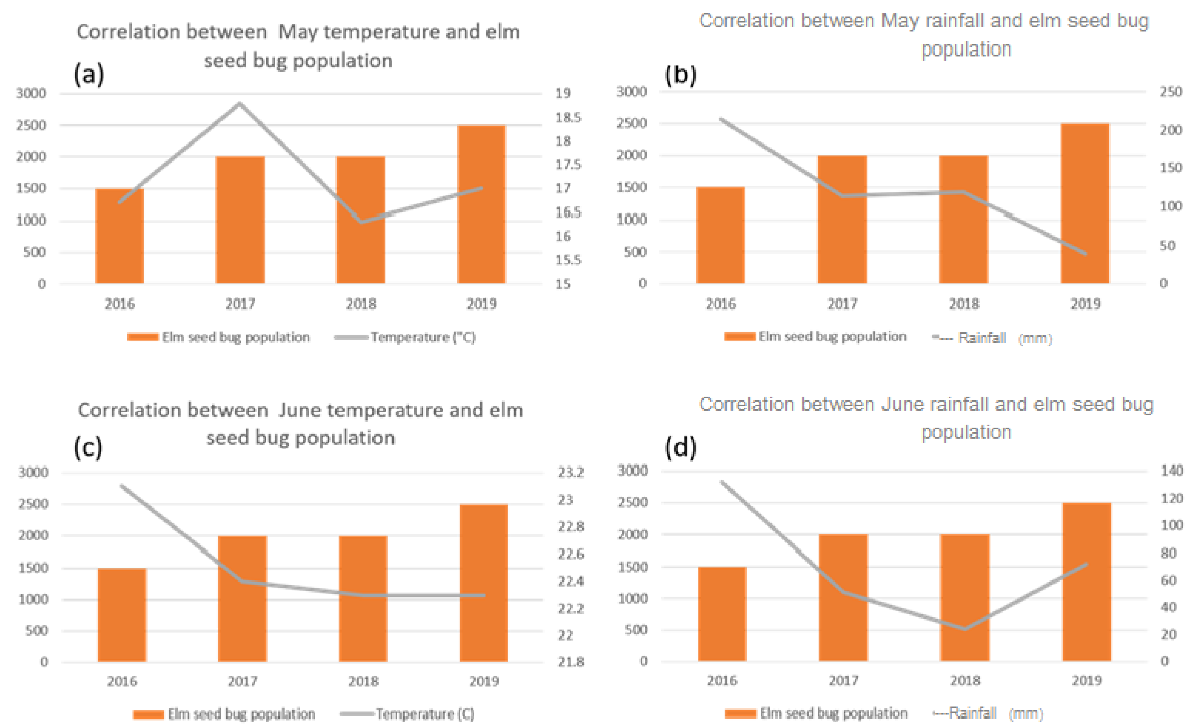

Figure 3. Correlation between the temperatures and rainfall in May and June during 2016-2019 and the *Arocatus melanocephalus* population.

(Table 3, Figure 3). Past studies also reported the negative correlation between rainfall and many insect populations (Norris *et al.*, 2002; Mutshinda *et al.*, 2011; Rahmathulla *et al.*, 2012; Ali *et al.*, 2014; Huang and Hao, 2020). A study on various moth species in the United Kingdom found that their population was negatively affected by rainfall. The studies also proposed that heavy rains may dislodge the larvae from their host plants thereby, affecting their feeding and survival.

Moreover, wet weather might favor the growth and spread of moth fungal pathogens. The rainfall also affects the egg hatching, immature stages of insects, and survival of adults. In elm seed bugs, the eggs hatched in May, and the heavy rainfall during this month greatly affect the egg hatching and nymph survival as the first and second stage nymphs do not have wings hence, are not able to fly. Thus, the rainfall in May can be used as an indicator to predict the population of elm seed bugs in the Almaty region during a particular season and appropriate steps can be taken for the management of the insect population.

The study was limited to a duration of four years, 10 sampling sites, and 15 elm trees in four districts of the Almaty region, Kazakhstan. Therefore, it is required to confirm the negative correlation between the rainfall in May and the elm seed bug population for a longer duration and over wider geographical areas in Kazakhstan.

CONCLUSIONS

This might be the first study describing the phenology of the elm seed bug (*Arocatus melanocephalus*) in the Almaty region, Kazakhstan. The study concluded that imago appears in June in Almaty, Kazakhstan, which is one month later compared with Italy, where it appears in May. This is likely due to comparatively colder weather in Almaty as compared with Italy. The insect causes considerable damage to all the species of elm trees, and the Russian elm is one of the worst affected species. Contrary to the behavior of this insect in other parts of the world where it does not inflict severe leaf damage, however, in the Almaty region, Kazakhstan it causes serious damage to the elm tree leaves. The insect population showed an increasing trend with decreased humidity, though the effect of low humidity was not sufficient to cause a large drop in the population. Further studies on the effects of environmental parameters on the development and population dynamics of the elm seed bugs are vital to gain sufficient knowledge to forecast outbreaks of this pest, and effectively manage its population.

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