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ENVIRONMENTAL FACTORS' INFLUENCE ON THE DIAMONDBACK MOTH (*PLUTELLA XYLOSTELLA* L.) POPULATION DYNAMICS ON CRUCIFEROUS CROPS

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SUMMARY

The diamondback moth (*Plutella xylostella* L.) (Lepidoptera: Plutellidae) is one of the most severe pests for cruciferous crops. Its widespread distribution and the ability to submissive migration led to an unexpected enhancement in its population, thereby obscuring the control measures aimed at this phytophagous. The presented study sought to determine the expansion of diamondback moth in cruciferous crops (rapeseed, mustard) in two agroclimatic zones of Northern Kazakhstan (Zone I: moderately humid and warm; Zone II: slightly humid and moderately warm). Analysis of population dynamics ran for the long-term during 2012–2022 based on bioecological patterns of the diamondback moth and factors affecting them. Numerical variables of population density and abundance indices served as diagnostic predictors for characterizing the phase state of the pest in a given period and, therefore, recognizing the population dynamics pattern of the diamondback moth. Based on the results, the biological regularity of the stage inception of the phytophagous abundance dynamics does not always persevere, and variations occur with the sway of environmental factors. Hence, the abundance dynamics of diamondback moth depend upon the weather conditions of the previous and current year, as well as, on the accomplishment of the extent of chemical treatment and its regulations. The obtained data can be criteria for predicting the phase state of diamondback moth populations in the agroclimatic zones of northern Kazakhstan to justify and plan protective measures, as well as, to improve phytosanitary control.

Keywords: Diamondback moth (*Plutella xylostella* L.), phytosanitary monitoring, population dynamics, abundance index, protective measures, agroclimatic zones, Northern Kazakhstan

Key findings: The presented findings can help in improving the phytosanitary monitoring and forecasting of the diamondback moth, as well as, justify effective protective measures during the transition from massive pesticide treatments to preventive pest population management.

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INTRODUCTION

The diamondback moth (*Plutella xylostella* L.) (Lepidoptera: Plutellidae) is almost the universally recognized most dangerous pest of the crop plants of the cruciferous family (Cruciferae, Brassicaceae) (Furlong *et al*., 2013; Philips *et al*., 2014; Li *et al*., 2016; Fathipour and Mirhosseini, 2017; Gautam *et al*., 2018), including the territory of Kazakhstan, and the damage intensity from its ferocity continues to grow gradually (Andreeva *et al*., 2021).

According to research conducted by Australian scientists, the annual total cost of diamondback moth control for farmers cultivating crops of the cruciferous family varies from USD 1.3 to 2.3 billion (Zalucki *et al*., 2012). However, considering the decrease in crop yields due to pests, the cost estimates will be even higher, and a 5% crop loss adds another USD 2.7 billion to the total costs associated with the bugs. Thus, the overall expenses range from USD 4 to 5 billion. The lower bound reflects rational decision-making by pest control managers based upon the abundance of diamondback moth, having also been determined by the existing climatic conditions. The upper approximation is mainly according to the common practice of weekly insecticide use and the assumption of an insecticide treatment given to rapeseed (*Brassica napus* L.) at least once during the growing season (Zalucki *et al*., 2012).

The moth population and its harmfulness have various biotic and abiotic factors affecting these, as well as, anthropogenic factors. Of the biotic factors, the host plant has a significant influence on the dynamics of the pest population. The past research carried out in the Commonwealth of Independent States (CIS) countries revealed that the feed sources like species (Schuler *et al*., 2003; Chandrashekar *et al*., 2005; Harvey *et al*., 2007; Gols *et al*., 2008; Shternshis *et al*., 2012; Andreeva *et al*., 2013; Popova and Hoang, 2015; Fathipour *et al*., 2019), and their cultivars (Saeed *et al*., 2010; Soufbaf *et al*., 2010; Askarianzadeh *et al*., 2013) affected the survival and abundance of diamondback moth.

In tropical regions like India, Brazil, Malaysia, and Senegal, the diamondback moth has the status of an economically significant pest (Uthamasamy *et al*., 2011; Sow *et al*., 2013; Mohammad *et al.*, 2014; Marchioro and Foerster, 2016). There is data from Brazilian studies exploring the effect of temperature on the reproduction rate of the diamondback moth (Marchioro and Foerster 2011). In the tropical region of Brazil, the number of generations of the diamondback moth is almost twice that in the subtropical zones of the country. These past findings confirmed at least the higher population of this species in the tropical region of Brazil also demonstrates that *P. xylostella* L. is resistant to a wide range of temperatures (6.1 °C–32.5 °C). Thus, temperature is not a limiting factor for the emergence of the diamondback moth during the entire growing season in most regions of Brazil.

The populations of cruciferous crop pests, including the diamondback moth, in various regions of Russia and Kazakhstan and globally gradually experience significant variations. The pest population disparities might refer to the cruciferous crops' acreage, the diversity of the cultivars and hybrids, and the intensive use of chemicals for its control, as well as, variations in climatic conditions (Marchioro and Foerster, 2011; Santos, 2011; Sow *et al*., 2013; Mohammad *et al*., 2014). The pest resistance development to insecticides is also one of the causes for the increased population and harmfulness of *P. xylostella* L. Observations of these facts have also been notable in different regions of the world (Santos, 2011; Kovalenkov and Tyurina, 2016; Andreeva and Shatalova, 2017; Richardson *et al.*, 2020).

According to the monitoring of the phytosanitary control services of Russia, recent years revealed the destructiveness of the diamondback moth has enhanced, with this phytophagous considered one of the dangerous pests of cruciferous crops in Russia (Andreeva and Shatalova, 2017). However, in Russia, the higher abundance of diamondback moth recordings was during the years 1998, 2000 (Ovchinnikova, 2002), 2002, 2008, and 2009 (Shternshis *et al*., 2012; Andreeva *et al*., 2013). The outbreaks of diamondback moth emergence in different regions of Russia also recurred in 2007, 2013, 2014, 2015, and 2019 (Shpanev, 2015; Poddubnaya, 2016; Andreeva and Shatalova, 2017).

A recorded significant increase in the diamondback moth population in rapeseed crops occurred in Belarus in 2014 and in 2016, led to mass reproduction (Zaprudskii *et al*., 2019). Increased planted rapeseed acreage is also one of the chief causes of boosting the diamondback moth's ferocity in Kazakhstan. According to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, in 1999, the spring rapeseed sown area was only 20,100 ha; in 2014, the planted area was 30,300 ha, and in 2018, it reached 374,300 ha.

In Northern Kazakhstan, the documented outbreaks of the diamondback moth were in 2014, 2015, 2018, 2019, and 2021. Therefore, it is crucial to know its bioecological features for the diamondback moth's effective control. During the season, the diamondback moth can develop up to 10 generations. However, in Northern Kazakhstan, the phytophagous can reach up to 2–3 generations. The sum of effective temperatures for the development cycle of the diamondback moth is 390–416 degrees. The lower temperature threshold for the development of eggs is +8 °C, +5 °C for caterpillars, and +9 °C for pupae (Andreeva and Shatalova, 2017).

The economic injury level (EIL) of the diamondback moth varies depending on the type and phase of development of the damaged crop. There are some EIL approximations for the diamondback moth on rapeseed, and during the germination period, 2–3 caterpillars per plant in 10% colonized plants, and with 10%–15% damage to the leaf surface (Gorbunov and Tsvetkova, 2001; Shpanev, 2015). To date, protective measures against the diamondback moth have progressed based on the indicator of the EIL of their abundance, at which it is necessary to carry out treatment with insecticides (Churikova and Silaev, 2020).

We propose a preventive approach to managing diamondback moth populations based on the study and analysis of seasonal and long-term population dynamics, allowing us to identify the patterns and causes of the distribution of these phytophages, along with their bioecological features. Based on this, one can build a prediction system of their number and development for the subsequent justification of protective measures, which is the main task of phytosanitary monitoring.

The study aimed to investigate the features of the population dynamics of the diamondback moth depending on environmental factors in northern Kazakhstan. Using the obtained results makes it possible to improve phytosanitary monitoring and forecasting of the diamondback moth, as well as, justify effective protective measures during the transition from massive pesticide treatments to preventive pest population management.

MATERIALS AND METHODS

The study conducted research at the Department of Biology, Plant Protection and Quarantine of the Kazakh Agrotechnical Research University named after S. Seifullin in 2021–2022. Focusing on the diamondback moth (*Plutella xylostella* L.), the rapeseed (*Brassica napus annua* L.) and mustard (*Sinapis alba* L.) were the study's selected crops in Northern Kazakhstan's different regions, i.e., Akmola, North Kazakhstan, and Kostanay, depending on the agroclimatic zones. According to records (Baisholanov, 2017a, b, c, d), agroclimatic zoning divides the territory into various zones that are adequately homogeneous within their borders for temperature and moisture availability. The distribution of the average long-term values of the humidification coefficient (C) over the territory of Northern Kazakhstan and the sum of active air temperatures above 110 °C allowed the division of Kazakhstan's plain region into six agroclimatic zones. At the same time, Zones III to VI split into subzones (a and b) according to thermal conditions. The names of the zones, the limit K values, and the sum of temperatures (ΣT_{10}) are available in Table 1.

Table 1. Agroclimatic zones of the territory of Northern Kazakhstan (Akmola, Kostanay, North Kazakhstan, and Pavlodar regions).

No.	Description of the zone	C	ΣT_{10}, °C
I	Moderately humid and moderately warm	1.0-1.2	2,000-2,300
II	Slightly humid and moderately warm	0.8-1.0	2,200-2,500
III	a) Slightly arid and moderately warm	0.6-0.8	2,400-2,500
	b) Slightly arid and warm		2,500-3,000
IV	a) Moderately arid and warm	0.4-0.6	2,500-3,000
	b) Moderately arid and moderately hot		3,000-3,500
V	a) Very arid and moderately hot	0.2-0.4	3,000-3,500
	b) Very arid and hot		3,500-4,000
VI	a) Dry and hot	< 0.2	3,500-4,000
	b) Dry and very hot		>4000

Thus, in Northern Kazakhstan, only two zones belonged to the agroclimatic zones that also grow rapeseed and mustard, i.e., Zone I (moderately humid and warm) and Zone II (slightly humid and moderately warm). Zone I includes the northern part of the Akmola region and the northern and southern parts of the North Kazakhstan region. Part of the northern and entire central part of the Akmola region, the western, middle, and eastern parts of the North Kazakhstan region, and the whole northern part of the Kostanay region belonged to Zone II.

The study used various methods of analyzing the dynamics of the abundance and population structure of harmful species (Sagitov *et al*., 2016). Using data from the surveyed areas and areas populated with diamondback moth larvae was advantageous according to the criteria of the degree of settlement (up to 5 insects/m^2, up to 10 insects/m^2, up to 15 insects/m^2, and above). These materials were available from the Republican State Institution (RGU) "Republican Methodological Center for Phytosanitary Diagnostics and Forecasts" of the State Inspection Committee (KGI) in the Agro-industrial Complex of the Ministry of Agriculture of the Republic of Kazakhstan (APK MSKh RK) from 2012 to 2022 within the framework of cooperation of the research university with these organizations.

The distribution dynamics of different types of pests also varied depending upon the nature of their responses to the environmental conditions. It determines the range and speed of variation in the distribution of each species, i.e., quantitative changes in the population processes of pests belonging to the existing species. Population processes were characteristic of factors affecting the development of insects of the same species living in a particular region.

The mass appearance of harmful species in particular periods was an indicator of variations in the abundance of insects over time. The state of the pest population dynamics consists of stages, such as, depression, population growth, mass reproduction, peak abundance, and decline in abundance, as established by statistical and mathematical methods based on the analysis of population dynamics over several years. In identifying the phase state of pests in the analyzed years, calculations of the prime indicators measuring the pest population levels also ensued on various crops. These were the relative (Z_{rel}), basic (Z_{bas}), and absolute (Z_{abs}) populations formulated based on long-term official data using the following formulas (Azhbenov, 2010; Dubrovin *et al*., 2011):

$$Z_{bas} = (P_z\,[0-5] \times N_{av}\,[0-5]) + ... + (P_z\,[>30] \times N_{av}\,[>30]) / P_z$$

$$Z_{rel} = P_z \times 100 / P_o \qquad (1)$$

Where:
Z_{rel} is the relative population (%)
P_z is the populated area (thousand ha)
P_o is the surveyed area (thousand ha)

$$Z_{bas} = (P_z[0-5] \times N_{av}[0-5]) + ... + (P_z[>30] \times N_{av}[>30]) / P_z \quad (2)$$

Where:
Z_{bas} is the basic population (insects/one m^2)
P_z [0-5]... [>30] is the populated area with population density in insects/1 m^2 (thousand ha)
N_{av} [0-5]...[>30] is the average population density (insects/one m^2)
P_z is the populated area (thousand ha)

$$Z_{abs} = Z_{rel} \times Z_{bas}/100 \quad (3)$$

Where:
Z_{abs} is the absolute population (insects/one m^2)
Z_{rel} is the relative population (%)
Z_{bas} is the basic population (insects/one m^2)

In population processes, displaying the quantitative variations over time can result using population indices. The most significant population indices were those that characterize the variation in the number of pests on crops, the intensity of reproduction, and the dynamics of populations, including the settlement coefficient (C_{set}), the colonization coefficient (C_{col}), the reproduction coefficient (C_{rep}), the settlement energy (E_{set}), the reproduction energy (E_{rep}), and the progradation coefficient (C_{pro}). Computations for all the above used the following formulas:

$$C_{set} = Z_{rel(j)}/Z_{rel(j-1)} \quad (4)$$

Where:
C_{set} is the settlement coefficient
$Z_{rel(j)}$ is the relative population in the (j)th year
$Z_{rel(j-1)}$ is the relative population in the (j-1)th year

$$C_{col} = Z_{bas(j)}/Z_{bas(j-1)} \quad (5)$$

Where:
C_{col} is the colonization coefficient
$Z_{bas(j)}$ is the basic population in the (j)th year
$Z_{bas(j-1)}$ is the basic population in the (j-1)th year

$$C_{rep} = C_{set} \times C_{col} \quad (6)$$

Where:
C_{rep} is the reproduction coefficient
C_{set} is the settlement coefficient
C_{col} is the colonization coefficient

$$E_{set} = C_{set(j)} \times C_{set(j-1)} \quad (7)$$

Where:
E_{set} is the settlement energy
$C_{set(j)}$ is the settlement coefficient in the (j)th year
$C_{set(j-1)}$ is the settlement coefficient in the (j-1)th year

$$E_{rep} = C_{rep(j)} \times C_{rep(j-1)} \quad (8)$$

Where:
E_{rep} is the reproduction energy
$C_{rep(j)}$ is the reproduction coefficient in the (j)th year
$C_{rep(j-1)}$ is the reproduction coefficient in the (j-1)th year

$$C_{pro} = E_{set} \times E_{rep} \quad (9)$$

Where:
C_{pro} is the progradation coefficient
E_{set} is the settlement energy
E_{rep} is the reproduction energy

Selyaninov's hydrothermal humidification coefficient (HTC) calculation employed the formula:

$$C = R \times 10/\Sigma t \quad (10)$$

Where:
R is the sum of precipitation in millimeters for a period with temperatures above +10 °C, and Σt determines the sum of temperatures (°C) for the same time.

Statistical analysis of the data of the study results by year continued using the Statistica Basic Academic software for Windows 13 Ru/13 En.

Table 2. Population density of diamondback moth caterpillars depending on the agroclimatic zones of Northern Kazakhstan for 2012–2022.

Years	Relative population density (% Z_{rel})		Absolute population density (pcs/m^2 Z_{abs})	
	Zone I	Zone II	Zone I	Zone II
2012	62	74.3	2.9	2.5
2013	83.9	67.5	3.7	2.9
2014	93.3	100	4.1	5.7
2015	94.8	84	5.3	4.1
2016	89.7	80	3.9	3.9
2017	78.6	77.2	2.9	2.7
2018	76.4	100	3.1	5.5
2019	79.9	99	5.9	6.1
2020	69.5	90.3	2.8	3.7
2021	58.6	100	2.2	5.2
2022	36.5	100	1.7	3.5

Table 3. Phases of population dynamics of the diamondback moth depending on diagnostic indicators of pest population density (analysis for 2012–2022).

Dynamic phase	Diagnostic indicators of population density	Analyzed years	
		Zone I (moderately humid and moderately warm)	Zone II (slightly humid and moderately warm)
Depression	Zabs minimum	2022	
Rise in abundance	Zabs ≥ optimum	2013, 2014, 2018	2012, 2013
Mass reproduction	Zabs maximum	2015, 2019	2014, 2018, 2019, 2021
Peak abundance	Zabs ≤ maximum	2012, 2016, 2017, 2020	2015, 2016, 2017, 2020, 2022
Decline in abundance	Zabs ≤ optimum	2021	

RESULTS AND DISCUSSION

Diamondback moth population dynamics pattern

The analysis of the main patterns of population dynamics of the diamondback moth in agroclimatic zones of Northern Kazakhstan from 2012 to 2022, the dynamics of population density indicators and measures of the population density levels by year, as well as, indices of the abundance of non-resident locusts attained establishment. The comprehensive analysis of the dynamics of the phytophagous population helped determine the profusion of the pest and its variability. The analytical results ascertained quantitative indicators of the state of the populace, such as, absolute and relative population density (Table 2).

The numerical data results on absolute population density and variations in the phases of population dynamics (depression, population rise, mass reproduction, peak, and decline in abundance) were according to the analyzed years of the study (Tables 2 and 3). Thus, based on diagnostic indicators, mass reproduction was evident in Zone I during 2015 and 2019, with the population peak in 2012, 2016, 2017, and 2020 and a decline in 2021. In Zone II, mass reproduction happened in 2014, 2018, 2019, and 2021, with the population peak recorded in 2015, 2016, 2017, 2020, and 2022.

Population dynamics of diamondback moth

Based on the surveyed area, and after determining the population density, the indices of the diamondback moth population obtained calculations, showing the level of settlement, colonization, and reproduction of the pest depending on the current and previous

Table 4. Population dynamics indices of diamondback moth caterpillars (average for 2013–2022, Zone I: moderately humid and moderately warm).

Years	Colonization coefficient	Coefficient of settlement	Reproduction coefficient	Colonization energy	Reproduction energy	Progradation coefficient
2013	1.35	0.95	1.42	1.43	1.5	0.95
2014	1.04	1.0	1.04	0.77	0.73	1.05
2015	1.01	1.24	0.81	0.97	0.77	1.25
2016	0.94	0.78	1.2	0.93	1.48	0.62
2017	0.87	0.86	1.01	0.92	0.84	1.09
2018	0.97	1.1	0.88	1.11	0.87	1.27
2019	1.04	1.79	0.58	1.07	0.65	1.64
2020	0.87	0.54	1.61	0.83	2.7	0.30
2021	0.84	0.95	0.88	0.96	0.54	1.7
2022	0.62	1.23	0.50	0.73	0.56	1.3
St. dev.	0.186741057	0.334969319	0.346572102	0.200709851	0.668783307	0.426303231

Table 5. Indices of the abundance of caterpillars of diamondback moths, (average for 2013–2022, Zone II: slightly humid and moderately warm).

Years	Colonization coefficient	Settlement coefficient	Reproduction coefficient	Settlement energy	Reproduction energy	Progradation coefficient
2013	0.9	1.2	0.75	0.64	0.70	0.91
2014	1.4	1.3	1.06	1.5	1.5	1.07
2015	0.82	0.87	0.94	0.58	0.88	0.65
2016	0.96	0.97	0.98	1.17	1.04	1.25
2017	0.96	0.71	1.35	1	1	1
2018	1.2	1.2	1.0	1.3	0.74	1.75
2019	0.99	1.37	0.72	0.76	0.72	1.05
2020	0.91	0.67	1.35	0.91	1.87	0.48
2021	1.1	1.2	0.89	0.91	0.65	1.4
2022	1	0.67	1.49	0.90	1.67	0.53
St. dev.	0.169325459	0.271628832	0.261960557	0.288253361	0.443597666	0.396300952

analyzed years. Analytical studies execution also ran in two agroclimatic zones, i.e., Zone I – moderately humid and moderately warm, and Zone II – slightly humid and moderately warm in Northern Kazakhstan (Lestari *et al.,* 2015; Babayan, 2022; Saimova *et al.,* 2022). The results of the calculated population indices appear in Tables 4 and 5, and the fluctuation in the population indices of the diamondback moth population dynamics for 2012–2022 are visible in Figures 1 and 2.

The data recorded on the abundance indices of the diamondback moth by agroclimatic zones is illustrative in Figures 1 and 2. In this case, a variation arose in the phases of the pest population over the period from 2012 to 2022, which was a key indicator in predicting variations in the dynamics of the abundance of phytophages in question. Weather conditions are also vital factors influencing the dynamics of the abundance and species diversity of harmful insects (Saeed *et al*., 2010; Soufbaf *et al*., 2010; Askarianzadeh *et al*., 2013).

Selyaninov's HTC, as a chosen integral indicator of the weather conditions, simultaneously shows the effects of temperature and precipitation on the growth and development of pests. Thus, Figures 3 and 4 present the results of a comparative analysis of variations in the HTC for 2012–2022 in two agroclimatic zones of Northern Kazakhstan, growing rapeseed and mustard. Further, Figures 4 and 5 show the relationship of the change in the HTC with the absolute population density of the diamondback moth by year (Tables 6 and 7).

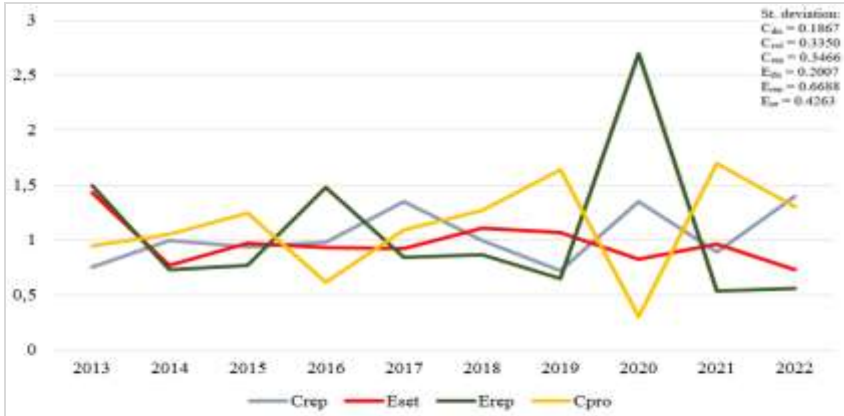

Figure 1. Fluctuation of indices of population dynamics of the diamondback moth, (2013–2022, Zone I: moderately humid and moderately warm).

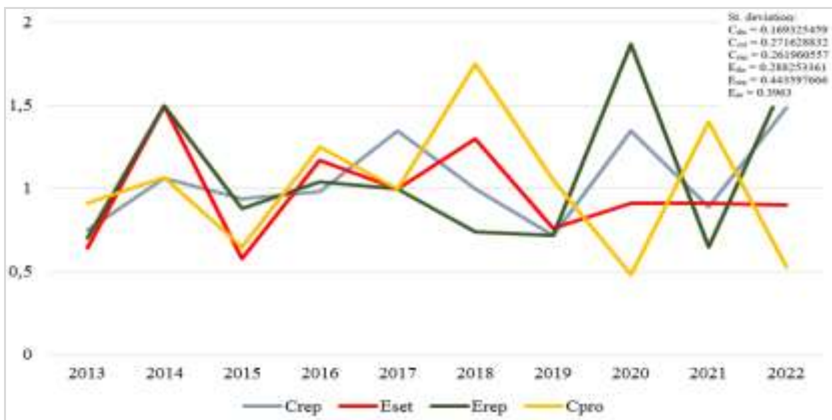

Figure 2. Dynamics of indices of the abundance of the diamondback moth, (2013–2022, Zone II: slightly humid and moderately warm).

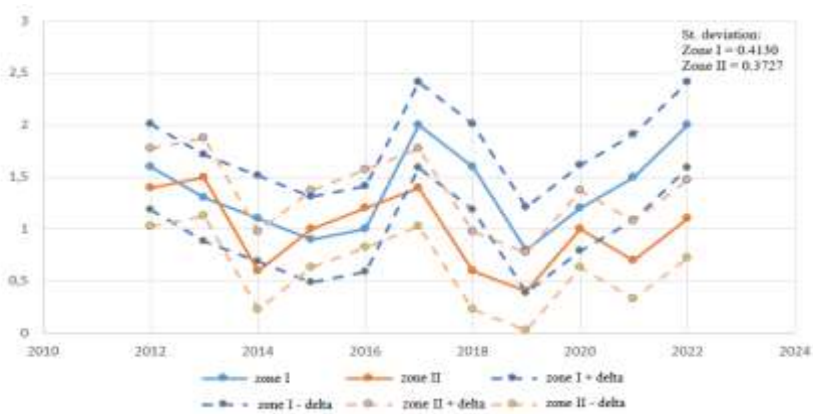

Figure 3. Comparative analysis of the dynamics of the HTC indicator by year, on average, in Northern Kazakhstan for 2012–2022 in two studied agroclimatic zones (Zone I: moderately humid and moderately warm; Zone II: slightly humid and moderately warm).

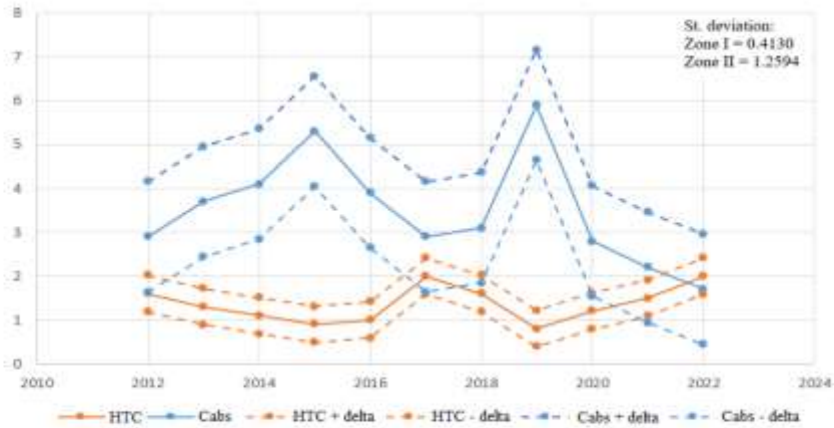

Figure 4. The relationship between the HTC and the absolute population density of diamondback moth caterpillars, on average, in the agroclimatic zones for 2012–2022.

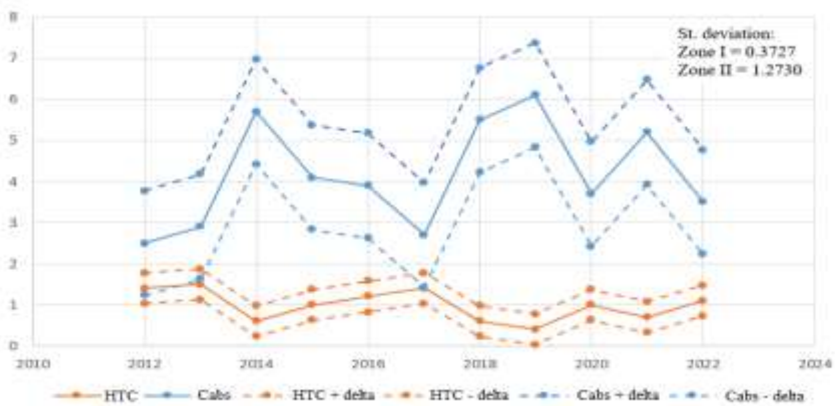

Figure 5. The relationship between the HTC and the absolute population density of diamondback moth caterpillars, on average, in the agroclimatic zones for 2012–2022.

Table 6. Population density of diamondback moths on cruciferous crops, 2012–2022 (Zone I: moderately humid and moderately warm).

Years	Surveyed area, thousand ha	Settlement area, thousand ha	Including, insects/plant			Treated area
			up to 2	2-5	>5	
2012	98.33	61.70	43.25	16.25	2.2	18.45
2013	73.70	61.90	46.45	15.45	-	15.45
2014	75.02	70.06	50.86	19.2	-	19.2
2015	76.77	72.81	39.09	25.94	7.78	33.72
2016	79.85	71.68	57.23	10.95	3.50	14.45
2017	52.19	41.07	37.41	3.66	-	3.66
2018	72.6	55.52	44.89	9.63	-	9.63
2019	72.88	58.19	47.02	10.99	0.18	11.17
2020	69.58	48.38	41.42	6.96	-	6.96
2021	34.0	12.41	8.10	4.31	-	4.31
2022	34.5	20.25	17.81	2.44	-	2.44

Table 7. Population density of diamondback moths on cruciferous crops, 2012–2022 (Zone II: slightly humid and moderately warm).

Years	Surveyed area, thousand ha	Settlement area, thousand ha	Including, insects/plant			Treated area
			up to 2	2-5	>5	
2012	7.15	5.25	5.25	-	-	-
2013	6.25	4.22	3.32	0.90	-	0.90
2014	7.0	7.0	3.15	3.85	-	3.85
2015	7.0	5.80	3.60	2.20	-	2.20
2016	7.0	5.60	3.65	1.95	-	1.95
2017	4.0	3.09	3.09	-	-	
2018	5.50	5.50	4.13	1.37	-	1.37
2019	5.50	5.45	1.75	3.70	-	3.70
2020	5.50	4.97	4.0	0.97	-	0.97
2021	0.679	0.679	0.469	0.300	-	0.300
2022	1.0	1.0	1.0	-	-	-

In Zone I, the HTC ≤ 1 values were evident in 2015, 2016, and 2019, while for Zone II, in 2014, 2015, 2018, 2019, 2020, and 2021 (Figure 3). Of the 11 analyzed years, the dry years' phenomena emerged three times in agroclimatic Zone I and six times in Zone II. The optimal temperature for the growth and development of the diamondback moth is 10 °C; however, it can also develop at an air temperature of 5 °C in a wide range of humidity. The upper-temperature limit of development that the diamondback moth survives is 35 °C to 37 °C, which is 2 °C to 3 °C above the permissible level for other insects. The embryonic development of the diamondback moth depends on the temperature regime. At an average daily air temperature of 14 °C to 18 °C and HTC of 2.3, the caterpillar appears after 9–12 days and after 20 °C to 25 °C and HTC of 1.5, after 4–7 days. The development of diamondback moth caterpillars lasts from 30 days at a temperature of 14 °C to 16 °C to 20 days at 17 °C to 19 °C, and up to 10 days at 23 °C to 25 °C.

For the reproduction and development of the diamondback moth, the dry and hot weather conditions are favorable. Cool and rainy weather negatively affects the reproduction and development of moths, leading to a decline in the pest population. An analysis considering the HTC and absolute population density determined the influence of weather conditions on the development and reproduction of the diamondback moth. Figures 4 and 5, in the form of curves, provide the indicators of HTC and Zabs, where one can see a significant difference in the level of harmfulness of diamondback moth caterpillars in different agroclimatic zones. Thus, in Zone I, the abundance of diamondback moth caterpillars above EIL appeared twice, whereas in Zone II, it was evident four times. Hence, based on Figures 4 and 5, the intensity of development and reproduction of the diamondback moth grew under conditions of elevated temperatures and low HTC. In years with high air temperature and low humidity, the diamondback moth caterpillar causes complete or partial death of cruciferous seedlings (rapeseed, mustard) due to mass reproduction. Therefore, controlling the abundance of diamondback moths is an essential element for growing cruciferous crops (TOO Pervaya Agrokhimicheskaya Kompaniya, 2019).

A problem in diamondback moth control is the search for effective chemical agents, viz., insecticides. By applying the recommended insecticides against the diamondback moth, one must bear in mind that this pest may be resistant to active substances of chemical preparations. Therefore, if the phytophagous does not respond to the used insecticide, it needs replacement with another chemical agent. However, in this case, mixed preparations of more than one insecticide may be more effective. According to their biology, diamondback moth butterflies are active at dusk and night, but at high temperatures, their abundance increases, and daytime activity becomes more pronounced. The strengthening of the daytime swarming of butterflies serves as a signal of the outbreak of pest reproduction. The EIL of a pest is critical when detecting 2–5 caterpillars on a plant if colonization is 10% in plants.

Analysis of the effect of chemical treatments continued on the absolute population density of diamondback moth caterpillars in rapeseed crops from 2012 to 2022 by agroclimatic zones. Figure 6 shows that the volume of chemical treatments impacted the decrease in the absolute population density index. From 2012 to 2014, the decline in absolute population density was insignificant. In subsequent years, the chemical treatments contributed to a decrease in the number of caterpillars per plant. In Zone II, the population density of diamondback moth caterpillars on rapeseed plants was significantly lower compared with Zone I (Figure 7).

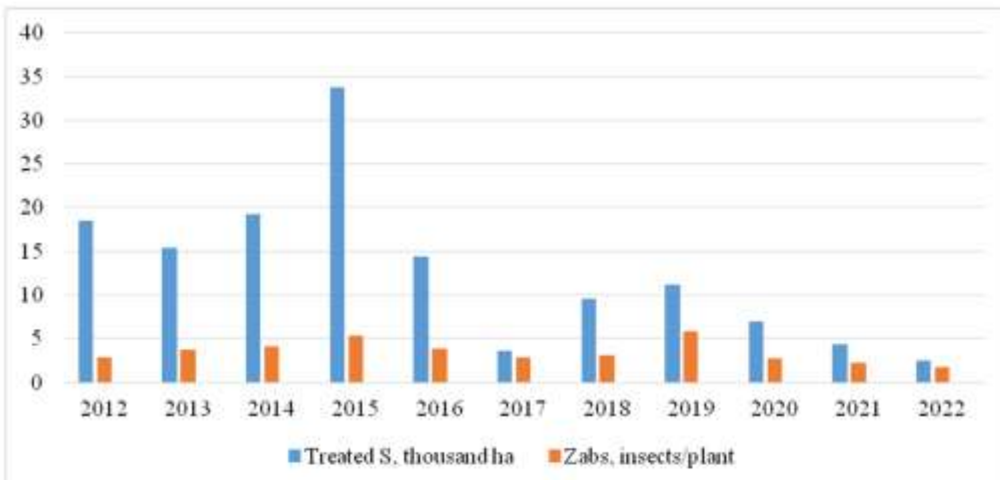

Figure 6. The relationship between the area inhabited by diamondback moth caterpillars and the area treated with pesticides, 2012–2022. (Zone I: moderately humid and moderately warm).

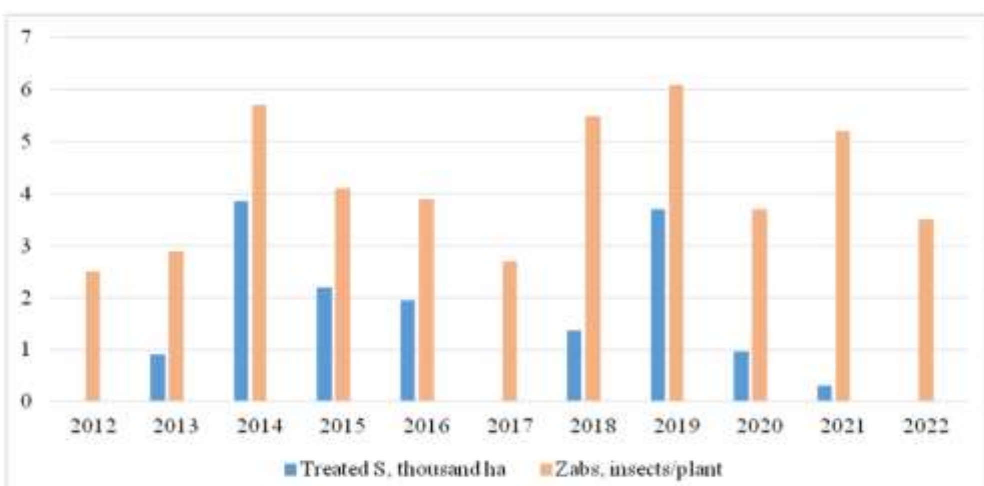

Figure 7. The relationship between the area inhabited by diamondback moth caterpillars and the area treated with pesticides, 2012–2022, (Zone II: slightly humid and moderately warm).

In 2012, the absolute population density was 2.5 insects/plant, which did not exceed EIL, and, accordingly, the chemical treatment also did not proceed. In 2013, the indicator rose to 2.9 insects/plant, which illustrated an increase in the number of diamondback moth caterpillars per plant and the need for chemical treatment. By 2014, the absolute population density index reached a critical level of 5.7 insects/plant, causing a massive reproduction of this pest. In the following years, chemical treatments ensued until 2017. In 2017, no treatment took place, and thus, in 2018 and 2019, the number of diamondback moth caterpillars reached a level above the EIL. The protective measures taken against the diamondback moth in 2018 and 2019 caused a decrease in population density by almost two times in 2020, and a reduction in the area of treatments in 2020 led to an increase in population density in 2021. In the histograms for chemical treatments by agroclimatic zones, an observation can suggest that chemical treatments significantly contributed to reducing the abundance of caterpillars not only during the growing season but also in subsequent years. However, in contrast, a decrease in the volume of chemical treatments contributed to a direct increase in the pest population.

CONCLUSIONS

The long-term data on the development and distribution of diamondback moths in the agroclimatic zones of Northern Kazakhstan revealed the regularity of variations in the dynamics of the pest population, which is one of the chief factors of phytosanitary forecasting. Besides, the indices of diamondback moth abundance were also well-defined. These indices were the prime indicators for diagnostic predictor schemes of pest populations and their quantitative indicators for predicting the pest population. Chemical treatment had a temporary effect on reducing the abundance of phytophages; however, the profusion of pests depended on the volume of the chemical treatment. The proposed approach can be considerably vital in predicting the cyclical nature of the mass reproduction of diamondback moths.

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