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We conclude that grain suffers more damage when it acts as the source patch than the sink patch. Resident infestation elicits more grain damage and weight loss than visiting infestation in the short term; but both elicit equal losses in the long term. *P. truncatus* and *C. ferrugineus* prefer the bottom levels of grain, whereas *S. cerealella* prefers top levels. *T. castaneum* and *S. zeamais* did not show any specific grain depth preferences.

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Climate change and its implications on stored food grains

Daphna Gottlieb^{1*}, Elazar Qvinn¹, Mula Nega¹, Aviv Rapaport^{1,2}, Josef Doron¹, Moshe Kostyukovsky¹

¹Department of Food Quality & safety, Institute for Postharvest and Food Science, The Volcani Center, ARO, Israel.

²Faculty of Agriculture, Food and Environment, Hebrew university, Israel.

*Corresponding author. E-mail: dafnag@volcani.agri.gov.il

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Abstract

Safe food grain storages are considered as a measure to adapt to the changing global climates and as a channel to food security, particularly in periods when agriculture fails. However, grain storage themselves can be heavily affected by changing global climates. One main aspect of the 'climate change' is the rise of global temperature that may lead to an increase in atmospheric humidity. This climate change, warm and humid, are not suitable for grain storage. At such a scenario, stored grain is at a risk due to the favorable conditions developed for the growth of insect pests. Predicting the future ecological impact of climate change drivers requires understanding how these same drivers have acted in the past on the dynamics of insect's population. In the past ten years there has been a detailed documentation on the biotic and abiotic conditions of two storage sites in Israel. This historical ecological data can reveal long-term consequences of multiple drivers of climate change. The changes can be evident at the level of the species and at the level of the societies of insect-pest in the grain storage. The differences between two storages located at different climate regions in Israel further predict the direction current IPM practice may lead to. Following this understanding, we hope to develop feasible mitigation strategies that might overcome the changes ahead of us.

Keywords: Climate change, Historical ecology, grain storage insects

Introduction

The annual consumption of grain for human and animal consumption in Israel is about 5.1 million tons worth about 1.5 billion dollars. The insects living in grain storage can cause a great deal of economic damage: reduction in quantity and quality of the grains. In developing countries the damage can reach 30-50% and in developed countries the weight loss of grain after a prolonged storage period reaches up to 5-10%. In recent years, there is an increase in the population of grain storage insects [1]. There is a struggle to control the increase via raising the quantities and frequency of the provision of pesticides. This study examines the effect of climate change on the increase of insect populations in storage.

Much work has been done to examine the appropriate climatic and geographical position for grain storage. However, there is limited information to allow careful examination of the effect of climate change on the biotic factors, their interactions and their impact on the vulnerability of the grain storage. Insects infesting grain storages, among them: *Sitophilus oryzae* (Linnaeus), *Tribolium castaneum* (Herbst), *Rhizopertha dominica* (Fabricius), and *Oryzaephilus surinamensis* (Linnaeus), have a major effect on the quality and quantity of stored grains. They constitute a real threat that amounts to large economic losses [1]. The climatic changes can lead to changes in the geographical distribution of the pests, but also within the storage itself, such as changes in the rate of population development, an increase in the number of generations, an increase in the season of activity and changes in synchronization between the time of gathering the seeds from the field and the time of insect activity [2, 3, 4, 5]. One of the most prominent effects on insects' success in grain storages is temperature [6]. The temperatures at which the insects can survive in a grain storage range from 8-41 °C [1] with the optimum temperature ranging between 25 °C and 35 °C [1]. Environmental changes outside of this temperature range can directly and indirectly affect the storage insects. Climate changes can affect interactions and lead to the strengthening and / or extinction of species from the warehouse [7]. This work examines the possible significant interactions in the storage and their character (negative or positives) in light of future climate changes.

Materials and Methods

Storage facility

The study was conducted at two sites; northern site (NS) located in the Mediterranean climate zone in Israel (Jazreel Valley) and southern site (SS) located in a semi-arid zone, in the Negev desert. Each site has several storerooms (NS-10, SS-7). The storerooms are made from concrete and have solid roof. Grain introduction and fumigation are conducted yearly.

Sampling

In each storeroom temperature in-between flour grains, captured moisture of seeds and species presence were estimated monthly ranging between 1-34 locations on the grain mount, depending on the amount stored. Temperature in-between grains was estimated via a thermometer probe pushed 1 and 2 meters inside the grain mount. Grain moisture content was estimated in the lab. The presence of live insects was directly estimated via 1 kilo of seeds collected.

Results

In total, 147,328 insects were found during the entire sampling period. These can be characterized in 8 Coleoptera species and 2 Lepidoptera species (Table 1). The most abundant Coleoptera were *S. oryzae* and *O. surinamensis*. These two species correspond to >>50% of the total number of the individual collected. For Lepidoptera the most numerous Lepidoptera species were *P. interpunctata*, corresponding to 1% of the number of individuals found. Grain moisture content was in the range of 5-25%, temperature at the depth of 1 meter from the surface of the grain mount was 15-58°C and 2 meter below surface 15-46°C. Whereas the range of temperature in Israel during the sampling period 6-43°C.

Site characteristics

Abiotic factors outside the storage- NS and SS annual temperature and humidity similarly deviate from the mean temperature and humidity 2008-2017. Whereas southern site is characterized in significantly higher temperature ($t_{(106)}=5.276$, $P<0.0001$, Fig. 1.1a,b) and lower humidity ($t_{(106)}=3.142$, $P<0.0001$).

Abiotic factors inside the storage- grain moisture content, temperature at 1 meter below grain surface and temperature 2 meters below surface were significantly higher at the SS (Table 2).

Insects' dynamics

SS had in total more insects than the NS (Table 2). At both sites there is a significant linear regression between the years since the commodity started to function and the level of infestation (NS; $R^2=0.870$, $P<0.001$, SS; $R^2=0.737$, $P<0.003$). In 2010 *S. oryzae* is the dominant pest both NS and SS. After 2010, in the north the dominancy alternates between *S. oryzae* and *O. surinamensis* and in the southern storage *O. surinamensis* uniquely dominates the storage. There is a significant negative correlation between *S. oryzae* and *O. surinamensis* in both sites (NS; Pearson -0.956, $P<0.0001$ and SS; Pearson -0.983, $P<0.0001$, Fig. 1). There is no evident correlation between these species and the other species in both sites (Pearson ranges between -0.204 to -0.083, P value between 0.848 to 0.628).

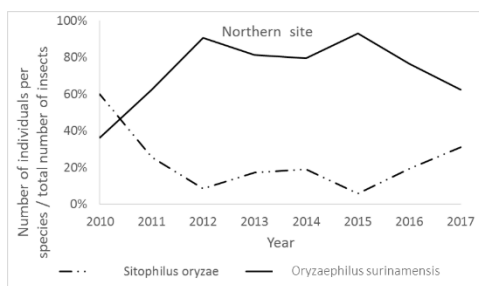


Fig. 1a Proportion of two main species found in the grain storage at the Northern Site.

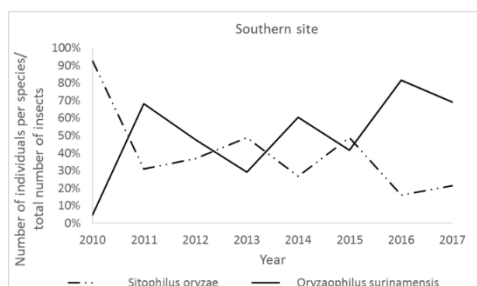


Fig. 1b Proportion of two main species found in the grain storage at the southern site.

Table 1. Insects found during the entire sampling period.

Species/taxa	%Southern Site	%Northern Site
Coleoptera		
Silvanidae		
<i>Oryzaephilus surinamensis</i>	55.542	66.941
Curculionidae		
<i>Sitophilus oryzae</i>	24.133	14.987
Tenebrionidae		
<i>Tribolium castaneum</i>	12.859	11.072
<i>Tenebrio molitor</i>	0.000	0.014
<i>Tenebrio mauritanicus</i>	0.078	0.011
Bostrichidae		
<i>Rhyzopertha dominica</i>	0.311	0.909
Mycetophagidae		
<i>Typhae stercorea</i>	0.041	0.032
Cucujidae		
<i>Cryptolestes ferrugineus</i>	6.549	1.539
Lepidoptera		
Gelechiidae		
<i>Sitotroga cerealella</i>	0.063	1.384
Phycitidae		
<i>Plodia interpunctella</i>	0.424	3.111

Table 2. In-between grain temperature at 1 and 2 meters below grain mount surface, grain moisture content and total number of insects (both latter collected from the surface of the grain mount).

	Site	n	Mean	± std	F	P
Temperature (°C)-1 meter	NS	449	28.07	5.193	8.622	0.003
	SS	1300	28.23	4.547		
Temperature (°C)-2 meter	NS	796	30.67	4.273	5.390	0.020
	SS	1681	31.08	4.032		
Grain moisture content (R.h)	NS	1946	11.70	0.969	33.178	<0.0001
	SS	3734	12.09	2.897		
Total number of insects	NS	1974	18.46	66.02	16.589	<0.0001
	SS	3782	25.25	46.69		

Discussion

Our understanding of climate change and its implications on stored food grains, is still limited. The historical ecological data collected in the north and south of Israel can unravel long-term consequences of multiple drivers of climate change. The most prominent result of this study is that infestation levels are higher at the southern site of Israel. Such an observation stands in accordance with the faster developmental rate at higher temperature and humidity (so long it does not exceed the maximum temperature of survival). The main insect species that dominant the northern and southern grain storage are *S. oryzae* and *O. surinamensis*. The results of this study reveal significant negative correlation between the species. There are two non-mutually exclusive explanations; 1- dynamics between primary, *S. oryzae*, and secondary pests *O. surinamensis*. Grain damage caused by primary pest are known to facilitate colonization by secondary pests and reduce the infestation level of the primary pests [8]. 2- Each species has a unique range of optimal temperature, humidity and time of activity. This explanation stands in accordance with previous studies indicating that they have different spatial distribution [9] and temporal distribution (personal observation, Gottlieb Daphna). Although both explanation can explain the phenomenon the first is less likely as it assumes that there is a limited amount of grains in the storages. We are currently conducting a detailed analysis of monthly data to reveal the possible interaction between these species.

In both sites there is a significant linear regression between the years since the commodity started to function and the level of infestation. This can suggest that the facility itself, during the course of the years, accumulates increased amount of insects and treatment in-between storage is not sufficient or the insects developed resistance to pesticides (e.g. previous studies [10]). We are currently studying populations' dynamics within the year to reveal if a new harvest of grains initiates with high infection or if the infection level is equal in all years at the beginning of the storages but reacts differently to insecticides.

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Innovative stored plant products in Germany and the potential threat by native and invasive pest insects

Benjamin Fürstenau*, Kathrin Heindorf, Cornel Adler, Garnet M. Kroos

Julius Kühn-Institut, Federal Research Centre for Cultivated Plants, Institute for Ecological Chemistry, Plant Analysis and Stored Product Protection, Königin-Luise-Str. 19, 14195 Berlin, Germany,

*Presenting author

E-Mail: benjamin.fuerstenau@julius-kuehn.de, garnet-marlen.kroos@julius-kuehn.de

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Abstract

Climate change, economic-political developments as well as new trends in diet and in bio-economy considerably influence the assortment of cultivated plants in Germany and thereby, determine the plant products which have to be stored after harvest. In the light of the International Year of Pulses 2016 and also, as a result of the European Soya Declaration, the acreage cultivated with new plants such as pulses, stress tolerant wheat varieties and also oil seed rape expanded worldwide. Due to increasing stocks of novel commodities, the emergence of economically important insects infesting stored products and the possible risk caused by native and invasive pest species have to be generally considered during storage. In this overall context, we studied the capacity of various stored-product pest insects to infest two important pulses. In laboratory tests different varieties of soy and lupine have been offered as whole seeds, grist and flour to selected moth and beetle species common in Germany. Over 14 weeks we examined the developmental time from egg to eclosion as well as the number of adults in the F1 generation compared to control insects reared on their standard feeding substrate. First findings under laboratory conditions (20-25 °C, 65-70 % RH) indicate that these innovative stored products, and in particular its simply processed plant products are highly susceptible to moths (i.a. *Ephestia elutella*, *Plodia interpunctella*) and to a much lesser extent also to some beetle species (i.a. *Callosobruchus chinensis*, *Tribolium confusum*), but the usually recommended optimal storage conditions ($T \leq 16$ °C, $RH \leq 65\%$) can prevent a loss of volume and quality.