Changes in the distribution and pest risk of stored product insects in Europe due to global warming: need for pan-European pest monitoring and improved food-safety

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Abstract. Global warming affects the distribution of stored product pest insects across Europe in a way comparable to field crop and orchard pests. Nevertheless, stored product research has been neglected in Europe and detailed monitoring is lacking. This paper aims to illustrate current knowledge about the movement of storage pests up north today triggered by altered environmental conditions. In addition, it stresses the need for a pan-European surveillance to monitor the distribution, movement and spreading of stored product pests in a rapidly changing environment. Global warming and a growing number of extreme weather conditions may influence on climate and can negatively affect global food security, especially in the case of durable commodities, which are of fundamental importance for human nutrition. It is thus suggested that the distribution of stored product pests within Europe is uniformly monitored and studied by a joint initiative. Furthermore, for additional food safety the World Food Program should receive more support to fund research needed and provide larger food storages in regions prone to agricultural instability. It is also suggested that the missing quarantine/ regulated status for the most serious stored product and invasive pests (such as *Trogoderma granarium*) should be re-evaluated in the EU.

Stored product insects are not confined to stored products

The keyword "global warming" does not immediately trigger thoughts about stored product insect pests because one generally assumes these insects occur in storages where they are protected from external weather conditions (Hodges et al. 2014). Moreover, these pests are expected to develop only in a warm or heated, human-made environment, which may limit their distribution in cooler climates. However, contrary to general perception stored product pests do also occur out in the field. In Southern and Central Europe stored product insects can be found outside on their way actively searching for new habitats. In a project on long-term grain storage, adults of the Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera, Pyralidae) were caught in outside funnel traps coinciding with infestation in unsealed grain storages (Adler et al. 2015). While the occurrence of stored product insects outside, in the open field, e.g. in arable crops, such as maize, is expected to be common in tropical areas, there are several paradigms illustrating large population densities of stored product insects in weeds, cereal crops, vineyards etc. (Mohandass et al. 2007, Trematerra 2015). According to unpublished data (Trematerra et al.), in Italy and Serbia the occurrence of the maize weevil, *Sitophilus zeamais* Motschulsky

(Coleoptera, Curculionidae) has in recent years steadily increased in the fields during the growing season.

Bruchids (Coleoptera, Chrysomelidae) are a specific group of storage pests known to attack and invade host plants in the field after the flowering period (Raina, 1971; Schmale et al., 2002; Antoin et al., 2005; Hagstrum and Subramanyam, 2006). Only some genera of the subfamily Bruchinae, such as *Acanthoscelides* and *Callosobruchus*, can attack dry seeds during storage, while the primary infestation often occurs in the field.

More than thirty years ago, Buchelos (1989) found thistles in Greece with individuals of the cigarette beetle, *Lasioderma serricorne* (F.) (Coleoptera, Anobiidae), the lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera, Bostrichidae) and the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). Within another project devoted to monitoring tobacco pests from the field to a cigarette factory in Portugal, adults of *L. serricorne* and the tobacco moth, *Ephestia elutella* (Hübner) (Lepidoptera, Pyralidae) were caught in several tobacco fields using sticky traps and specific pheromones (Carvalho et al., 2000). More recently, Buonocore et al. (2017) found *R. dominica* infesting olive groves in Sicily, Italy, while Trematerra (2015) found a considerable distribution of the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera, Gelechiidae) in different types of crops in Central Italy. Also, in Serbia a significant number of *S. cerealella* infestations on maize in the field was recorded in the last decade (Gvozdenac unpubl. data). Kucerova et al. (2005) documented that outdoor-populations of the granary weevil, *Sitophilus granarius* (L.) (Coleoptera, Dryophthoridae) may continually occur in the vicinity of grain storages during warm periods of the year in the Czech Republic. Kleydysz et al. (2015) recorded, using Johnson suction trap for flying insects, outdoor occurrence of several stored-product Coleoptera species in arable landscape in Poland. During a one-year period in 2009, the traps caught 2,869 beetle specimens, of which 13.7 % were stored product pests including 63 specimens of *R. dominica*. Apparently, stored product insects can be mostly considered open area insect species that co-evolved with mankind from the onset of agriculture (Hagstrum and Phillips 2017). Eventually, storage of agricultural commodities by humans made these species stored product insects (Plarre 2013).

Global warming and factors affecting food security

In recent years, global warming and extreme weather conditions affect the complete agricultural production chain. Harvests become increasingly insecure if the frequency of drought periods, flooding, hurricanes, wild fires, late frosts, or hail storms increase. While these incidents may lead to rising prices locally or on the global market due to scarcity and thus indirectly affect stored product protection, there is also a direct effect of global warming on the occurrence and distribution of storage pests further north in Europe. There has been little discussion of the impacts of climate change on postharvest agriculture. Many studies have focused on potential crop yield and pre-harvest implications of different climatic projections, but have omitted an analysis of the need and ability to then protect this increasingly valuable harvest as a vital aspect of food security. Sudden changes in humidity during ripening in the field can reduce the storage durability of a bulk of grain by several years (BLE grain inspector K. Müller, Germany, personal communication). Postharvest systems are affected by changes in temperature, rainfall, humidity, as well as the natural and human responses to climate change (Stathers et al. 2013). Historical trends and models suggest that sustained wheat production will be more difficult under projected climate change (Asseng et al. 2014; Challinor et al. 2014; Wilcox and Makowski, 2014). Unfortunately, these projections are limited in that they do not incorporate constraints on production from diseases, weeds and insect pests. Incorporating these factors is a significant challenge because information is limited (Eigenbrode 2017).

Sufficient amounts of stored grain may be considered a measure to adapt to the changing global climate and a backbone of food security, particularly in periods when agriculture fails.

However, grain storage itself can be affected by changing global climates. One main aspect of climate change is the rise of global temperature that may lead to an increase in atmospheric humidity (https://www.unep.org/news-and-stories/story/how-climate-change-making-record-breaking-floods-new-normal). This atmospheric change to more warm and humid conditions is not suitable for grain storage but favours the development of insect pests and moulds, which constitutes essentially the adoption of improved grain storage technology methods.

The Covid 19 pandemic showed that pandemics may be another threat to global food security. The growing human population, intensified travelling activity and trade increase the risks for rapidly spreading diseases. A pandemic could severely hamper agriculture.

Unfortunatly, aggression and warfare as witnessed in Ukraine, a major grain producer, is still another threat to food security. Thus, more local long-term storage rather than just-on-time delivery could add security to local communities.

Figure 1. Maize cob perforated and damaged by stored product pests and moulds on the stem in Tanzania (photo: C. Adler)

The three grain weevils and their distribution

Literature data state that the beetle fauna associated with stored cereals consists of mainly three species of the genus *Sitophilus* (Coleoptera, Dryophthoridae) which have not been recorded in natural habitats and one, the granary weevil *S. granarius*, is hardly found far from synanthropic situations (Plarre, 2013). Flightless, in contrast with its congeners, the rice weevil, *Sitophilus oryzae* (L.) and maize weevil, *S. zeamais*, which in the tropics may infest crops in the field (Kranz et al. 1978), *S. granarius* is believed to owe its present worldwide distribution to accidental transport by man from the area of m. However, the species is cold hardy (Solomon and Adamson 1955). A study conducted by Bahr et al. (1995) proved that *S. granarius* and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera, Laemophloeidae) can survive Central European winters in stacks or wheels of straw outside in the field. Some authors ascribe the northward progress of *S. granarius* to be dependent upon the availability of suitable permanent stores and most records in North West Europe are within the Roman Empire (Buckland 1981). However, according to newer data, the granary weevil occurred already in a Neolithic settlement close to Goettingen, Germany, from 5000-4000 B.C. (Buechner and Wolf 1997).

Sitophilus granarius, *S. oryzae* and *S. zeamais* have often been found to coexist and coinfest stored grains in different parts of the United Kingdom and main-land Europe (Buckland 1981, Athanassiou and Buchelos 2001a, b; Bagci et al. 2014). Archaeological data illustrated that for thousands of years, *S. granarius* was more commonly found in Pharaonic Egypt and Ancient Greece than the other two species (Solomon 1965, Levinson and Levinson 1985, Panagiotakopoulou and Buckland 1991, Panagiotakopoulou 1997-1998, 2000, 2001). Thus, over the last ten to twenty centuries the granary weevil, outcompeted by the rice and maize weevils in warmer climates may have found a niche in temperate and cooler climates. More recent studies have shown that *S. oryzae* is much more common than *S. granarius* in Southern Europe, while *S. zeamais* may be an effective competitor of *S. oryzae* (Athanassiou and Buchelos 2011, Athanassiou et al. 2017). In fact, among these three species, *S. oryzae* and *S.*

zeamais have a higher population growth at elevated temperatures than *S. granarius,* while *S. zeamais* is considered more "tropical" than *S. oryzae* (Aitken 1975, Longstaff 1981, Obata et al. 2011, Correa et al. 2017, Athanassiou et al. 2017).

In Mediterranean countries the distribution of these species seems to have drastically changed in recent years. A recent survey carried out in Ankara, located in the central part of Turkey, showed that amongst the three weevils, *S. zeamais* was most numerous (75.8%) followed by *S. oryzae* (20.8%) and *S. granarius* (3.5%) (Bagci et al. 2014). In previous surveys, however, the only weevil found in the Central Anatolian part of Turkey was *S. granarius* (Esin 1962, Dörtbudak and Aydin 1984). While *S. oryzae* was the major coleopteran pest in rice mills in Spain at the beginning of the 2000s (Lucas and Riudavets 2000), now *S. zeamais* is also abundantly present. Moreover, *S. zeamais* is considered the key-pest of stored rice in Portugal (Carvalho et al. 2011). Similar results were found after monitoring grain, stored in several Portuguese ports during at least four months in 2019 (Duarte et al. unpubl. data). On the other hand, *S. granarius* was the only one of the three species present in a barley store located in the North-East of Spain in an area far from the coast and with a cooler climate (Castañé and Riudavets 2015). A European south-north geographical shift of pasta-adapted strains of *S. oryzae* was recently recorded (Stejskal et al. 2015). Moreover, the incidents of *S. zeamais* records in Serbia and Slovenia seem to have been increased lately (Bohinc et al. 2020).

In the dry and hot summer months of 2018, for the first time, *S. granarius* were recorded hatching from wheat grains in the fields of Germany (fig. 2). This means that the grain was sufficiently mature and dry in the ear for at least six to seven weeks. But where did these weevils come from, and how did they find the ripening ears of grain? If they can overwinter in straw as mentioned before, they could possibly also survive winters in burrows of field mice and hamsters storing both straw and grains. Normally, in Central Europe the time span for grain maturation and drying in the field is too short for insects to complete a life cycle. Thus, farmers and storage managers are not accustomed to finding stored product insects in their new harvest. In 2018, significant numbers of the red flour beetle, *T. castaneum*, the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera, Tenebrionidae), the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera, Silvanidae), *C. ferrugineus*, *S. oryzae*, and *R. dominica* were found in newly harvested grain south of Berlin (Müller-Blenkle et al. 2020). While an infested combined harvester, trailer or conveyer equipment cannot completely be ruled out, the severity of the infestation hints towards a field infestation.

Figure 2 *Sitophilus granarius* adults hatching from wheat grains in the field in Germany indicating mature grain at high temperatures for at least six to seven weeks (photo: BayWa 2018).

Long-distance invasion?

It is well documented that many stored pests have capacity to actively (e.g. flight - Sinclair, Haddrell, 1985) or passively travel (e.g. with the infested transported commodities - Aitken; 1975) over long distances. Recently the commodity transport nod-based models, or eco-genetically based models were suggested to model geographical risk of spread in USA and Australia (Nopsa et al., 2015, Cordeiro et al., 2019). However, no such data and models are available in Europe although there are indications of long-distance dispersal and invasion in this geographical area. For example, a German pest control company using deltamethrin was puzzled about the fact that while *S. granarius* can be controlled with this pyrethroid in Germany, *S. oryzae* would be much more tolerant. This may be due to *S. oryzae* frequently arriving north originating from the Mediterranean where the species had been exposed to pyrethroids since the 1970s. While *S. granarius* cannot fly and is thus hampered in its long-distance distribution, Mediterranean populations of *S. oryzae* could have brought their acquired tolerance along. Whether *S. oryzae* really move north and if they do so along rivers such as Rhone and Rhine valley or are carried along with warm air streams across the Alps has not yet been studied. To make things more complicated, passive transportation by trucks, ships, trains or even airplanes exporting goods from the Mediterranean to Central Europe cannot be ruled out.

Movement of stored-product Bostrychids

Originally, grain-store hot-spots were postulated as the only survival mechanism of un-acclimatized/un-adapted populations of subtropical bostrychid species, *R. dominica,* during the cold winter conditions occurring in Central Europe (Stejskal et al. 1995). *Rhyzopertha dominica* has been described from South America, but it is native in India, and has been found in tombs of Kahun (Amarna) (Panagiotakopulu, 1998). *R. dominica* was reported in the Croatian port of Split in 1945 (Novak 1952) and at the end of 1980s was found to be spread in the whole country (Hamel 1990). Recently, *R. dominica* was also found infesting grains in farms close to the city of Berlin. This pest has been reported to occur in forest areas in the Central United States (Kansas) and to be rather independent in its field distribution from the frequency of grain storages (Jia et al. 2008, Campbell et al. 2009). The authors suggest that the beetles move north along forested rivers. The species has been reported to infest acorns and woody plants with a higher starch content. *Rhyzopertha dominica* specimens from the stored product protection team in Berlin could be kept on acorns from two different oak species for almost a year (fig. 3). As various species of Lyctidae and Bostrychidae, such as brown or common splintwood beetle, *Lyctus brunneus* (Stephens) or the bamboo beetle, *Dinoderus minutus* (F.), are forestry pests, an increase in average temperature in Central Europe may allow *R. dominica* to become not only a severe stored product but also a forestry pest. Conversely, some additional bostrychids that are major wood borers, can easily “jump” to durable agricultural commodities, such as the yam beetle, *Dinoderus porcellus* Lesne that can outcompete other major stored beetles in maize (Sakka and Athanassiou 2018). Another stored product bostrychid of major economic importance for durable commodities is the larger grain borer, *Prostephanus truncatus* (Horn), a species that was introduced into Eastern and Western Central Africa (Tanzania and Togo) from Central America possibly by food aid in the 1970s and/or early 1980s (fig. 4). There was published a recent review on *P. truncatus* containing a list of the countries where *this pest* has been intercepted (Quellhorst et al. 2021). It was first detected in Tanzania (Dunstan and Magazine 1981; Quellhorst et al. 2021), and a few years later in Togo (Harnisch and Krall 1984). A number of years after its first introduction, *P. truncatus* had spread into more than 10 African countries, causing enormous losses in stored maize. This species also attacks maize plants, prefers to bore into wood rich in starch, and may survive adverse conditions hidden in wood. In fact, several studies have clearly demonstrated that after its first detection in Africa, this species has adapted to several tree species that can serve as habitats for its further spread (Borgemeister et al. 1998). *Prostephanus truncatus* has been recorded in African countries north of the Sahara desert, and more than fifteen years ago it was detected in Sicily, Italy (Suma and Russo 2005). There are several records of interceptions of *P. truncatus,* including Canada (Manitoba), the USA (Arizona, Montana, New York and New Jersey), Germany (interception from Guatemala), Israel and Iraq (IIE 1995). Therefore, this species can be regarded another potential pest endangering Europe in the case of rising temperatures.

Figure 3 Jar with 10 adult *Rhyzopertha dominica* on acorns, three months after starting the test. The dark frass at the bottom depicts insect activity (photo: C. Adler).

Bruchids as ambivalent field-, stored-product, regulated non-quarantine and invasive pests

Bruchids of the chrysomelid subfamily Bruchinae may be equally destructive in stored pulses, although, in Europe, the primary infestation mostly occurs in the field. Burleigh and Southgate (1975) note a bruchid species of from Egyptian lentils of approximately 215-48 B.C., other records are either much more recent or less clearly synanthropic (e.g. Shotton and Coope, 1983). Species able to attack pulses in storages, such as the bean weevil, *Acanthoscelides obtectus* (Say), were more recently introduced to Europe. This species occurring in horsebeans (*Vicia faba* L.) has been taken (introduced) to Spitzbergen (Svalbard in Norway) by seventeenth century whalers (Van Wijngaarden-Bakker and Pals 1981) most probably originates from North America (Dillon and Dillon 1972). *A. obtectus* was found for the first time in bean sample imported from America in a place near Split (Croatia) in 1918 brought from the Croatian port of Zadar in 1917 (Novak 1952) and since then it spread all around the country (Hamel 1990). Bruchid beetles are able to cause substantial damage to legume seeds (Stejskal et al. 2014). In Europe, most of bruchid species complete their entire life-cycle under field conditions. However, some species may survive after harvest in stores for some time, or even may continue their development inside dry seeds during storage, such as the bean weevil, *A. obtectus* on beans (*Phaseolus vulgaris* L.), or other *Bruchus* and *Bruchidius* species (Aitken 1975, Bohinc et al. 2013). Warm-adapted bruchids are occasionally coming to Europe with infested consignments of legume (*Callosobrochus* spp., *Zabrotes* spp.) or peanuts seeds (*Caryedon* sp.) (Aitken 1975, Contessi and Mucciolini 1993, Nicoli Aldini 2003). They pose a certain threat for future establishment since they may be introduced as large populations. Recently such a case was documented from the Czech Republic for a freight container with imported legumes from Africa (Stejskal et al. 2020). Quantification of pest infestation was performed not by taking a limited number of samples but by sieving the content of the entire freight container. From the analyzed freight container loaded with 24 tons of infested pinto beans, 1,101,060 adult individuals of the Mexican bean weevil, *Zabrotes subfasciatus* (Bohemann) (Coleopera, Chrysomelidae), were extracted. This represents a density of 45.9 adults per 1 kg of imported beans, and shows the exponential multiplication under favourable conditions (Stejskal et al. 2020).

Some bruchid species are the only stored-product pests that currently reached at least minimal regulated status in EU. Relatively recently, there were substantial changes in the EU plant health regime associated with the introduction and implementation of Regulation (EU) No 2016/2031. The Regulation entered into force in December 2016, was applicable from 14 Dec 2019; with 3 years transition period for pests. This legislation introduced 3 new regulatory categories in line with IPPC: (i) quarantine pests (most of HOs from Annex IAI, IAII and 10% QP – priority pests); (ii) protected zone quarantine pests; and (iii) regulated non-quarantine pests (RNQP). The article 6(2) of Regulation (EU) 2016/2031 of the European Parliament and the Council on protective measures against pests of plants empowers the Commission to adopt delegated acts supplementing that regulation by establishing a list of so called priority pests. The lists of the pests and requirements were prepared and adopted by 2019 as secondary implementing act. Since local species of bruchids *A. obtectus* on *Phaseolus coccineus* L. and *P. vulgaris, Bruchus pisorum* (L.) on *Pisum sativum* L. and *Bruchus rufimanus* L. on *V. faba* may spread across Europe through infested legume seed packages for gardening purposes, they are classified as regulated non-quarantine pests (RNQP) (Anon 2019). However, the regulated status has not been required by EU for *B. pisorum* on *P. sativum* seed and *B. rufimanus* on *V. faba* seed as fodder plants.

Figure 4. From a single freight container loaded with bags (covered by stretch wrap) filled with 24 t infested beans (A), 1,101,060 adult individuals (it is an equivalent of some 4.5 liters of pest individuals) of *Z. subfasciatus* filling five plastic cylinders of 400 mm height and 55 mm diameter (B) (photos: V. Stejskal).

The khapra beetle *Trogoderma granarium,* a priority pest elsewhere, but not in Europe?

The European and Mediterranean Pest Protection Organization (EPPO) coordinates phytosanitary policy and plant protection in the European and Mediterranean region. Among many other tasks, EPPO publishes and updates lists of quarantine pests (www.eppo.int). In principle, a quarantine pest is a species that may spread and cause harm in new territories. Usually, such species cause major losses to agriculture or forestry in their natural environment, while there is a risk that this particular species may be established in a new habitat making equal or greater damages if precautionary measures are not taken. Quarantine species are classified as “species not present in Europe” (A1- lists) or “species present in some European countries” (A2 lists). *T. granarium* is included in the A2 list of EPPO (i.e.locally present in the EPPO region and assumed to be present in the island of Cyprus), that recommends that the species has a potential for further spread within the EPPO geographical zone. However, the European Union (EU) has not listed this species as a quarantine or otherwise regulated pest according to the new Regulation (EU) No 2016/2031. The authors of this paper feel alarmed that EU authorities obviously do not consider this stored product pest as a serious threat worth to reach at least the lowest status of regulated species. The authors fear that severe damage could be caused to European agriculture, should this species make its way up north.

Trogoderma granarium Everts (Coleoptera, Dermestidae) has been included into the list of the100 most important invasive organisms globally (Lowe et al. 2000). In contrast, the European Commission recently published a list of 20 regulated quarantine pests qualifying as priority pests, whose economic, environmental and social impact on EU's territory is the most severe. *T. granarium* is not included. This species can be devastating in different types of commodities, especially grains and their related products, but it has the unique ability to develop easily in more than 100 different substrates, ranging from dried blood to milk powder (Athanassiou et al. 2019). The larvae of *T. granarium* (fig. 5) can remain in diapause for several years, and have the unique characteristic of doing occasional “foraging excursions” (Wilches et al. 2016). Apart from the quantitative loss, this species can cause important qualitative degradations, while it easily outcompetes other major stored product insect species

(Kavallieratos et al. 2017) in dry-hot climates. *T. granarium* can be spread easily through different devices, equipment or personal items, such as clothes, refrigerators, pallets etc., and it is currently a top priority quarantine species in USA, Australia, Canada, New Zealand and elsewhere, with numerous interceptions (Athanassiou et al. 2019).

T. granarium has been historically detected in several European countries, intercepted in Italy (Nicoli Aldini 2003, Trematerra and Gentile 2006, Nardi and Hava 2013), but newer detailed data are not available, partially due to the fact that accurate identification of this species is difficult, which further complicates its detection, in conjunction with its highly cryptic behavior. Italy declared its territory free from both *T. granarium* and *P. truncatus* (GU Serie Generale n. 203 of 01-09-2018).

Fortunately, new tools based on molecular diagnostic tests are now available that can complement morphological identification by an expert (Olson et al. 2014, Castañé et al. 2020). In a surveillance in different facilities in Spain, Castañé et al. (2020) found different species of the genus *Trogoderma*, but none of these individuals belonged to *T. granarium*. This has made it possible to change the status of this pest according to EPPO from present since 1952 to absent in 2020 confirmed by sampling. In Portugal, the SafeGran project is running to detect *T. granarium* using PCR as rapid identification assessment. The experiments are still conducted in several ports and grain facilities and until now no *T. granarium* were identified, whereas some *T. inclusum* LeConte (Coleoptera Dermestidae) larvae were collected in a flour mill located in the Centre region. This work is carried out following the Sampling Protocol developed by the consortia countries (Portugal, Spain, Italy and Greece) using traps, indicating or not its presence and distribution in specific areas of these countries (Duarte et al. 2021). A report shall be prepared and distributed to the authorities and stakeholders and also submitted to EPPO and EFSA (European Food Safety Authority), in order to point to the presence of this species in Southern Europe.

Figure 5 Larvae of the khapra beetle *Trogoderma granarium* (photo: P. Trematerra)

Global warming, human migration and activities of the World Food Program (WFP)

As can already be witnessed, global warming and all kinds of extreme weather conditions increase conflicts regarding the distribution of water, agricultural land, and pastures. Numbers of migrating or displaced persons have risen considerably over the last few decades. Should the sea level rise or should the number of large fires, droughts, military unrest, and aggression increase, this would be a severe challenge for affected regions and the world community as a whole. Effects of global warming on stored product protection are summarized in Table 1.

Due to the increasing risk of food shortage, it would be important to increase the budget of international bodies such as the World Food Program (WFP) in order to prepare larger food storages in various regions of the world to improve mid-term food safety. As postulated during the 12th International Working Conference on Stored Product Protection in 2018, Berlin (Mballa 2018), WFP today provides more ready-to-consume food for under-nourished children. Isabelle Mballa, WFP regional supply chain advisor for West Africa mentioned that WFP is losing large quantities of provisions “in the last mile” due to insufficient cooling, packaging and pest attack.

At present, WFP holds no funds for research but would need some to finance research on how to maintain quality and prolong the shelf-life of various goods. Moreover, innovation is needed on how to build mobile, independent and sturdy food storages that can keep supplies cool and dry, as well as safe from stored product pests or theft. A policy change is needed, in order to improve the efficacy of international food aid and to support food safety in regions where weather conditions render agriculture impossible.

Tab. 1 Signs of global warming, potential consequences for stored product protection and strategies to counteract

Signs of global warming	**Consequences (for stored product protection)**	**Strategies to counteract**
Rising mean annual temperature worldwide	Increased reproduction of pests increases infestation pressure and supports microbial deterioration; more tropical species develop up north (e.g. lesser grain borer, maize weevil, khapra beetle).	Cooling, drying, pest-proof or hermetic storage and packaging, and other preventive methods become crucial in order to avoid losses and mycotoxin contamination, more research on improved storage, transportation, and packaging needed.
Early maturation of agricultural products	Pest attack in the field, carry-over from the field into storage.	Control option needed, preferably non-chemical, research e.g. on the use of drying technology, impact mills, and the optimized structural design of storage structures, including hermetic silo bins, ships and containers.
Weather extremes, droughts, hurricanes, frosts, flooding	More overwintering pests, early attack, higher risk of mycotoxin contamination. Reduced storability of grains. Volatile prices, uninhabitable landscapes, increased human migration. More need for stored food products.	Improved monitoring both indoors and in the field. Plant breeding for temperature tolerant plants. International initiatives to grow forests and reduce global warming, investment into food safety by increased storage. Internationally coordinated food safety policy for crisis prevention.

Modern technology: from laboratory research to practice

If more products reach the storage site already infested with insect pests, Integrated Pest Management (IPM) needs to imply means to stop insect development such as thorough grain cleaning, product cooling, extreme temperatures for product drying and pest control, the use of impact mills (entoleters), possibly also hermetic storage or vacuum storage (Adler et al. 2016) to suffocate pests and increase shelf life. For monitoring, besides classical sampling, improved traps and additional detection devices such as acoustic systems are needed (Trematerra and Fleurat-Lessard 2015, Müller-Blenkle et al. 2020). Semi-automated traps would enable more frequent and more precise monitoring at a large number of sites simultaneously. Cameras with artificial intelligence can detect and determine pest species at the beginning of infestation in order to use laser beams (Adler et al. 2018, 2019) or biological control with parasitoids or predators (Riudavets 2018). Molecular techniques based on PCR analysis (Solà et al. 2018) should be involved in pest determination whenever feasible, because they provide clear and unequivocal information about which species are present. Besides, PCR analysis could enable detection of many harmful pests that are morphologically similar to established species and easily overlooked otherwise. International shipment using cargo ships, airplanes or rail should receive a systematic evaluation under the aspect of stored product protection and quality maintenance including the principles of Hazard Analysis Critical Control Points (HACCP).

Area-wide surveys in stored products: to serve and protect

Stejskal et al. (2015) prepared an extensive account on the published information regarding the pest monitoring and surveillance of stored- product pests in European durable commodity stores over the past 80 years. The analysis of the historical literature resources identified a problem of missing quantitative data hampering a statistically robust evaluation of population trends and geographical pest spread in most of the European countries. This review documented that the published European data on stored pest surveillance, funded by governments or executed by their National Plant Protection Organizations (NPPOs), was available exclusively for former East Germany (GDR) and Czechoslovakia from 1960s to 1980s (Stejskal et al. 2015). Different programs of collecting stored product insects were performed in Croatia in the period from 1969 till 1990 (Korunic 1990). Inspection organized official survey of store-houses with the goal to collect information about performed control measures and spreading of stored product insects (Hamel et al. 2001). Since that time publicly available data regarding surveillance programs in storages are missing. While there are data of insects and mites intercepted in ports such as Ravenna, Italy (Contessi and Mucciolini 1993) or intercepted in goods arriving in Italy through international trade (Nicoli Aldini 2003), area-wide studies are missing. Thus, how do we draw information from patchy data, more than 30-years old?

Conclusion and recommendations

The Covid-19 crisis, apart from other facts, revealed the importance of durable commodities that can be stored for a long interval without the need of highly specialized conditions (i.e. refrigerators, etc.). From the very beginning of the pandemic in the EU in spring 2020, the price of certain grains, such as wheat and rice, went up. This is a paradigm of the importance of stored product protection during periods of crisis with projections in global food security. Yet, despite the fact that there are projects financed by EU Commission, and numerous EPPO-oriented national surveys for agricultural field insect species, some of which have been already widely established within the EU countries, there is not a single survey in the case of stored product insects. In this context, a **pan-European project monitoring the occurrence of stored product insects** in grain production with a special focus on *T. granarium, P. truncatus*, *Sitophilus* spp., and *R. dominica* could be a good start to overcome the scarce knowledge on recent stored product pest distribution. Based on the above, the authors of this paper suggest that standardized surveys for stored product pest species in a wide range of areas within the EU may serve towards discovering the main routes of invasion and differences in population density. A grid of sampling points and tools could help to better understand the correlation between agricultural crop, abiotic conditions, species distribution, and population density. This initiative could also provide a platform for quick control actions where necessary. Measures to prevent losses and to improve stored product integrated pest management could be tested across various climatic zones. Minimum requirements for national emergency storage of durables should be established within the European Union.

The authors also suggest that the **United Nations provide WFP with a budget for research** regarding improvements in food packaging and the development of mobile, cooled storage units. Additionally, larger WFP storage sites for staple food crops are recommended in anticipation of adverse weather conditions impeding agriculture in certain areas.

Post-harvest losses in durable agricultural commodities are over-looked as compared with pre-harvest protection measures. It is time for improvements in storage structures that have been neglected for too long. It is necessary to improve knowledge and awareness of stored product pest influence on the nutritional value, allergenic load, quality and quantity of stored commodities and final products. And it is time to re-discover the value of modern preventive and sustainable stored product protection.

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Data in brief

This paper summarizes changes in the distribution of stored product insects recently found in Europe. The data indicate that Mediterranean species move further north and that sometimes attack may already occur in the field. This would need a change in stored product protection policy in order to prevent severe losses and a degradation in product quality. Climate change will increase this effect and the risk of mycotoxin contamination, as well as the pest risk of more tropical species such as *Trogoderma granarium*. Thus, authors call for a pan-European monitoring project and additional efforts to improve food safety.