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RESEARCH ARTICLE

Hypothetical study of Small Hive Beetle *Aethina tumida* Infestation in Honeybees, Risk Commodities and Probabilities for Its Introduction in Türkiye

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Abstract: Türkiye is the second-largest honey producer globally; however, the export of honey and bee products does not adequately support the beekeeping industry. Pests account for the largest share of expenditure for agents found in honeybees in the country. Although the Small Hive Beetle (SHB) has not been detected in Türkiye, a risk assessment was performed to determine what happens if it enters the country. The risk assessment included: a) hazard identification; b) risk pathway determination; c) risk assessment for entry via the identified pathways; and d) outcome assessment for becoming endemic in Türkiye. The Risk AMP add-in program was used to assess the probability of distribution for each method of entry, pathway, and simulation. According to the simulations, the probability of SHB introduction in Türkiye varies from 0.17 per 1000 events/days (1.7 per 10000 days or 27 years) to 0.6 per 1000 events/imports (6 per 10000 days or 27 years). The highest likelihood of introduction comes from fruit import (11/15) and soil/compost import (4/15). The mean probability of introducing SHB infestation after 1000 iterations of the constructed model is 0.37 per 1000 events/days (3.7 within 10000 days or 27 years). Finally, the simulated average cost of SHB after the possible introduction is 523 million US $ for Türkiye. With these simulated data, risk assessment of a non-detected pest, SHB, was determined for Türkiye.

Keywords: *Aethina tumida, Risk, Small hive beetle, Türkiye*

Bal Arısında Küçük Kovan Kurdu *Aethina tumida*'nın Hipotetik Çalışması: Türkiye'ye Girişi İçin Riskler ve Olasılıklar

Öz: Türkiye, dünyanın en büyük ikinci bal üreticisidir. Fakat bal ve arı ürünleri ihracatı, arıcılık endüstrisini tam olarak destekleyememektedir. Ülkede bal arılarında bulunan etkenler için yapılan harcamalarda en büyük payı zararlılar oluşturmaktadır. Küçük Kovan Kurdu *(Aethina tumida)* (KKK) Türkiye'de bulunmamasına rağmen, bu çalışmada risk değerlendirmesi ve ülkeye girişi durumunda verebileceği ekonomik zarar değerlendirmesi yapılmıştır. Risk değerlendirme süreci birkaç aşamada gerçekleştirilmiştir: a) tehlikenin tanımlanması; b) risk yollarının belirlenmesi; c) tanımlanmış yollara giriş için riskin değerlendirilmesi, d) ekonomik zararın değerlendirilmesi ve e) hastalıkların Türkiye'ye girişinden sonra endemik hale gelme riskinin değerlendirilmesi. Bu amaçla, Excel için Risk AMP eklentisini kullanan bir elektronik tablo, benimsenen yollara göre her bir giriş yolu için olasılık dağılımı ile oluşturulmuş ve simülasyonlar Monte Carlo yöntemi kullanılarak yapılmıştır. Simülasyonlar için verilen varsayımlarla, Küçük Kovan Kurdunun Türkiye'ye giriş olasılık değeri, 1000 olay/gün için en düşük 0.17 (10.000 gün veya 27 yıl içinde 1.7) ile 1.000 olay/ithalat için en yüksek 0.6 (10.000 gün veya 27 yıl içinde 6) arasında değişmektedir. Giriş yolu olarak en yüksek olasılık meyve ithalatından (11/15), ikinci olarak toprak/kompost ithalatından (4/15) olabilecektir. Oluşturulan modelin 1000 yinelemesinden sonra KKK istilasının ortaya çıkma olasılığı ortalama 1.000 olay/gün başına 0.37'dir (10.000 gün veya 27 yılda 3.7). Son olarak, KKK'nun ülkeye girişinden sonra simüle edilmiş ortalama ekonomik zararı 523 milyon $ olarak bulunmuştur. Bu çalışmayla, Türkiye'de henüz görülmeyen KKK zararlısının, bulaşma risk olasılıkları ve ülkeye girişi halinde verebileceği ekonomik zararlar ortaya konmuştur.

Anahtar sözcükler: *Aethina tumida, Küçük kovan kurdu, Risk, Türkiye*

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Introduction

The insect *Aethina tumida* Murray (Coleoptera, Nitidulidae), also called the small hive beetle (SHB), is native to Africa and causes relatively little harm as a minor scavenger pest of honey bee colonies. It is a fruit pest that feeds on fruit remains and was first identified in 1940 in South African beehives [1]. This pest spread to many regions of the world by the end of the 1990s, particularly on the American continent and Australia, by importing fruit and beehives. When the imported beetle was discovered, it was so well established that there was little or no chance of eradication. The colony is damaged by the larvae burrowing through the brood combs and consuming the brood and honey. The amount of harm depends on the infestation level. If SHB infests an apiary and is not treated, up to 100% hive mortality is expected [2,3].

The adult *A. tumida* is 5-7 mm long, has three pairs of legs, two pairs of strong wings, and is a dark brown, almost black colour. The strong chitin layer on the beetle's body prevents the bees from stinging them. They can fly up to 24 km, rapidly spreading throughout the environment. The eggs are fusiform and laid irregularly into the deep, hard-to-reach corners of the hives and cells. Larvae are long, oval, approximately 11 mm long, and have a whitish-light brown colour [4]. Although the SHB larvae have a similar appearance to the wax moth larvae, they have three underdeveloped legs and well-developed dorsal spikes, distinguishing them from the wax moth. The larvae feed on pollen and honey and defecate in the cells. As the larvae feed, they leave a sticky repellent substance on the combs, which may cause the bees to abandon the hive. So, they damage the honey in combs and cause the fermentation of nectar/honey. Adult beetles prefer feeding on a brood instead of honey and pollen. Weakened and stressed colonies collapse within two weeks [2,5].

The World Organization for Animal Health (OIE) [1] states that currently, *A. tumida* is present on the Northern/Central/Southern American continent, in Cuba, Jamaica, Hawaii, South Korea, Australia, Portugal, and Italy. There is no verifiable information about its localisation in Africa. However, the pest is endemic in that region [1,6]. Although the pest is not officially reported to the OIE, the Terrestrial Animal Health Code from the OIE states the pest is present in Egypt (2000), and Portugal (2004) [1]. It has also been recorded in the Calabria region of Italy without wide establishments [2,7].

African bee species are considered very aggressive and have strong self-cleaning and defensive traits, which prevent beetle access to the colony by aggressively harassing them. They remove beetle larvae from the hive and confine beetle to a 'propolis prison'. This behaviour of African bees limits SHB reproduction and keeps its population below the damaging threshold [5]. Therefore, SHB is considered a minor economic pest of weak honey bee colonies in Africa [1].

Unlike African honeybees, Western honeybee races have less aggressivity behaviour against SHB. Consequently, SHB could reproduce much more effectively [8], and their population would overgrow if introduced in Türkiye.

The economic consequences of the SHB infestation are significant and multiple. In 11 states of the USA between 1998 and 2004, the disease killed almost one in three colonies [5]. From those days to now, SHB is spread across 48 states in the continental United States and continues to suffer economically [9]. In addition, there were substantial and valuable losses in plant production because these bees were used in the pollination process. The USA has to import bee colonies due to the contamination of honey, fermentation and pesticides used to control the disease. State support per hive was 35 $ which increased 2-3 fold due to colony losses [4,5,10].

A spreadsheet with the Risk AMP add-in (Structured Data, LLC), a Monte Carlo simulation engine for the Microsoft Excel® programme, was created with a probability distribution for each entry method per the adopted pathways - imported commodities. The simulation uses a computational algorithm with repeated random sampling to generate numerical results within a user-specified range and distribution [11,12]. The technique accounts for biological variability and diversity in health events. Such methods are able to see future results under current risks and can be used in similar studies [13,14].

This infestation is not present in Türkiye, where migratory beekeeping is performed [15]. Also, the disease is not present in the country's immediate neighbourhood. There is no particular geographical area at the current time that is considered at greater risk than others. Therefore, this study aimed to evaluate whether SHB infestation is introduced in Türkiye by economic modelling.

Material and Methods

To determine the risk commodities and probabilities, gained parameters and their values were entered into the simulation engine programme. All the parameters and their values are obtained from the Statistical Institute of Türkiye, the Central Beekeepers Association of Türkiye and the American Ministry of Agriculture *(Table 1)*.

Risk is significantly dependent on the imported quantities, especially their origin, i.e., only from an infested country. However, the lack of official information on these quantities and sources prevents such delineation of the calculated risk. Therefore, the possibility of disease

Table 1. Türkiye's beekeeping parameters and their values	
Parameter	**Value (2021)**
Unit price of a colony	62.5 $ [a]
Average honey production per hive	14.62 kg [b]
Minimum honey production per hive	6 kg [b]
Maximum honey production per hive	55 kg [b]
The average unit price of 1 kg honey	3 $ [b]
The average unit price of 1 kg wax	5 $ [b]
Min number of infested apiaries	30% [c]
The average number of infested apiaries	35% [c]
Maximum number of infested apiaries	50% [c]
No. Professional beekeepers	81 000 [b]
Months/year utilized for professional beekeeping	9 [b]
Average monthly salary	355 $ [b]
Average Total colonies in Türkiye	8.4 million [b]

[a] *According to the Central Beekeepers Association of Turkey (2021)*
[b] *According to the Turkish Institute of Statistics (2020)*
[c] *According to the American Ministry of Agriculture (2020)*

introduction via imports from infested countries has been evaluated and included as an additional risk.

The considered criteria and direct and indirect losses due to the infestation are; i) Loss of colonies, honey, and frames within the infested colonies, and ii) damaged equipment. Costs for disease control are; i) Time and labour to detect and treat the disease, ii) Treatment materials and consumables, and iii) Additional costs for control of the disease. Possible invasion routes of this pest in Türkiye are migratory beekeeping, queen importations, and fruit imports from infested continentals.

Results

The risk of introducing SHB through the legal import of bees and apiculture products was considered negligible. The Turkish national legislation on prohibiting imported bees and honey products from countries with reported SHB and prescriptions indicated with the International veterinary health certificate was considered. However, the disease cannot be detected in exporting countries until it is well spread; a very low probability was allocated. In addition, the possible illegal import of small quantities was considered in the risk assessment *(Fig.1)*.

According to the data in *Table 2,* assumptions and line with the results of the risk assessment process, if the infestation is introduced in Türkiye, it could happen in any region of the country since importing those commodities is not regionalised. Further and detailed investigation describing the likelihood of occurring above assumptions and measures for prevention is required.

This simulation reported the probability of SHB introduction in Türkiye varied from 0.17 per 1000

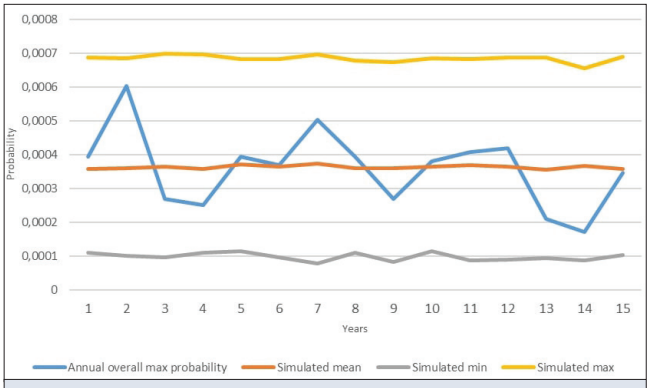

Fig 1. Introduction probability of SHB infestation in Türkiye using Monte Carlo procedure with 1000 iterations

events/days (or 1.7 per 10000 days or 27 years) to 0.6 per 1000 events/imports (or 6 per 10000 days or 27 years). The simulation results suggested that importing fruit (11/15) and importing soil/compost (4/15) had the highest likelihood of causing the infestation. The mean probability of SHB introduction after 1000 iterations of the constructed model was 0.37 per 1000 events/days (or 3.7 in 10000 events/days or 27 years) *(Table 3)*.

According to the Monte Carlo procedure after 1000 simulations, the consequence assessment of direct losses after introducing SHB in Türkiye is 523 million US $ on average, with a minimum of 482 million US $ and a maximum of 565 million US $ range. Labour loss was calculated only for the professional beekeepers since the hobby beekeepers are mainly professionally involved with other jobs, and they spare minimal time (on average, 20 days/year).

Discussion

Climate change is a global environmental problem that can interact by changing the impact and distribution of invasive species. Although invasive species play a role in endangering the health of honey bees, the effects of climate change on the severity are unknown [16]. In June 1998, *A. tumida* was first reported in the Northern Hemisphere in honey bee colonies *(Apis mellifera)* in Florida [17]. It was previously known only in sub-Saharan Africa. By October 2001, the SHB had been found in 30 states, most of which were east of the Mississippi River. Migratory beekeepers carry bee colonies from SHB-infested areas, contributing to their spread. This pervasiveness is expected due to the immigrant pollination demands in the USA. States with SHB report occasional problems with insects invading and destroying beehives. However, more issues occur with SHB damaging stored honey [4,5,18]. International trade also facilitates biological invasions, but the role of the wax trade-in SHBs is not fully understood. Adequate mitigation measures are needed to address the critical role

Table 2. *Risk assessment of SHB in Türkiye*

Entry Way	Biologic Stages	Risk	Current Practices in Türkiye	Probability of Entry (%)
Wax	Adult	The wax represents an attractive medium for the beetle and therefore, its storage after heat treatment poses a risk of additional infestation. Raw wax presents a great risk for the introduction of adult beetle	Minimal quantities are imported	Very low to negligible Min: 0.00001 Mean: 0.0005 Max: 0.0001
Queen bees or package bees (workers)	Adult	Packing queen bees is associated with the risk of packing an adult insect. This has proven to be a model for the spread of the disease in the United States	Minimal quantities are imported	Very low to negligible Min: 0.00001 Mean: 0.0005 Max: 0.0001
Used hives and apiculture equipment	All biological stages	If they are previously infested or infested during storing, they present a risk of introducing all beetle stages	Very limited or no import	Very low to negligible Min: 0.00001 Mean: 0.0005 Max: 0.0001
Comb honey or honey in drums	All biological stages	If imported generally illegally, honey is given as feed for bees	Very limited or no import	Very low to negligible Min: 0.00001 Mean: 0.0005 Max: 0.0001
Colonies	All biological stages	No colony imports but can be brought in illegally	Limited or no import	Very low to negligible Min: 0.00001 Mean: 0.0005 Max: 0.0001
Bumble bees for pollination purposes	Adult	Packaging of has a risk of unintentional packaging of an adult beetle	No. They are produced in Turkey for a lower price	Negligible to low Min: 0.000001 Mean: 0.00005 Max: 0.00001
Soil or compost associated with the plant trade	All biological stages	In the insect diapause stage, it poses a great risk for the initiation of all stages	Yes, insufficient information on quantities and origin	Low Min: 0.000005 Mean: 0.0001 Max: 0.0005
Fruit imports – especially tropical fruits	All biological stages	Ripe fruit will be considered a risk when imported or stored from infested countries. Low sensitivity of visual inspection of such commodities increases the probability of introduction. Turkish legislation on the import of fruits does not cover the risk of the entry of SHB	Yes, but no information on the quantities and origin of ripe fruit if imported	Low due to the assumption of ripe fruit is not imported Min: 0.00007 Mean: 0.00025 Max: 0.0007

Table 3. *Risky products and probabilities of SHB entry into Türkiye*

Year	Route of Introduction	Probability of Introduction (per 1000)
1	Fruit	0.393
2	Fruit	0.603
3	Fruit	0.267
4	Soil or compost	0.249
5	Fruit	0.394
6	Soil or compost	0.368
7	Fruit	0.502
8	Fruit	0.394
9	Soil or compost	0.268
10	Fruit	0.380
11	Fruit	0.408
12	Fruit	0.418
13	Soil or compost	0.210
14	Fruit	0.171
15	Fruit	0.346

of wax imports in the further spread of SHBs. Combining genetics with trade data may be an effective tool to better track and reduce biological invasions [10,18,19].

Currently, SHB infestation is a notifiable disease of honey bees in the European Union and an OIE-listed pest [7]. The best defence of a beekeeper against SHB is to protect strong colonies, keep apiaries free of abandoned hive material (especially wax combs), and implement preventive measures when insects are detected in the colonies. Unfortunately, no economic threshold (number of insects to act in a hive) has been established for SHB. Their reproduction and damage to the colonies depend on factors such as colony strength and the prevalence of other pest pathogens.

Migratory beekeeping practices in the United States of America and Türkiye are very similar in many ways. Turkish professional beekeepers move an average of 2000 km annually in the country. Therefore, introducing the SHB factor into the country is a severe problem. To date,

the eradication of *A. tumida* in the USA and Italy does not show an apparent success as in the other ten infested countries [6,20]. The existence of 8.4 million colonies and 80 thousand professional beekeepers (have 50 hives and more) in Türkiye poses a severe threat of possible infestation for sustainable beekeeping [2,21].

Different risk assessment studies are based on meteorological variables [22] or their biology and migratory beekeeping [14,23]. However, there is no study about the simulated economic risk assessment of SHB, even in infested or uninfested countries.

In countries without SHB infestations, strict import regulations and an early warning system are needed to prevent the pest's introduction and to detect it as soon as possible if it is introduced. Once introduced and well established, SHB cannot be eradicated. The international experience from the USA and Australia suggests good pest control management is the best defence. This management begins with maintaining strong colonies that can control the beetle [24].

As a result, the cost of SHB introduction and contamination risk probabilities was documented for Türkiye with statistical models. Our study is the first documentation of an economic price for an undetected parasite of honeybees in Türkiye. These data can lead to having an economic cost model for other uninfested countries.

Availability of Data and Materials

All the data and materials are kept in the laboratory of the Department of Parasitology, Veterinary Faculty, Bursa Uludağ University.

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Competing Interests

The authors declared that there is no competing interest.

Author Contributions

LA conceived and designed the analysis, and interpreted the outputs; AOG and YEY contributed the data and analysis tools; AOG finalized the presentation of the work.

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