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Determining Powdery Mildew (*Podosphaeraaphanis* var. *aphanis*) Risk Areas for Wild Strawberry (*Fragariavesca*)in Turkey by Geographic Information Systems

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Abstract: Powdery mildew caused by *Podosphaeraaphanis* var. *aphanis* mostly infects the wild and cultivated strawberries in Turkey. The disease affects leaves, stems and fruits. Mycelia of the fungi inhibit the photosynthesis and nutrients uptake from the host cells. This reduces yield, quality, and market value of the fruit. In Turkey, intense strawberry cultivations in Mediterranean and Aegean regions are mainly influenced by contamination levels of nursery plants. However, scattered wild strawberry cultivations (*Fragaria vesca*) in Marmara and Black Sea regions are mainly affected by environmental conditions, particularly by the climate. Determining spatial distribution of powdery mildew of wild strawberry in Turkey is important for plant protection experts, producers, and breeders. In this study, powdery mildew risk areas for wild strawberry in Turkey were spatially analyzed and mapped in geographic information systems (GIS). In analyzing and mapping process, climatic raster maps and optimal climatic requirements of the disease were utilized. According to the produced raster maps, disease risk areas concentrated in the Black Sea and Marmara geographic regions of Turkey between May and October. Powdery mildew risk areas covered maximum area (3141.18 km^2) in October, and these areas were detected in Istanbul (2790.92 km^2), Sinop (215.0 km^2), and Giresun (155.26 km^2) provinces, respectively. Accuracy assessment of each risk map was performed by using geo-referenced field data collected between May and October in 2015. Accuracy changed between 75.68 % and 83.33 % in monthly basis, and overall accuracy was determined as 80.00 %.The results of this study supplied a good and reliable basis to control the disease.

Keywords: Ecology, early warning, GIS, powdery mildew, plant disease, wild strawberry

Türkiye`de Yabani Çilek (*Fragariavesca*) için Külleme (*Podosphaeraaphanis* var. *aphanis*) Risk Alanlarının Coğrafi Bilgi Sistemleriyle Belirlenmesi

Öz: *Podosphaera aphanis* var. *aphanis*`in neden olduğu külleme Türkiye`de çoğunlukla yabani ve kültür çileklerini enfekte eder. Hastalık yaprakları, sapları ve meyveleri etkiler. Fungusun miselleri fotosentezi ve konukçu hücrelerden besin alımını engeller. Bu meyve verimini, kalitesini ve pazar değerini düşürür. Türkiye'de, Akdeniz ve Ege bölgelerindeki yoğun kültür çileği yetiştiriciliği en çok fidanlık bitkilerinin kontaminasyon seviyelerinden etkilenmektedir. Ancak, Marmara ve Karadeniz bölgelerindeki dağınık yabani çilek (*Fragaria vesca*) yetiştiriciliği, başta iklim olmak üzere çevresel koşullardan etkilenmektedir. Türkiye'de yabani çilek küllemesinin mekansal dağılımının belirlenmesi bitki koruma uzmanları, üreticileri ve yetiştiricileri için önemlidir. Bu çalışmada, Türkiye'de yabani çilek için külleme risk alanları, coğrafi bilgi sistemlerinde (CBS) mekansal olarak analiz edilmiş ve haritalandırılmıştır. Analiz ve haritalama sürecinde iklim raster haritaları ve hastalığın optimal iklim gereksinimleri kullanılmıştır. Üretilen raster haritalara göre, hastalık riski alanları Mayıs ve Ekim ayları arasında Türkiye'nin Karadeniz ve Marmara coğrafi bölgelerinde yoğunlaşmıştır. Ekim ayında külleme riski alanları maksimum alanı (3141.18 km^2) kapsarken, bu alanlar sırasıyla İstanbul (2790.92 km^2), Sinop (215.0 km2) ve Giresun (155.26 km^2) illerinde tespit edilmiştir. Her bir risk haritasının doğruluk değerlendirmesi, 2015 yılının Mayıs ve Ekim ayları arasında toplanan coğrafi referanslı alan verilerini kullanarak gerçekleştirilmiştir. Doğruluk aylık bazda % 75.68 ve % 83.33 arasında değişmiş ve genel doğruluk % 80.00 olarak belirlenmiştir. Bu çalışmanın sonuçları hastalığın kontrolü için iyi ve güvenilir bir temel sağlamıştır.

Anahtar Kelimeler: Ekoloji, erken uyarı, CBS, külleme, bitki hastalığı, yabani çilek

1. Introduction

The strawberry genus, Fragaria is included in rose family. Because of its soft smell, rich vitamin source and aroma, the wild strawberry (*Fragaria vesca*) has been currently used in the bakery and cultivated around Asia, Europe and Africa (Çalış and Çekiç, 2013). Powdery mildew (*Podosphaera aphanis* var. *aphanis*) is one of the fungal species that causes disease on strawberry (*Fragaria* ssp.). Because pollens of strawberry plants and fungus spores have the same protein structure, the spores may easily germinate and induce powdery mildew on strawberry. Leaves wriggle when the fungal mycelia penetrate into the leaves. Powdery mildew covers all leaf surfaces, limits the photosynthesis (Maas, 1998) and the pollen production, and stops fruit growth almost totally. In advanced stages of the disease, the fruits become purple (Louws and Ridge, 2015). This fungus reduces yield, quality, and market value of the fruit (Strand, 2008).

The leading strawberry-producing regions of Turkey are Mediterranean (62%), Marmara (20%), and Aegean (12%). The other regions account for only 6% of Turkey's production (Turhan and Kargi, 2007). The strawberry cultivars the mostly used in Turkey can be summarized as Camarosa (USA-California), Chadler (USA-California), Cruz (USA), Diamante (USA-California), Douglas (USA-California), Fern (USA-California), Gaviota (USA-California), Maya (Italy), Miranda (Italy), Oso Grande (USA-California), Ottoman (Turkey), Paros (Italy), Pocahontas (USA-Maryland), Seascape (USA-California), Selva (USA-California), Sweet Charlie (USA-Florida), Tioga (USA), Yalova 110 (Turkey), and 216 Dorit (Israel-Volcani) (Turhan and Kargi, 2007). There are also diploid species such as *Fragaria vesca* and *Fragaria viridis* in Turkey's flora. These wild species are considered as genetic resources available for the improvement of the octoploid *Fragaria xananassa* (Serce et al., 2005). In Marmara and Black Sea regions, the wild strawberry (*Fragaria vesca*) is collected to produce jam that is very rich in aroma and sold at very high prices (Kaska, 1997; Serce et al., 2005). Annual production of wild srawberry is estimated at 400-500 t, and exported frozen. Fruits are also used fresh as well as medical and cosmetic purposes (Serce et al., 2005).

Intense strawberry cultivation in Mediterranean and Aegean regions are mainly influenced by contamination levels of nursery plants. In those regions, planting susceptible cultivars with infected crowns can cause very high risk and real losses. However, scattered wild strawberry (*Fragaria vesca*) production in Marmara and Black Sea regions are mainly influenced by environmental conditions, particularly by the climate.

Climatic conditions are the most important factors in the spread of powdery mildew. The disease prefers to grow in shaded areas and does not like the sunlight. Spores of fungi run away from the UV lights (Yarwood, 1957). The highest level of conidia germination of powdery mildew was reported at the range of 76-96% relative humidity and 15-25^{o}C temperature (Hewitt; 1974). Optimum disease development was observed in June around 20°C mean temperature (Selochnik et al., 1994). Basova (1987) reported that a massive development of powdery mildew was favoured by a temperate climate, with mean temperatures of 16–21 °C in the growing season. Accordingly, the suitable climatic conditions of the powdery mildew could be assumed as 15-25°C temperature and 76-96% relative humidity. Consequently, the disease has been reported around the coastal regions of Turkey that meets these temperature and relative humidity requirements (Amsalem et al., 2004).

Healthy, accessible and cheap climatic data is the must component to predict suitable environments for diseases. Starting 1937, Turkish State Meteorological Service (TSMS) has been collecting meteorological data since 1937 (TSMS, 2015). However, accessing the published data of TSMS is likely difficult, and the data do not included detailed climatic surfaces (raster maps) for cheap, reliable, and effective utilization. Several climatic software were developed to solve data access and evaluating problems. One of them is powerful Local Climate Estimator (LOCCLIM) software developed by Food and Agriculture Organization (FAO) (Grieser, 2002). Simply, LOCCLIM presents prediction of the climatic variables at any location (point) in the world by using either 1 km resolution or user-defined elevation data. This flexibility provides to produce more-accurate estimates, if detailed elevation data exists. The generation of climatic surfaces from point-source data is important for ecological and epidemiological modeling (Jolly et al., 2005). In this contex, spatial interpolation techniques have been applied successfully to construct climatic surfaces (Semenov and Brooks, 1999; Jeffrey et al., 2001; Gyalistras, 2003; Apaydın et al., 2004) and geographic information system (GIS) has facilitated the interpolation, modeling, and mapping processes of climatic data (Osterkamp et al., 2001; Svensson et al., 2002; Bradley et al., 2002). Accordingly, it is possible to produce reliable climatic raster maps at the regional level using LOCCLIM and GIS together (Dogan, 2007).

Turkey has an important geographic position where climatic, biological and agricultural (including diseases) diversities exist. Consequently, climatic raster maps are beneficial data sources to determine disease risk areas in the country. To satisfy the requirements, we, here, spatially analyzed and mapped the powdery mildew risk areas for wild strawberry in Turkey by utilizing GIS, the optimal climatic requirements for the disease (15-25°C temperature and 76-96% relative humidity), and climatic raster maps. The developed risk maps established a well-built background to guide scientists and producers.

2. Materials and Methods

This study covers Turkey's total land area (814 578 km2). Turkey is situated between the 36°–42° northern latitude and the 26°–45° eastern longitude, and has seven geographic regions (Mediterranean, Aegean, Marmara, Black Sea, Central Anatolia, Eastern Anatolia, and South-eastern Anatolia). Of these, Black Sea region is characterized by warm wet summers and cool to cold wet winters (typical temperate oceanic climate). It is the region where the highest rainfalls (2500 mm annually) of the country received. The Mediterranean and Aegean regions are characterized by hot-dry summers and humid-cool winters, and are defined as temperate Mediterranean climate. Marmara region has a transitional climate between Black Sea and Mediterranean regions, and is characterized by warm to hot, moderately dry summers and cool to cold, wet winters. Generally, there is no snowfall in those coastal areas of Turkey. However, central Anatolia (plateau) experiences extremes of hot summers and cold winters with limited rainfall (400 mm). Winters are harder in the eastern Anatolia where the highest mountains prevail. South-eastern Anatolia is characterized by hot and dry summers with temperatures above 30°C. In south-eastern Anatolia, spring and autumn are generally mild, but during both season sudden hot and cold spells occur frequently in the region (Serhat et al., 2008). Turkey has 81 provincial administrative units, of which has a government (provincial) center in the central district and its districts around.

The research was completed in five main steps: (1) creating monthly temperature and relative humidity raster maps of Turkey, (2) reclassifying created temperature and relative humidity raster maps using optimal climatic requirements for powdery mildew (15-25°C temperature and 76-96% relative humidity), (3) converting reclassified temperature and relative humidity raster maps to polygon (vector) maps, (4) intersecting temperature and relative humidity polygon maps to determine the areas for temperature and relative humidity requirements of powdery mildew, (5) mapping powdery mildew risk areas, calculating their surface areas, and displaying their maps in country, province and administrative district basis. We mainly used GIS to accomplish most of these steps.

We utilized digital elevation model (DEM) of Turkey and LOCCLIM software (version 1) of FAO (Grieser, 2002) in order to establish monthly temperature and relative humidity point database with a grid size of 83 km. Throughout this process, we followed a methodology developed by Dogan (2007) and produced a climatic point database for a total 125 points covering whole country. Then, all produced LOCCLIM files were organized in Microsoft Excel, and saved in dbf file format. In order to produce the raster maps, created point database, ArcGIS (version 9.3.1) software and its 3D Analyst (raster interpolation) tool were employed (ESRI, 2004, 2005). In the creation of all raster maps, Inverse Distance Weighted (IDW) method with a grid size of 412 m was applied.

Produced raster maps of temperature and relative humidity were reclassified using reclassify function of 3D Analyst tool in ArcGIS. In this process, temperature between 15°C and 25°C and relative humidity between 76% and 96% were defined as one unique class in each raster map. Reclassified monthly temperature and relative humidity raster maps were converted to polygon layers by using conversion tools (from raster to polygon) of ArcGIS. Temperature and relative humidity polygon maps of each month were combined by analysis tools (overlay and union functions) of ArcGIS. As a result, the areas that meet powdery mildew temperature and relative humidity requirements were mapped in monthly basis. Overlaying provincial and district boundary database of Turkey on the predicted powdery mildew risk areas maps, results were analyzed and summarized at country, province, and administrative district basis. In overlaying process, analysis tools (overlay and intersect functions) in ArcGIS was utilized.

The accuracy assessments of the produced risk maps were performed by utilizing field data and GIS. For this aim, field surveys in the study area were conducted between May and October in 2015. In the field surveys, infected locations were determined and recorded. Field data were organized as a Microsoft Excel (XYZ dataset) file, and converted to point map layers in monthly basis. Then, produced point map layers were overlayed on the corresponding risk area polygon map layers. Inside and outside points of the predicted risk area borders were calculated. Finally, partial and overall accuracy of all produced risk maps were determined.

3. Results and Discussion

Powdery mildew risk areas were determined in the Marmara and Black Sea regions of Turkey at the country level (Figure 1). The optimal conditions for the powdery mildew occurred in May, June, July, August, September, and October. The maximum geographic range for the disease expanded up to seven provinces (Giresun, Istanbul, Sinop, Ordu, Rize, Trabzon, and Kirklareli) in May, and shrunk to two provinces (Sinop and Giresun) in July. However, maximum (3141.18 km^2) and minimum (432.72 km^2) risk areas were recognized in October and July, respectively.

Generally, risk areas were found dynamic in each province. The largest risk area (613.66 km^2) of Sinop province was detected in May within Ayancik (490.00 km^2), Turkeli (120.00 km^2), Center (1.93 km^2) and Erfelek (1.73 km^2) districts (Figure 2). However, the smallest risk area (215.00 km^2) was observed in October within Ayancik (180.00 km^2) and Turkeli (35.00 km^2) districts. Both in terms of area and district numbers, May was the most risky month for Sinop province (Figure 2).

The maximum risk area (913.07 km^2) for Giresun province was recognized in May including Center (270.00 km^2), Kesap (180.00 km^2), Espiye (160.00 km^2), Yaglidere (100.00 km^2), Bulancak (84.00 km^2), Dereli (64.00 km^2), Tirebolu (42.00 km^2), Piraziz (9.77 km^2), and Guce (3.30 km^2) districts (Figure 3). The minimum risk area (60.08 km^2) was, on the contrary, in September within Kesap (54.00 km^2) and Center (6.08 km^2) districts. May was the most risky month for Giresun province considering both the area and number of districts.

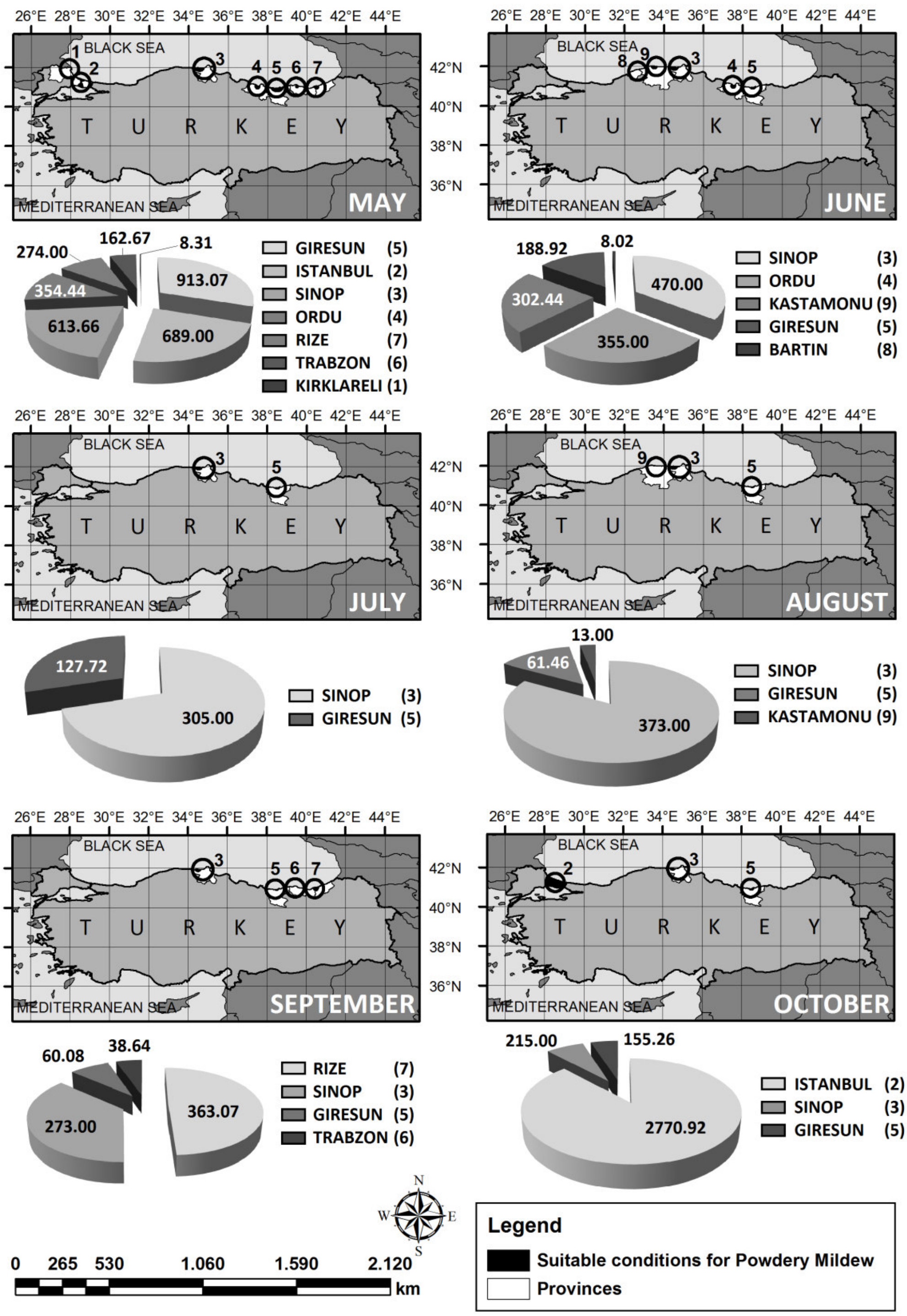

Figure 1. Predicted powdery mildew (*Podosphaeraaphanis* var. *aphanis*) risk areas (km^2) for wild strawberry (*Fragariavesca*) at the country level

Şekil 1. *Ülke düzeyinde yabani çilek (Fragariavesca) için tahmin edilen külleme (Podosphaeraaphanis var. aphanis) risk alanları*

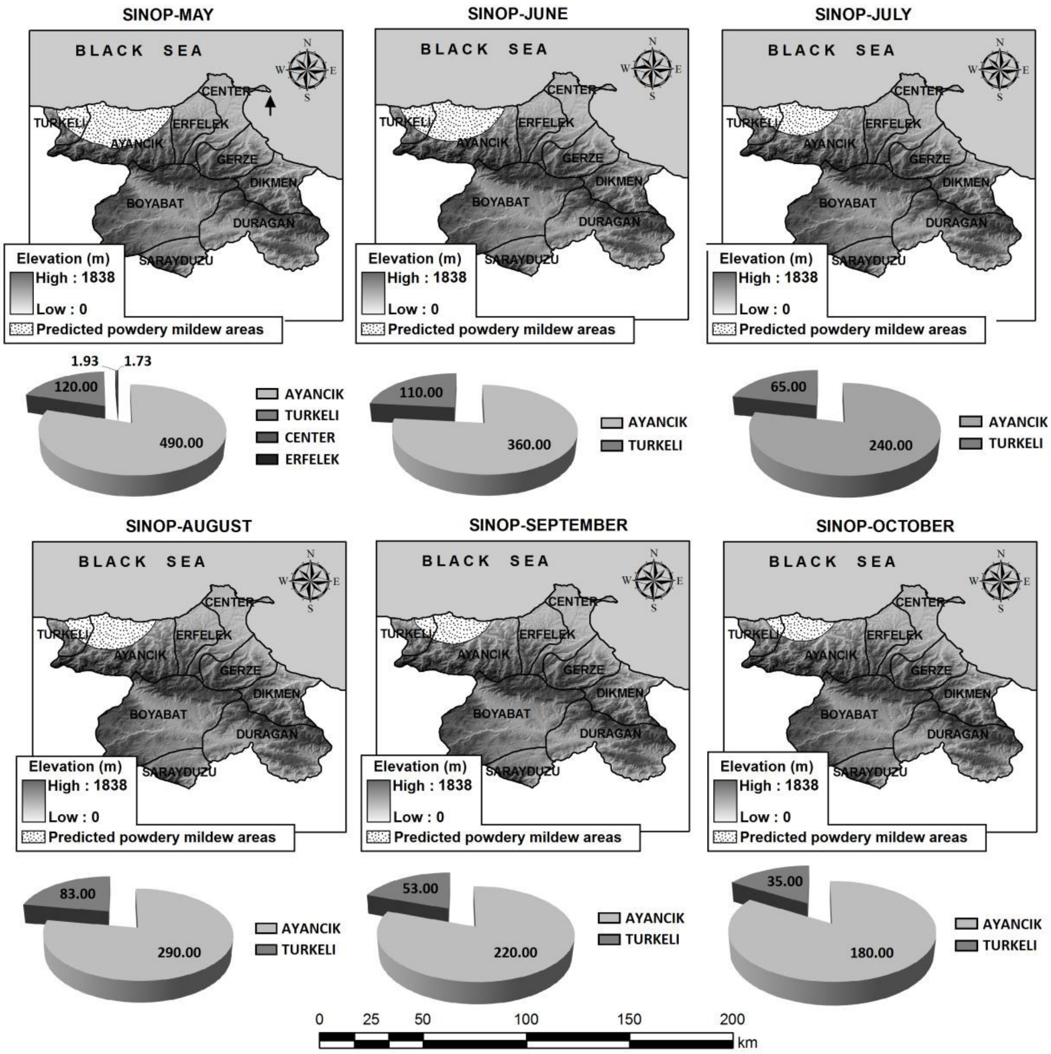

Figure 2. Predicted powdery mildew (*Podosphaeraaphanis* var. *aphanis*) risk areas (km^2) for wild strawberry (*Fragariavesca*) in Sinop province(very small risk area in the map are shown by black arrow)

Şekil 2. *Sinop ilinde yabani çilek (Fragariavesca) için tahmin edilen külleme (Podosphaeraaphanis var. aphanis) risk alanları (haritadaki çok küçük risk alanları siyah okla gösterilmiştir)*

The largest risk area (2770.92 km^2) of Istanbul was detected in October within Catalca (1200.00 km^2), Silivri (650.00 km^2), Buyukcekmece (240.00 km^2), Gaziosmanpasa (210.00 km^2), Eyup (180.00 km^2), Kucukcekmece (110.00 km^2), Esenler (39.00 km^2), Avcilar (39.00 km^2), Bakirkoy (29.00 km^2), Bagcilar (21.00 km^2), Sariyer (20.00 km^2), Bahcelievler (16.00 km^2), Gungoren (7.52 km^2), Bayrampasa (5.95 km^2), and Zeytinburnu (3.45 km^2) districts (Figure 4). However, the smallest risk area (689.00 km^2) was determined in May within Catalca (510.00 km^2), Buyukcekmece (160.00 km^2), and Silivri (19.00 km^2). Both for acreage and district numbers October was the most risky month in Istanbul. Moreover, Istanbul had the greatest risk area among all the provinces of Turkey.

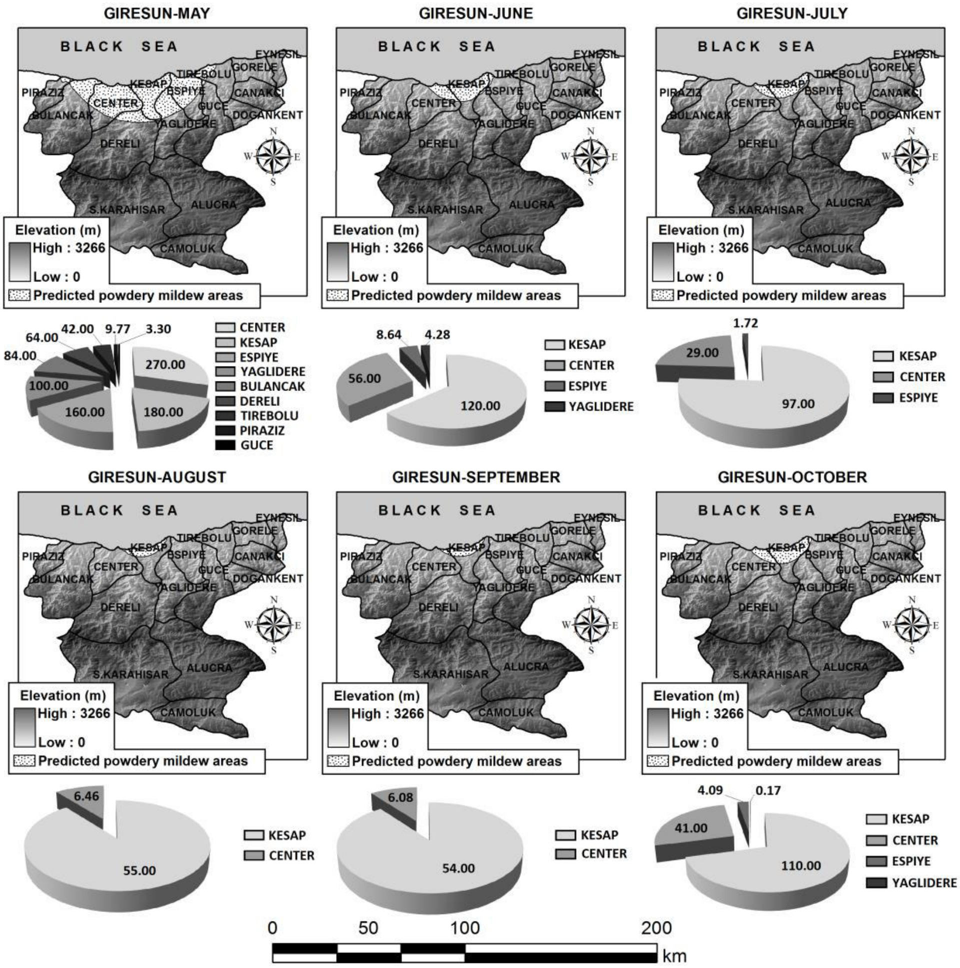

Figure 3. Predicted powdery mildew (*Podosphaeraaphanis* var. *aphanis*) risk areas (km^2) for wild strawberry (*Fragariavesca*) in Giresun province

***Şekil 3.** Giresun ilinde yabani çilek (Fragariavesca) için tahmin edilen külleme (Podosphaeraaphanis var. aphanis) risk alanları*

In Ordu province, risk areas appeared in May and June, and these areas were found close to each other (Figure 4). The largest risk area (355.00 km^2) in Ordu province was detected in June including Fatsa (250.00 km^2), Camas (58.00 km^2), Unye (21.00 km^2), Persembe (13.00 km^2), and Catalpinar (13.00 km^2) districts. However, the smallest risk area (354.44 km^2) was observed in May within Fatsa (250.00 km^2), Camas (46.00 km^2), Unye (42.00 km^2), Catalpinar (8.39 km^2), Persembe (7.80 km^2), and Gulyali (0.25 km^2) districts. June and May were the most risky months for area and number of districts, respectively. In Rize province, risk areas were determined in May and September, and these areas were found close to each other (Figure 4). The largest risk area (363.07 km^2) of Rize province was recognized in September within the Center (220.00 km^2), Kalkandere (52.00 km^2), Guneysu (46.00 km^2), Iyidere (28.00 km^2), Derepazari (17.00 km^2), and Ikizdere (0.07 km^2) districts (Figure 4). However, the smallest risk area (274.00 km^2) was revealed in May within the Center (190.00 km^2), Kalkandere (34.00 km^2), Derepazari (17.00 km^2), Guneysu (17.00 km^2), and Iyidere (16.00 km^2) districts. Both for the area and district numbers, September was the most risky month in Rize province.

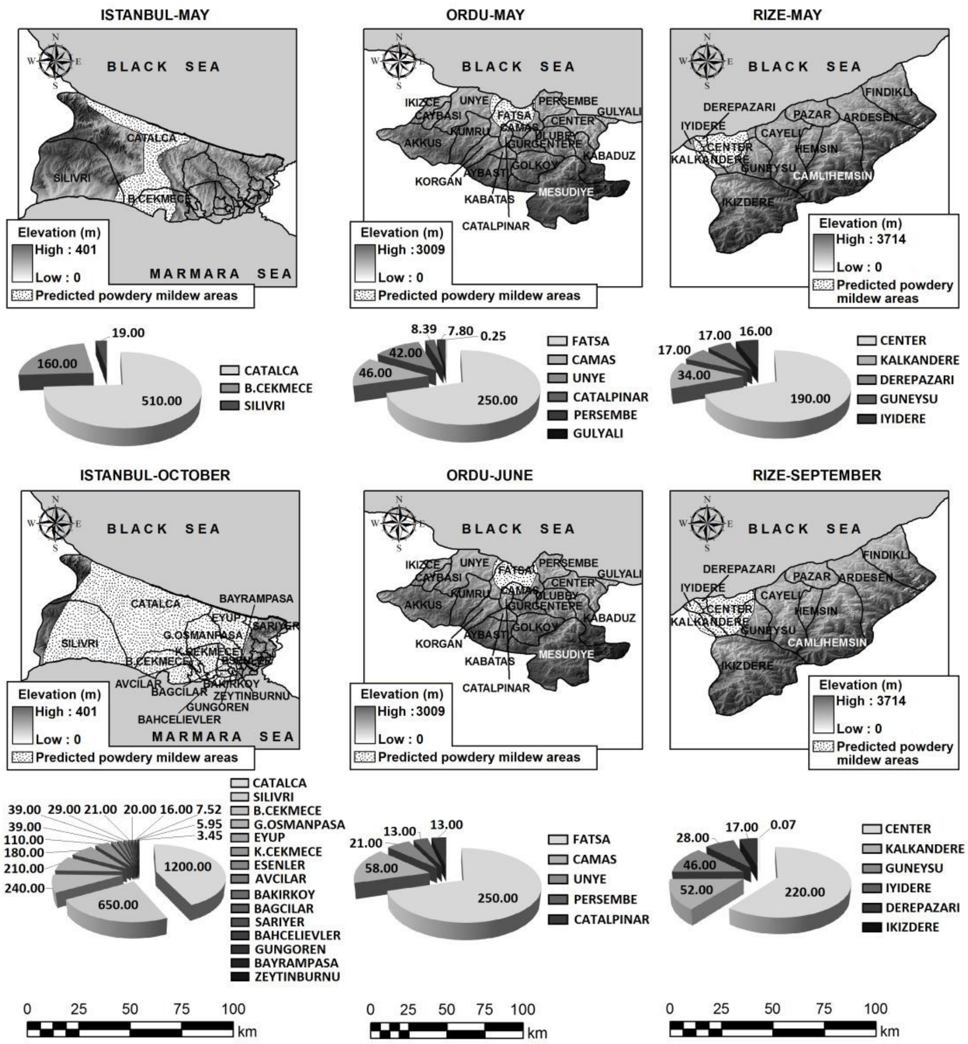

Figure 4. Predicted powdery mildew (*Podosphaeraaphanis* var. *aphanis*) risk areas (km^2) for wild strawberry (*Fragariavesca*) in Istanbul, Ordu and Rize provinces.

Şekil 4. *İstanbul, Ordu ve Rize illerinde yabani çilek (Fragariavesca) için tahmin edilen külleme (Podosphaeraaphanis var. aphanis) risk alanları.*

In Kastamonu and Trabzon provinces, risk areas appeared in two months (Figure 5). However, risk areas emerged in just one month in Kırklareli and Bartin provinces (Figure 5). The largest risk area (302.44 km^2) of Kastamonu province was observed in June within Doganyurt (250.00 km^2), Inebolu (39.00 km^2), Kure (6.68 km^2), Cide (4.45 km^2), and Azdavay (2.31 km^2) districts, whereas the smallest risk area (13.00 km^2) was seen in August within only Doganyurt district (Figure 5). The largest risk area (162.67 km^2) of Trabzon province was found in May within Akcaabat (150.00 km^2), Of (7.63 km^2), and Carsibasi (5.04 km^2) districts (Figure 5). However the smallest risk area (38.64 km^2) was caught in September within Of (38.00 km^2) and Hayrat (0.64 km^2) districts. A very small risk area (8.31 km^2) appeared in Demirkoy district of Kirklareli province in May. Similarly, a very small risk area (8.02 km^2) appeared in Kurucasile (4.87 km^2) and Amasra (3.15 km^2) districts of Bartin province in June (Figure 5).

Total 225 infected locations were determined in the field surveys (Figure 6a). The number of infected locations in May, June, July, August, September and October were determined as 53, 56, 27, 37, 24, and 28, respectively (Figure 6b). In these months, location numbers inside the predicted risk area borders were detected as 44, 46, 20, 28, 20, and 22, respectively (Figure 6b). Consequently, accuracy levels of produced risk maps were calculated as 83.02%, 82.14%, 80.00%, 75.68%, 83.33%, and 78.57% in these months (Figure 6c). Overall accuracy (80%) was determined using the total number of infected locations (225) and the total location number inside the predicted risk area borders (180). Results indicated that produced risk maps are accurate enough.

The capacity to recognize disease outbreaks in their early stages is a key component for efficient disease control and prevention. Increased readiness of digital environmental data and spatiotemporal analysis techniques, there is great potential to develop algorithms to enable more effective disease surveillance. However, to ensure that the algorithms are effective they need to be evaluated (Watkins et al., 2007). Here in this study, we utilized both GIS and LOCCLIM to determine powdery mildew (*Podosphaera aphanis* var. *aphanis*) risk areas on wild strawberry (*Fragaria vesca*) of Turkey. LOCCLIM successfully generated local climatic data for mapping process, and GIS enabled us to create and analyze climatic raster maps. The results we obtained here improved the quality of climatic data far beyond the raw data of TSMS (2015).

Determined risk areas indicated that Marmara and Black sea regions have appropriate environments for the disease. This was because, ranges for temperature (15-25°C) and relative humidity (76-96%) needed for powdery mildew development on wild strawberry exist in those regions. Conditions were optimum for powdery mildew during May, June, July, August, September, and October while wild strawberry was developing in different topographies and altitudes of the region (Kaska, 2002). Similarly risk areas were dynamic in each province depending on temperature and relative humidity.

Turkey's climate and genetic diversity is an important advantage for sustainable agriculture. However, this diversity creates suitable conditions for different diseases development on various crops, and induces difficulties for integrated disease management in the country (Zencirci and Kün, 1995; Zencirci and Karagöz, 2005; Braun et al., 2001; Zencirci, 2008). Therefore, GIS applications are good approaches to monitor, control, and overcome possible disease damages.

Provinces and administrative districts dynamically reflected risk areas based on the temperature and the relative humidity. That dynamism fitted previous studies (Guler and Karaca, 1988). Considering both area and geographic distribution, May was the most risky month in Turkey. Other risky months in province basis were also determined as October (Istanbul), June (Ordu), September (Rize), and June (Kastamonu). Wild strawberries and powdery mildew require similar conditions. Therefore, monitoring, preventing and even having an integrated pesticide control based on GIS is necessary for a safer-sustainable strawberry production.

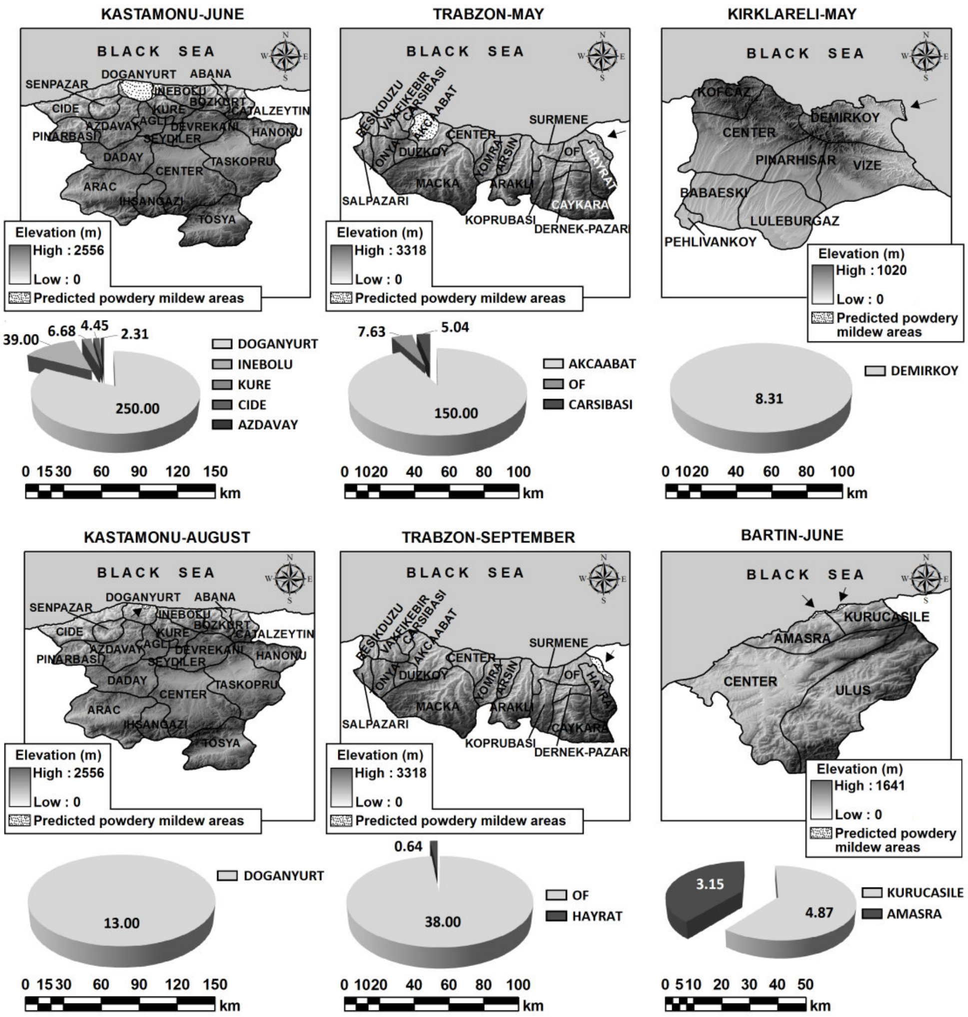

Figure 5. Predicted powdery mildew (*Podosphaeraaphanis* var. *aphanis*) risk areas (km^2) for wild strawberry (*Fragariavesca*) in Kastamonu, Trabzon, Kırklareli, and Bartin provinces (very small risk areas in the map are shown by black arrows)

Şekil 5. *Kastamonu, Trabzon, Kırklareli ve Bartın illerinde yabani çilek (Fragariavesca) için tahmin edilen külleme (Podosphaeraaphanis var. aphanis) risk alanları (haritadaki çok küçük risk alanları siyah okla gösterilmiştir)*

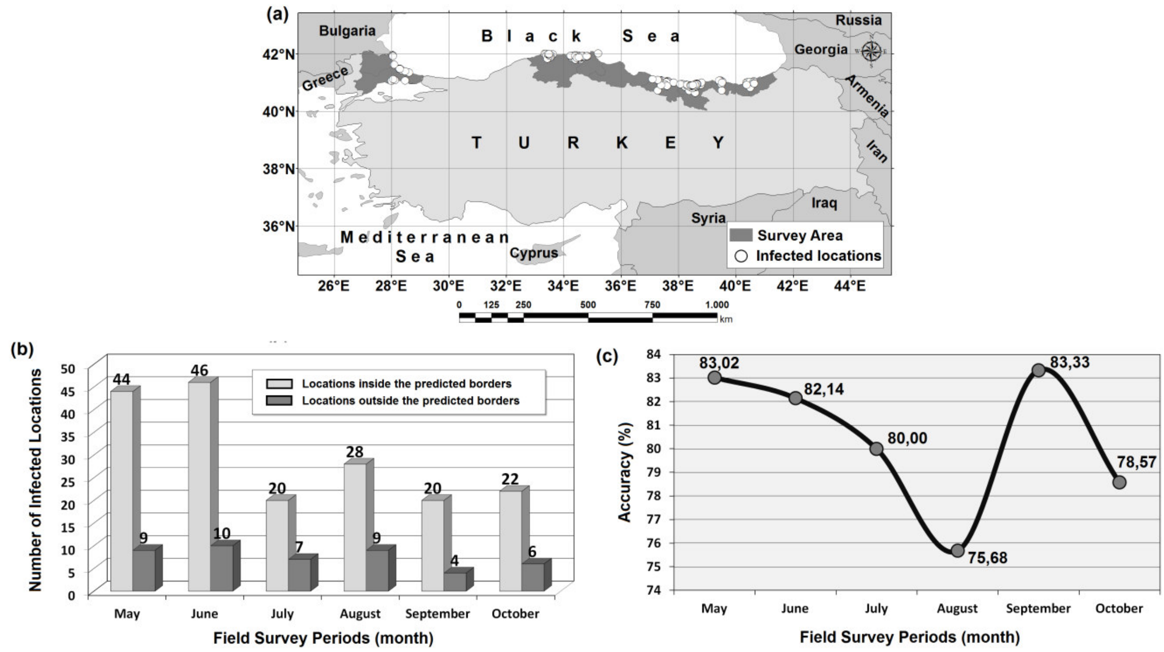

Figure 6. Total infected locations with *Podosphaeraaphanis* var. *aphanis* (a), observed locations inside and outside of the predicted risk areas (b), and accuracy assessment in monthly basis (c).

Şekil 6. *Podosphaeraaphanis var. aphanisile enfekte olan toplam alan (a), tahmin edilen risk alanlarının içindeki ve dışındaki gözlemlenen yerler (b) ve aylık bazda doğruluk değerlendirmesi (c).*

5. Conclusions

This study has supplied a good and reliable basis for forecasting and mapping powdery mildew risk areas for wild strawberries in Turkey. Basically, this type of map information is an important tool for disease control. The produced raster maps in this study depend purely on temperature and relative humidity variables. Anthropogenic effects, such as agricultural activities and urbanization, have not been taken into consideration. Consequently the resulting risk maps showed the powdery mildew risk areas without human effect, and implied the risk area scenario that might be formed by the prevailing two important ecological variables (temperature and relative humidity) if there are no precautions or interventions. This kind of information is valuable for growers to make them aware of the possible risk areas.

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