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Simulation of cucumber downy mildew Spread and sedimentation based on HYSPLIT

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Abstract

Cucumber downy mildew is a typical fungal airborne disease in which pathogenic spores are transmitted remotely by air currents, resulting in regional endemics. It is of great significance to study and analyze the temporal and spatial changes of downy mildew spores, especially the trajectory and sedimentation concentration of spores propagating with airflow in the air, for the prediction of downy mildew in cucumbers. Therefore, based on GDAS meteorological data from October to November 2017, this study uses the HYSPLIT-5 model to simulate the airflow propagation trajectory and sedimentation of downy mildew pathogen spores in the main cucumber planting areas in China, analyzes the trajectory frequency and sedimentation concentration in the long-distance and long-term series propagation process, and explores the transmission law of airborne disease spores, which provides a theoretical basis for predicting downy mildew in cucumbers.

Keywords: Cucumber downy mildew, HYSPLIT, Propagation law

1. Introduction

In recent years, with the rapid development of China's social economy, vegetable industry has developed rapidly in China. At present, the cultivated area of our greenhouse has exceeded 4 million hectares (Jin et al.,2020), occupying the first place in the global total greenhouse planting area. As one of the most popular vegetables (Zhao et al.,2020; Qin et al.,2021), cucumber occupies a high proportion in greenhouse vegetable cultivation and is of great economic significance. The high temperature and high humidity environment in the greenhouse is conducive to the prevalence and spread of cucumber downy mildew, which worsens year by year with the expansion of cultivation area and the increase of cropping years. In severe cases, it can lead to reduced production, yield loss of up to 20-50%, or even no harvest (Wallace et al.,2020). Therefore, timely prevention of greenhouse gas diseases becomes particularly important. `

The essence of cucumber downy mildew is the infection and propagation of pathogen spores. Cucumber downy mildew is a kind of fungal airborne disease. The downy mildew spores spread by atmospheric circulation. In order to realize earlier disease warning, it is also necessary to use atmospheric circulation technology to simulate the path of pathogenic bacteria transmitted by air flow according to the characteristics of the spores of pathogenic bacteria transmitted by air circulation, and to monitor and warn the spread and incidence of diseases in combination with the actual situation of topography and geomorphic features of specific regions and the time sequence of disease occurrence.

Isard et al. proposed a model framework for predicting downwind spore deposition from inoculant area sources based on the atmospheric boundary layer turbulent dispersion theory (Isard et al.,2016). The results of this model are in good agreement with published measurements of bean spore deposition and wheat leaf rust severity. Olsen et al. used the HYSPLIT model to study the transmission law of pathogen spores in the air. Their research confirmed that many plant fungal diseases spread from short to long distances in the form of spores via atmospheric circulation, and that distance determines the spread of plant diseases, while pathogen genotypes can also invade new areas (Olsen et al.,2019). Tao et al. developed an atmospheric circulation model for predicting the risk of soybean rust in Minnesota, which was mainly composed of the long-distance transmission and sedimentation module of airborne disease spores and the leaf humidity module. The forecast data of the US National Weather Service were used to predict soybean rust one week in advance (Tao et al.,2009). Pan et al. established a comprehensive model system of climate pathogens based on Hysplit4 model and MM5 model, which could be used to study the intercontinental transmission process of soybean rust. This model correctly predicted the transmission process of soybean rust spores from southern South America to Colombia and then to the United States in 2004, one month in advance (Pan et al.,2006).

Based on the meteorological data of GDAS from October to November 2017, this paper used the HYSPLIT-5

model to simulate the trajectory and deposition of downy mildew pathogen spores in the main planting areas of cucumber in China, and analyzed the trajectory frequency and deposition concentration during the long distance and long time series propagation process. It provides a theoretical basis for predicting downy mildew of cucumber.

2. Materials and Methods

In this experiment, Global Data Assimilation System of National Weather Service's National Centers for Environmental Prediction was used. The data was run four times a day at 00:00, 06:00, 12:00, 18:00 UTC. NECP stored the data in binary format with an accuracy of 360×181 grid points at 1° latitude and longitude. The meteorological data for October-November 2017 was obtained using an ftp server. The map data is 1:0.4 million map of China's national boundaries and provincial administrative regions, using Mercator map projection.

According to the survey results of vegetable diseases in China in 2017, this study selected Shandong County, Hebei Pingquan City and Huaian Huaiyin District of Jiangsu Province as the simulated source points of bacteria, and determined the simulation period and starting height of the test according to the planting period and landform of each planting area. Located in the Yellow flood plain, Xinxian County has a flat terrain with an elevation of 35m to 50m. Therefore, a layer with an initial height of 100m is selected for near-surface air flow and hollow air flow with a high spore density. Pingquan City is located in the hilly region of Yanshan Mountain in northern Hebei Province, with numerous mountains and an altitude of about 500m, so the air flow level is set as 1000m. The terrain of Huaiyin District is mostly plain depression, whose elevation is about 10m, so it is set as 100m level. The specific simulation information is shown in Table 1.

Table 1 Simulated source geographic information, time period and height in 2017

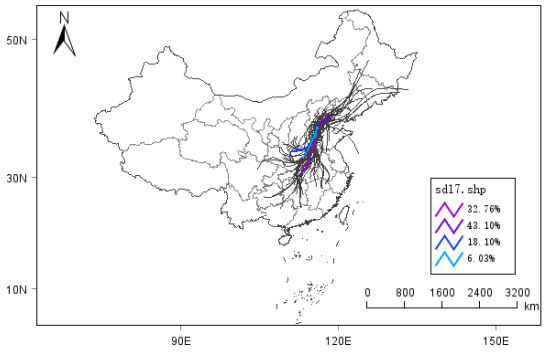
Simulated source point	Longitude and latitude	Simulation period	Simulated height /m (AGL)
Xinxian County, Shandong Province	36.18°N, 115.61°E	10.1-10.30	100
Pingquan City, Hebei Province	41.11°N, 118.75°E	10.1-10.30	1000
Huaiyin District of Huaian, Jiangsu Province	33.58°N, 118.86°E	11.1-11.30	100

3. Results and Discussion

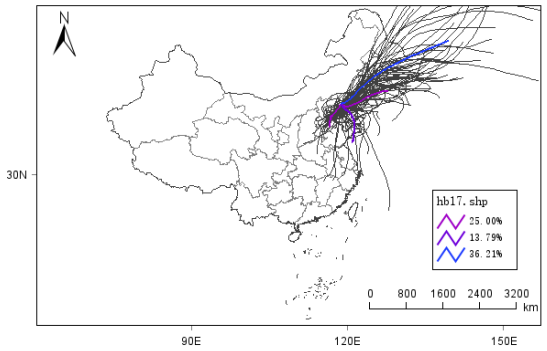
3.1 Transmission range and locus frequency of airborne disease spores based on forward trajectory

Taking Xinxian County of Shandong Province, Pingquan City of Hebei Province and Huaiyin District of Huai 'an, Jiangsu Province as the starting simulation points, the trajectory simulation was carried out at the ground height of 100m and 1000m at UTC0, 6, 12 and 18 hours each time from October to November 2017. Each simulation source point has 120 tracks at each height, and cluster analysis is carried out on all tracks to obtain the trajectory clustering diagram at different heights of each simulation point, as shown in Fig 1.

As can be seen from the Fig 1, downy mildew spores formed a variety of transmission paths along with the airflow, including the local transmission of spores and a large number of provinces and cities, which were also reflected in the other two regions. In October 2017, there were 120 tracks with Xinxian County, Shandong Province as the source of the disease in Fig 1 (a), which had a wide range of transmission. Cluster analysis showed that 43.10% of the tracks spread to the northeast, mainly affecting eastern Hebei, Tianjin, Liaoning and other regions. The other three types of tracks propagate in the southwest direction with a frequency of 32.76%, 18.10% and 6.02%, respectively. There are differences in the distance and height of the tracks, which mainly affect Henan, Anhui and Hubei provinces. Figure 1 (b) shows the transmission track of downy mildew spores in Pingquan City in October 2017. It can be seen from the figure that 36.21% and 25.00% of the tracks spread along the northeast direction, affecting Liaoning, Jilin and other places. 13.79% of the tracks spread into Bohai Sea along the southeast direction, mainly affecting Tangshan, Qinhuangdao and other areas. 25.00% of the tracks spread along the southwest direction, mainly affecting Hebei. Figure 1 (c) shows the transmission trajectory of downy mildew spores in Huaiyin District in November 2017. It can be seen from the figure that 50.89% of the spores spread along the southwest direction, mainly affecting Anhui. 33.04% of the tracks spread along the northeast direction, mainly affecting northern Jiangsu and eastern Shandong. 16.07% of the track passed into the East China Sea along the southeast direction, mainly affecting southern Jiangsu and other areas.



(a)



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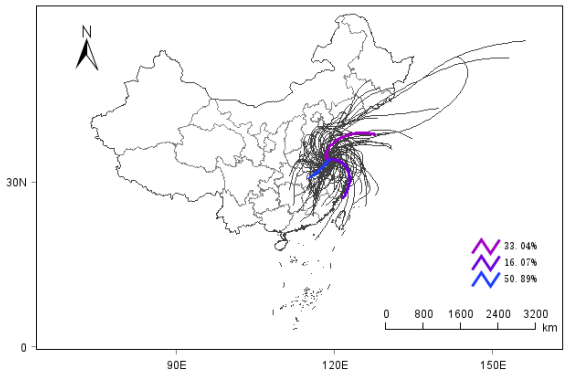


(c)

Figure 1. The trajectory cluster diagram of cucumber downy mildew spore in 2017, (**a**) Xinxian County, Shandong Province, (**b**) Pingquan City, Hebei Province, (**c**) Huaiyin District of Huaian, Jiangsu Province.

3.2 Sedimentation concentration simulation of spore transmission of cucumber downy mildew

From October 1 to October 30, 2017, Xinxian County, Shandong Province, Pingquan City, Hebei Province, and from November 1 to November 30, 2017, Huaiyin District of Huaian, Jiangsu Province were used as simulation points to simulate the concentration of multiple dispersal and sedimentation of downy mildew spores. The mass concentration of mildew spores was set as 1mg/m^3, the particle diameter as 25μm(Wang et al.,2022), the deposition rate as 0.01m/s, the simulated initial height of Xinxian County and Huaiyin district was set as 100m, and the simulated initial height of Pingquan City was set as 1000m. Each forward simulation was conducted for 48 hours. That is, from October 1 to October 30, 2017 and November 1 to November 30, 2017, 15 times respectively, the settlement concentration vector map of downy mildew spores in these 15 times was converted

into raster data in ArcMap 10.2, which was calculated by grid superposition and converted into percentage settlement probability. The settlement concentration probability distribution of cucumber downy mildew from October to November 2017 was obtained, as shown in Figure 2.

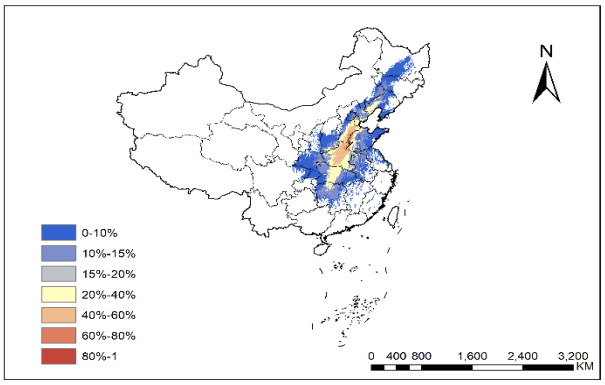
Figure 2 shows the deposition concentration distribution of downy mildew spores spreading at a height of 100m and 1000m in the three pathogenetic sites. As can be seen from the figure, the spores of downy mildew in each disease source area mainly settled in the local and surrounding areas, with a settlement probability of more than 60%. The spores gradually spread and settled in several neighboring provinces and regions, with a settlement probability of 20% to 60%. With the further spread of spores, their coverage covered more than a dozen provinces and regions around the disease source area. But the probability of spores settling is also low, below 20%. The specific situation of propagation and settlement is as follows:

Figure 2 (a) shows the deposition concentration changes of cucumber downy mildew spores in Xinxian County, Shandong Province in October 2017. As can be seen from the figure, due to the influence of air flow in the southwest and northeast directions, the frost mold spores in Xinxian County mainly settled in the northwest of Shandong, Henan and southern Hebei, and the probability of spores settling was more than 40%. As the airflow gradually diffused to southern Shandong, northwestern Jiangsu, northern Anhui, Hubei, Hunan, southern Shaanxi, southern Shanxi, Liaoning and northwestern Jilin and other areas, its subsidence probability was low, below 20%.

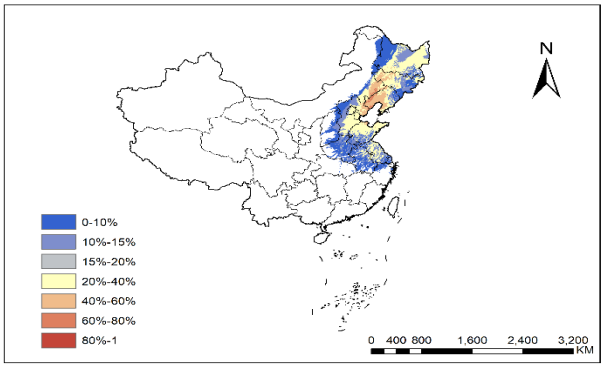
Figure 2 (b) shows the deposition concentration changes of cucumber downy mildew spores in Pingquan City, Hebei Province in October 2017. As can be seen from the figure, due to the influence of southwest wind, spores airborne in Pingquan City mainly settled in the three provinces of Northeast China, with the probability of spores settling in eastern Hebei, western Liaoning and northwestern Jilin exceeding 40%. As the airflow spreads to southern Hebei, northern Shandong, Tianjin and southern Heilongjiang, its subsidence probability is between 20% and 40%. The sedimentation probability of spore was below 20% when the diffusion range further increased to southwest Shandong, Henan, Anhui, Jiangsu, west Hebei and northwest Heilongjiang.

Figure 2 (c) shows the change of deposition concentration of cucumber downy mildew spores in Huaiyin District, Huaian, Jiangsu Province during the outward transmission in November 2017. As can be seen from the figure, due to the influence of the northeast air flow along the coast, the deposition range of spores is mainly concentrated in the southern northeast, East China, eastern Central China and Guangdong, etc. The deposition probability of spores in northern Jiangsu, northern Anhui and eastern Shandong is above 20%, and the probability of spores deposition in some areas is above 40%. Along with the airflow, the spores further spread to Guangdong, eastern Central China, southern East China and southern Northeast China, and the sedimentation concentration was less than 10%.

By comparing the change of spore deposition concentration in the three pathogen sites, the main change trend was consistent, the concentration of spore deposition in the central area was higher, and the concentration of spore deposition in the outward area was gradually reduced. The concentration of spore deposition in Huaiyin District of Jiangsu Province is generally lower than that in Xinxian County of Shandong Province and Pingquan City of Hebei Province. The reason for this may be that Huaiyin District is located in the plain coastal area and affected by the complex wind field at sea, and the spores of mildew are easy to go up with the air and spread over a long distance. Through the weather net (https://lishi.tianqi.com/) estimated the rainfall of the three regions, found in shen county of rain days in October 2017 for 9 days, hiraizumi city rainfall days for 7 days, but in huaiyin district in November 2017, there was no rain, may reduce the wet deposition behavior of downy mildew spores, The sedimentation concentration of spores was reduced.



(**a**)



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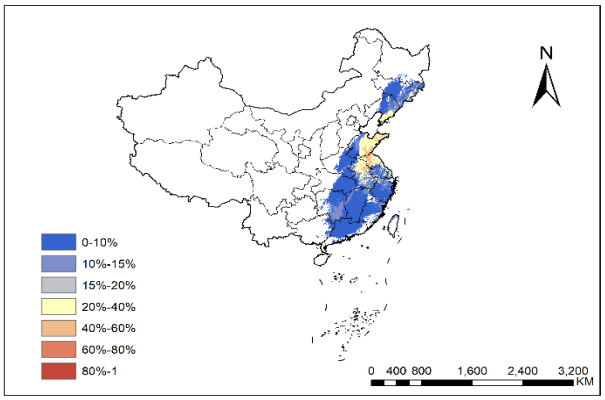

(**c**)

Figure 2. Settlement probability distribution map of cucumber downy mildew from October to November 2017, (**a**) Xinxian County, Shandong Province, (**b**) Pingquan City, Hebei Province, (**c**) Huaiyin District of Huaian, Jiangsu Province.

4. Conclusions

Affected by the atmospheric circulation, the spores spread to the surrounding areas of the source area along with the air flow. Different tracks cross each other, and the spread range is relatively wide, and the propagation law has a certain universality. The sedimentation regularity of frost mold spores was consistent, mainly settling in the local and surrounding areas of the disease source, and the sedimentation probability was above 60%. With the gradual outward diffusion of spores, the sedimentation concentration also gradually decreased to below 20%. Based on the analysis of the transmission trajectory and deposition concentration of cucumber downy mildew spores, the spatio-temporal dynamic distribution of spores in the air was explored. Combined with the actual disease investigation results and disease transmission prediction, it can provide some theoretical support for the realization of long-term prediction of cucumber downy mildew.

Conflicts of Interest

The authors have no conflict of interest to declare.

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