Plant Diseases and Pests 2024, 15 (5): 8 – 10, 18 DOI: 10.19579/j.cnki.plant-d.p.2024.05.003

Occurrence Regularity and Comprehensive Prevention and Control Techniques of Sunflower Downy Mildew

Weidong SHAN[1], Yantao LIU[2*], Wei DUAN[2], Huping ZHANG[3], Shengli LIU[2], Peng WANG[2], Zhonghua LEI[4], Lanlan ZHANG[3]

1. Seed Management Station of the Sixth Division of Xinjiang Production and Construction Corps, Wujiaqu 831300, China; 2. Crop Research Institute of Xinjiang Academy of Agricultural Reclamation Sciences, Shihezi 832000, China; 3. Agricultural Technology Extension Station of the Ninth Division of Xinjiang Production and Construction Corps, Emin 834600, China; 4. Institute of Economic Crops, Xinjiang Academy of Agricultural Sciences, Urumqi 830091, China

Abstract This paper examines the occurrence regularity and comprehensive prevention and control techniques for sunflower downy mildew. It provides a detailed discussion of the pathogens, symptoms, and associated risks, as well as the transmission pathways, underlying causes, and prevention and control techniques related to sunflower downy mildew. The aim is to offer valuable references and technical guidance for the effective management of this disease.

Key words Sunflower; Downy mildew; Occurrence regularity; Prevention and control technique

1 Introduction

Xinjiang is recognized as one of the three principal sunflower-producing regions in China, encompassing a cultivation area of approximately 133 300 to 166 700 hm^2. The sunflower cultivation area in Xinjiang, along with that of the Xinjiang Production and Construction Corps, exhibits significant annual fluctuations; however, the overall yield tends to demonstrate an upward trajectory, largely influenced by economic incentives. In 2022, the area dedicated to sunflower cultivation in Xinjiang was 121 600 hm^2, of which 32 000 hm^2 (26.32%) were allocated for oil sunflower production. In contrast, the sunflower planting area within the Xinjiang Production and Construction Corps amounted to 33 600 hm^2, with 8 893.33 hm^2 (26.52%) designated for oil sunflower cultivation. According to the international FAOSTAT statistics database, the global yield of sunflower seeds in 2022 was approximately 50.2 million t, with a harvested area of approximately 27.8 million hm^2. The area dedicated to sunflower cultivation in China has reached 1.12 million hm^2, yielding a total of 26 million t. This positions China as the fourth largest country globally in terms of sunflower planting area. Additionally, the annual sales have reached 78 billion yuan, indicating a positive trend in development[1].

Sunflower downy mildew is a prevalent disease affecting sunflowers, and its incidence can significantly impact both the growth and yield of the sunflower crop. The incidence of sunflower downy mildew is influenced by various factors, including climate, soil conditions, and cultivation management practices. In warm and humid environments, the proliferation and dissemination of pathogenic bacteria are facilitated, resulting in the emergence and prevalence of the disease. Consequently, in the cultivation and management of sunflowers, it is essential to implement strategies such as enhancing ventilation, minimizing humidity, optimizing fertilization practices, and promptly removing disease residues to mitigate the incidence and dissemination of diseases. The prevalence of sunflower downy mildew significantly diminishes both the quality and economic value of sunflower crops. Consequently, it is imperative to prioritize the prevention and management of sunflower downy mildew in sunflower production. Implementing scientifically sound and rational preventive and control strategies is essential to safeguard the yield and quality of sunflower.

Numerous scholars have conducted extensive research on sunflower downy mildew, primarily concentrating on the optimization of disease management strategies, the functional characterization of pathogen effectors, the discovery and application of resistance genes, and a comprehensive investigation of resistance mechanisms. Integrated Pest Management (IPM) serves as a crucial strategy for the management of sunflower downy mildew; however, the variability of pathogens poses significant challenges to the efficacy of control measures. The study evaluated critical components of sunflower downy mildew management and discussed existing challenges as well as future research directions[2]. Through the application of high-throughput sequencing techniques, the researchers identified potential effectors characterized by the presence of RXLR or CRN motifs, which have been previously described in other oomycetes. The expression of these effectors in pathogen spores and infected sunflower leaves was analyzed, and their subcellular localization was demonstrated for the first time in sunflower leaf cells. This finding offers new insights into the understanding of disease mechanisms. Researchers have employed marker-assisted selection to incorporate novel resistance genes, including *Pl8*, *Pl17*, and *Pl18*, into sunflower germplasm. This ef-

Received: May 15, 2024 Accepted: September 2, 2024

Supported by Wujiaqu City Science and Technology Program Project of the Sixth Division (2214); Science and Technology Research Project in Key Areas of the Xinjiang Production and Construction Corps (2024AB014); Financial Program of the Ninth Division (2024JS007); "Strengthening Youth" Science and Technology Innovation Backbone Talent Program of the Xinjiang Production and Construction Corps (2023007-06); Key R&D Program of Xinjiang Autonomous Region (2023B02008-1); Excellence Youth Program of the Xinjiang Production and Construction Corps; Earmarked Fund for China Agriculture Research System (CARS-16).

* Corresponding author. E-mail: ziheng1979@126.com

fort has resulted in the development of sunflower germplasm resources HA-DM9, HA-DM10, and HA-DM11, which exhibit dual resistance. These resources demonstrate broad resistance to all identified races of *Plasmopara halstedii* in North America and Europe, making them valuable for use in sunflower breeding programs aimed at enhancing downy mildew resistance. The genetic structure of *P. halstedii* populations was examined, contributing to the understanding of pathogen variability and the management of associated diseases. This study investigated the mechanisms of resistance to downy mildew in sunflowers, encompassing the localization and functional analysis of resistance genes, as well as the interactions between these resistance genes and pathogen effectors.

2 Pathogens and their infection process

2.1 Pathogens The causal agent of sunflower downy mildew is *Plasmopara halstedii* (Farl.) Berl. et de Toni, which is classified within the genus *Plasmopara*, family Peronosporaceae, order Peronosporales, and subphylum Mastigomycotina. This pathogen exhibits a high degree of specialized parasitism, and it has the capability to be transmitted over considerable distances via seeds[3-4].

The sporangiophore of the pathogen exhibits a size range of (180 – 500) × (6 – 12) μm, while the sporangium measures (16 – 35) × (14 – 26) μm. The oospores are characterized by a spherical shape and a yellowish-brown coloration, measuring between 23 and 30 μm in diameter. The germination of the sporangium occurs within a temperature range of 3 to 28 ℃, with an optimal temperature for germination identified as 5 to 10 ℃. Under arid conditions, sporangia exhibit a diminished capacity for germination. However, sporangia demonstrate the ability to germinate in 2% aqueous solutions of glucose, maltose, and sucrose at a temperature of 10 ℃, with a notably higher germination rate observed in the 2% sucrose solution.

In addition to sunflowers, *P. halstedii* has the capacity to infect a variety of crops, including eggplant, pepper, tomato, cotton, tobacco, potato, melon, watermelon, cucumber, peanut, kidney bean, mung bean, soybean, sesame seed, sugar beet, and others. However, it typically does not infest grass crops.

2.2 Infection process The pathogen persists through the winter in the endocarp and seed coat of sunflower seeds, primarily in the forms of mycelium and oospores. As temperatures increase during the spring, oospores undergo germination, leading to the formation of zoosporangia that subsequently release zoospores. Under favorable conditions, these zoospores will germinate and develop germ tubes. The germ tubes penetrate the interior of the sunflower plant by invading the epidermal cells. Under optimal conditions, the pathogen proliferates and develops mycelium within the plant. Mycelium develops within the plant and ultimately produces propagules of the pathogen, including sporangia and zoospores, thereby completing the infestation process. The disease manifests as a latent infestation, wherein seedlings derived from infected seeds may not exhibit symptoms immediately. However, following the sowing of infected seeds in a production setting, only a limited number of plants may display systemic symptoms during that growing season, while a considerable proportion of plants may serve as asymptomatic carriers.

3 Onset symptoms

The symptoms of sunflower downy mildew are primarily characterized by the emergence of yellow or white spots on the leaves. As the disease advances, these spots progressively enlarge, resulting in the formation of round or irregularly shaped lesions. The lesions exhibit a grayish-white center surrounded by yellowish margins. Under moist conditions, a white layer of mold develops on the lesions, which are conidia of the pathogen. In severe instances, the lesions on the leaves may coalesce, resulting in wilting, leaf abscission, and potentially leading to the demise of the plant.

The disease may manifest throughout the entire growing season, with the period from seed germination to the emergence of the first pair of true leaves identified as a critical risk period for sunflower susceptibility. Symptoms can be classified into four distinct categories based on their timing of occurrence and specific characteristics, as outlined below.

3.1 Dwarf type The plant exhibits significant dwarfism, characterized by shortened internodes and inadequate root development[4]. Additionally, there is a regression of the leaves to a green coloration, accompanied by the emergence of "mosaic" spots along the primary or lateral veins of the leaf blade. In instances of rainfall or elevated humidity, a dense white mold layer, consisting of the sporangia and sporangiophores of the pathogen, becomes evident on the abaxial surface of the affected leaves. Conversely, under sustained dry climatic conditions, this mold layer is absent, even in plants exhibiting significant disease severity. Sporangia-infested plants exhibiting disease symptoms have a considerable effect on yield, primarily due to the damage inflicted on the vascular tissues and the small, easily desiccated discs[5]. This symptom is predominantly a result of the pathogen's invasion and systemic proliferation during the seedling stage.

3.2 Leaf spot type The condition is attributed to the parasitization by a pathogenic fungus, which manifests as lesions on the leaves of sunflowers. This disease predominantly impacts the foliage, resulting in the appearance of irregular yellow or brown spots, often accompanied by a yellow halo surrounding the lesions. In certain instances, black dots may be observed at the center of these spots. As the disease progresses, these lesions may enlarge and coalesce, ultimately leading to wilting and abscission of the affected leaves.

3.3 Flower and fruit damage type The downy mildew, which infests flowers and fruits, primarily impacts the late stages of sunflower production and development. This occurs through the direct infestation of the floral organs and ovaries by sporangia, leading to partial desiccation of the flowers and subsequent embryo mortality[4]. The affected plant exhibits a significant decrease in its 1 000-grain weight, attributable to seed failure and seed thinning. Additionally, the plant's disc is frequently characterized by a lack of curvature and pendulousness, and it is not oriented towards the sun.

3.4 Latent type The latent type of downy mildew exhibits limited development in agricultural production. The external manifestations on the plant are not pronounced, and the sporangia primarily affect only the portions of the sunflower that are above the root system. In some instances, the infestation can extend up to 25 – 30 cm above the soil surface, resulting in a pale green coloration of the stems and a pale brown appearance of the cells surrounding the pith[2].

4 Route of transmission

4.1 Seed transmission The pathogen primarily exists in a latent state within the endocarp and seed coat of sunflower seeds, manifesting as mycelium and oospores. Transmission occurs through the transportation and sowing of seeds.

4.2 Soil transmission Disease residues that are interspersed among seeds also harbor bacteria. As temperatures increase in the spring, oospores germinate, leading to the production of zoosporangia, which subsequently release zoospores. These zoospores invade sunflowers, resulting in symptoms indicative of whole-plant infestation.

4.3 Agricultural activity Agricultural practices, including crop succession, the use of contaminated seeds, and the failure to promptly remove disease residues, and other activities, may elevate the risk of disease transmission.

5 Factors affecting disease occurrence

The incidence and prevalence of sunflower downy mildew are closely associated with temperature, humidity, rainfall, and other meteorological conditions. Optimal temperature and humidity levels facilitate the growth and reproduction of the pathogen, whereas rainfall promotes its dissemination. The incidence of the disease is correlated with the temperature and humidity during the sowing and emergence periods. Sunflower sowing under conditions of low temperature and high humidity is particularly susceptible to seedling diseases. Additionally, soil moisture levels and continuous cropping practices can exacerbate the development of these diseases. The sowing of sunflowers following exposure to low temperature and high humidity conditions can lead to an increased incidence of seedling diseases. Additionally, excessive rainfall during the spring, elevated soil moisture levels, high groundwater levels, and continuous cropping practices can further contribute to the development of these diseases. Furthermore, sowing seeds at excessive depths may exacerbate the prevalence of morbidity among the seedlings.

The cultivation and management practices of sunflower significantly influence the occurrence and prevalence of downy mildew[6-7]. Specifically, factors such as excessive planting density, inadequate plant growth, and improper fertilization can enhance the susceptibility of sunflowers to downy mildew. Different varieties of sunflowers exhibit varying levels of resistance to downy mildew. Generally, those varieties that demonstrate greater resistance are more effective in combating downy mildew. The populations of pathogens responsible for sunflower downy mildew significantly affect disease incidence and epidemiology. Variations among different populations of pathogenic bacteria result in distinct adaptations and levels of pathogenicity, which can consequently lead to variations in disease incidence and epidemiological patterns.

6 Control techniques

6.1 Agricultural control measures It is advisable to select sunflower varieties that exhibit resistance to downy mildew, as this represents one of the most cost-effective strategies for managing this disease. Additionally, it is recommended to avoid crop rotation with species that are susceptible to downy mildew, particularly sunflowers and other members of the Asteraceae family, in order to minimize the presence of pathogens in the soil. It is essential to select the appropriate sowing time based on local climatic conditions to prevent the plants from entering a vulnerable stage during periods of high downy mildew incidence, which typically occurs in warm and humid seasons. According to the growth characteristics of sunflowers and the principles governing disease occurrence, it is essential to arrange planting density appropriately. This approach helps to prevent overcrowding, which can lead to excessive humidity in the field and subsequently increase the risk of disease development. It is essential to promptly eliminate disease residues and weeds to mitigate the sources of initial infestations and overwintering habitats for pathogens. Implementing appropriate irrigation practices, while avoiding excessive flooding and waterlogging, can effectively decrease field humidity and subsequently reduce the risk of disease development. Enhancing soil structure and drainage conditions, as well as improving soil permeability and root health, contributes to the ability of plants to resist diseases. The judicious application of nitrogen, phosphorus, and potassium fertilizers is essential to prevent the adverse effects of excessive nitrogen application, which can result in excessive plant growth and an increased susceptibility to diseases[8]. Continuous monitoring of field conditions, timely identification of central diseased plants, and the prompt implementation of measures to mitigate the spread of the disease are essential.

6.2 Chemical control measures In regions with a high incidence of disease, seeds may be treated with 25% metalaxyl at a concentration of 0.5% of the seed weight. Prior to the flowering stage of sunflowers, it is recommended to apply Bordeaux mixture or mancozeb every 7 – 10 d for a total of 2 – 3 applications[9]. Following the onset of sunflower disease, it is advisable to apply fungicides such as metalaxyl, propamocarb, hymexazol, and other appropriate agents. These treatments should be administered every 7 – 10 d for a total of 2 – 3 applications. Chemical spraying should be conducted on sunny days, while avoiding application during rainy conditions or excessively hot periods. Additionally, the chemical spraying must be executed uniformly and with careful consideration to ensure that all parts of the sunflower are adequately protected by the chemical. Furthermore, the application of chemical spraying must be conducted with safety precautions in order to mitigate potential hazards to both human health and the environment.

References

[1] International FAO Statistical Enterprise Database (FAOSTAT) [EB/OL]. https://www.fao.org/faostat/zh/#home. 2024-09-19.

(To page 18)

growth of tomato plants. Lastly, Sun Ke *et al.* [18] screened for biocontrol *Bacillus* species against burdock root-knot nematode through *in vitro* bioassays of fermentation broth and field trials.

In this study, the fermentation supernatants of six distinct bacterial strains were individually assessed to evaluate their *in vitro* biological activity against *M. incognita*. Additionally, the biological effectiveness of a single bacterial strain against *M. incognita* was initially elucidated. After screening, it was found that among the six bacterial strains, the treatment of the fermentation supernatant of strain X-2 had the most obvious lethal effect on *M. incognita* and increased with time, with the corrected mortality rate reaching 97% at 72 h. The treatment of *M. incognita* eggs also produced the effect of preventing the nematode from hatching. The strain had been identified as *B. velezensis*, belonging to the genus *Bacillus*, and was designated as RKN1111. It has been deposited in the Centre for General Microbiology under the China Microbial Strain Preservation and Management Committee. In this experiment, the inhibitory effect of the fermentation broth derived from this strain on the activity of second instar larvae and the egg hatching of *M. incognita* was preliminarily assessed. However, the specific mode of action remains unclear. Further investigation into the mechanism of action will be conducted in subsequent studies to provide alternative strains and theoretical references for the research and development of biocontrol agents targeting *M. incognita*.

References

[1] MCCARTER JP. Nematology: Terra incognita no more[J]. Nature Biotechnology, 2008, 26(8): 882 – 884.

[2] OKA Y, KOLTAI H, BAR-EYAL M, *et al.* New strategies for the control of plant-parasitic nematodes[J]. Pest Management Science, 2000, 56 (11): 983 – 988.

[3] ZHAO JJ, WANG S, FAN HY, *et al.* Screening and identification of endophytic bacteria isolated from root nodules for control of *Meloidogyne incognita*[J]. Chinese Journal of Biological Control, 2020, 36(5): 811 – 820. (in Chinese).

[4] TAPIA-VÁZQUEZ, IRÁN. Root-knot nematodes (*Meloidogyne* spp.) a threat to agriculture in Mexico: Biology, current control strategies, and perspectives[J]. World Journal of Microbiology and Biotechnology, 2022, 38(2): 1 – 18.

[5] FAN H, YAO M, WANG H, *et al.* Isolation and effect of *Trichoderma citrinoviride* Snef 1910 for the biological control of root-knot nematode, *Meloidogyne incognita*[J]. BMC Microbiol, 2020, 20(1): 299.

[6] ZHANG SW, GAN YT, LIU J, *et al.* Optimization of the fermentation media and parameters for the bio-control potential of *Trichoderma longibrachiatum* T6 against nematodes[J]. Front Microbiol, 2020, 11(1): 574 – 601.

[7] D'ERRICO G, MORMILE P, MALINCONICO M, *et al.* *Trichoderma* ssp. and a carob (*Ceratonia siliqua*) galactomannan to control the root-knot nematode *Meloidogyne incognita* on tomato plants[J]. Canadian Journal of Plant Pathology, 2020(3): 1 – 8.

[8] SHARMA N, KHANNA K, MANHAS RK, *et al.* Insights into the role of *Streptomyces hydrogenans* as the plant growth promoter, photosynthetic pigment enhancer and biocontrol agent against *Meloidogyne incognita* in *Solanum lycopersicum* seedlings [J]. Plants Basel, 2020, 9(9): 1 – 18.

[9] ZHAO D, ZHAO H, ZHAO D, *et al.* Isolation and identification of bacteria from rhizosphere soil and their effect on plant growth promotion and root-knot nematode disease[J]. Biological Control, 2018(119): 12 – 19.

[10] HUANG Y, MA L, FANG DH, *et al.* Isolation and characterisation of rhizosphere bacteria active against *Meloidogyne incognita*, *Phytophthora nicotianae* and the root knot-black shank complex in tobacco[J]. Pest Management Science, 2015, 71(3): 415 – 422.

[11] XIAO TJ, CHEN F, ZHU Z, *et al.* Effect of different rhizobacteria on suppression root-knot nematode (*Meloidogyne incognita*) of tomato[J]. Journal of Nanjing Agricultural University, 2011, 34(4): 59 – 64. (in Chinese).

[12] VILJOEN JJF, LABUSCHAGNE N, FOURIE H, *et al.* Biological control of the root-knot nematode *Meloidogyne incognita* on tomatoes and carrots by plant growth-promoting rhizobacteria[J]. Tropical Plant Pathology, 2019, 44(3): 284 – 291.

[13] SUN YF, BAI C, LONG HB. Nematicidal activity of supernatant from *Bacillus lhuringiensis* fermentation[J]. Fujian Journal of Agricultural Sciences, 2017, 32(4): 410 – 414.

[14] DING L, XU YM, WANG JM. Toxic effect and identification of biocontrol potential bacterium PFMP-5 on root knot nematodes[J]. Journal of Shanxi Agricultural University (Natural Science Edition), 2017, 37 (5): 330 – 334.

[15] ZHAO H, FAN HY, ZHAO D, *et al.* Controlling efficiency of *Bacillus* Sneb709 against root-knot nematode and its growth-promoting effect on tomato[J]. China Plant Protection, 2018, 38(7): 13 – 19.

[16] YAO ML, FAN HY, ZHOU YY, *et al.* Biocontrol efficacy of metabolites by *Penicillium chrysogenumsnef* 2367 against *Meloidogyne incognita*[J]. Journal of Shenyang Agricultural University, 2018, 49(2): 143 – 149.

[17] ZHU JY, WANG JY, GAO CH, *et al.* Effects of *Bacillus* spp. AMCC100153 on growth of greenhouse tomato and controlling efficiency of root-knot nematodes[J]. Journal of Changjiang Vegetables, 2018, 18: 67 – 70.

[18] SUN K, WANG M, FENG XY. Screening of bacillus for biocontrol of *Arctium lappa* root-knot nematode and its biocontrol mechanism[J]. Jiangsu Agricultural Sciences, 2022, 50(19): 117 – 123. (in Chinese).

(From page 10)

[2] RITA B, JÓZSEF K, ZOLTÁN P, *et al.* Placing management of sunflower downy mildew (*Plasmopara halstedii* (Farl.) Berl. et de Toni) under an integrated pest management (IPM) system approach: Challenges and new perspectives[J]. Agronomy, 2023, 13(4): 1029.

[3] ZHANG LQ, YANG SF, WANG LX, *et al.* Research on the pathogen of sunflower downy mildew and seed testing[J]. Gansu Agricultural Science and Technology, 1993(9): 27 – 28. (in Chinese).

[4] NURLANBEK AHAI. Occurrence and control measures of downy mildew in pollution-free sunflower in Altay region[J]. Rural Science & Technology, 2014(12): 44. (in Chinese).

[5] BAI YL. Sunflower integrated pest control technology[J]. Nong Min Zhi Fu Zhi You, 2014(1): 76. (in Chinese).

[6] LIU YT, DUAN W, LIU SL, *et al.* Cultivation technology of sunflower in wide and narrow rows in cold and cool areas of Northern Xinjiang[J]. Seed Science & Technology, 2018, 36(1): 36 – 37. (in Chinese).

[7] WU F. Occurrence and control of downy mildew in sunflower[J]. Agricultural Science-Technology and Information, 2005(2): 16 – 16. (in Chinese).

[8] LIU YT, SHAN WD, DENG TH, *et al.* Law of fertilizer requirement and fertilization technology of edible sunflower in Xinjiang[J]. Heilongjiang Agricultural Sciences, 2022(11): 113 – 116. (in Chinese).

[9] YANG JF. Occurrence and control of downy mildew in sunflower[J]. Xinjiang Agricultural Science and Technology, 2001(6): 20. (in Chinese).