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Seed borne disease transmission in Cannabis

Growing cannabis outdoors presents unique challenges. Numerous variables, including weather, water and soil quality, insect presence, and invasive weeds, can significantly impact crop success. Given this unpredictability, it is essential for cultivators to maximize control over the factors within their influence.

One critical factor that outdoor growers *can* control is starting with healthy cannabis seeds. Many harmful pathogens that threaten crop health are seed-borne, posing a serious risk to yield and could potentially spread across an entire field, leading to devastating economic losses.

To ensure a high-yielding, disease-free harvest, it is important for growers to prioritize pathogen testing before sprouting seeds. Preventatively testing for pathogens in seed lots is the most effective way to safeguard plant health, minimize risk, and optimize yield from the start.

What Pathogens to Test?

Numerous pathogens can be transmitted via cannabis seed, including viruses, viroids, fungal pathogens, oomycetes, and bacteria. Knowing which pathogens to test for, and why, is essential for ensuring a successful crop while avoiding unnecessary costs on tests for pathogens that are not seed-borne or unlikely to cause significant damage.

So, which pathogens could be harbored in cannabis seed.

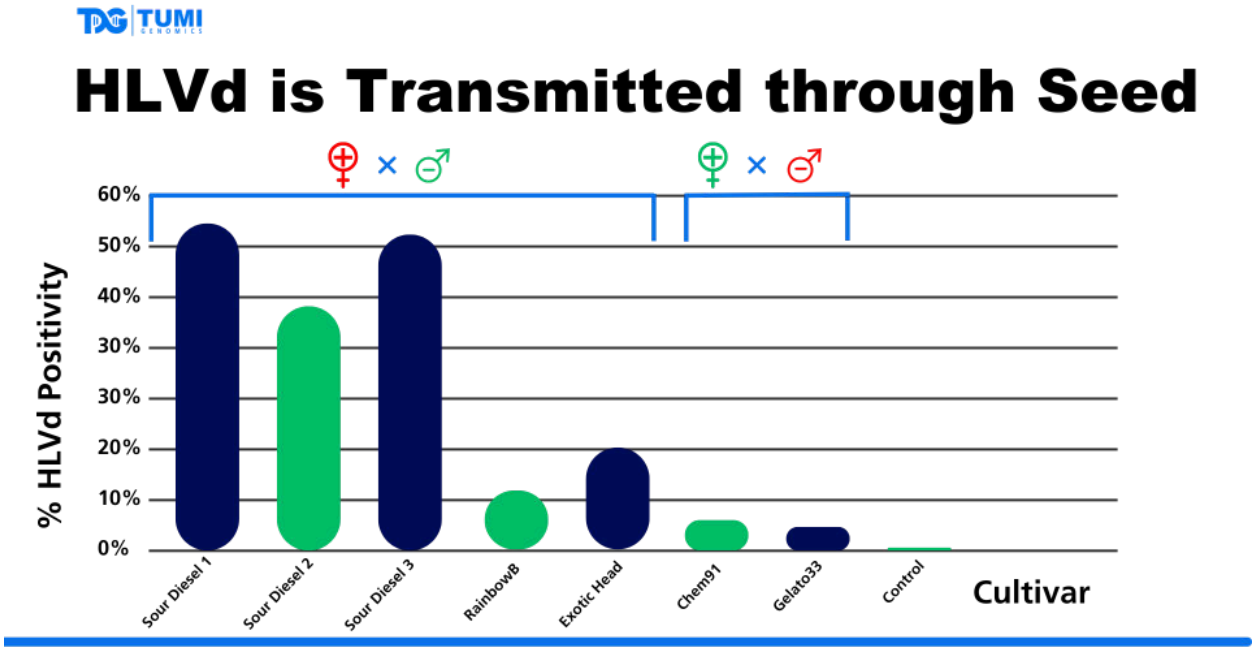
Seed-borne Viroids in Cannabis

Among the most insidious seed-borne pathogens are viroids. The symptoms of viroid infections often begin subtly, initially mimicking abiotic stress, making early detection difficult. As a result, infections are frequently identified only after significant spread has occurred**.** Among these, Hop Latent Viroid (HLVd) currently poses the greatest threat to cannabis cultivation.

Like all viroids, HLVd is a tiny molecular parasite that spreads mechanically, through water runoff, and likely via insect vectors[1,2,3]. Infected plants exhibit stunted growth, poor root development, decreased biomass, and severely reduced cannabinoid content**.** While research on HLVd seed transmission is still emerging, multiple studies[4,5] have reported transmission rates ranging from 50% to 90%**.**

Cannabis flower from infected plants also accumulate a substantial viroid load, suggesting seed surface contamination by HLVd may also be an important source of infection spread. Studies conducted at TUMI Genomics further support these findings, showing that seed-to-seedling transmission ranges from 20% to 50% when originating from a HLVd positive mother plant, depending on factors such as strain, infection level of the mother plant, and seed age.

In addition, at TUMI Genomics seed transmission of HLVd from infected males has been observed but at a much lower rate (~5%). However, rates of HLVd infection in seedlings due to positive male plants has been shown to be as high as 80% by others[5].



HLVd is widespread in both indoor and outdoor cannabis cultivation, with research showing that over 50% of symptomatic plants test positive for the viroid[1,2,6]. TUMI Genomics studies further indicate that around 75% of cultivation facilities around the world have either an active or past HLVd infection, highlighting its prevalence across the industry.

Given seed transmission of HLVd is highly efficient, it is extremely likely that a given seed batch could contain seeds from infected plants. The ease with which HLVd spreads and the significant impact it has on plant health and yields makes testing seed batches for this pathogen critical to ensuring a successful, disease-free crop.

Seed-borne Viruses in Cannabis

Beyond viroids like Hop Latent Viroid (HLVd), viral pathogens can be a significant concern, especially for outdoor cannabis growers. Among them, Beet Curly Top Virus (BCTV) is one of the most prevalent and damaging. BCTV causes severe upward leaf curling, leaf yellowing and growth defects. The virus is transmitted by the beet leafhopper (*Circulifer tenellus*), an insect endemic to the western United States and several other states. During times of high leafhopper prevalence, the percentage of BCTV infected plants can approach 90% in symptomatic plants[7]. While multiple sources suggest that BCTV is not seed-borne, no comprehensive study has been conducted to confirm or refute this mode of transmission in cannabis. However, research on petunias demonstrated BCTV seed transmission rates between 38% and 78%[8], suggesting that seed transmission remains a possibility.

Listed below are several other viral pathogens that infect cannabis and have evidence for seed transmission:

- Tobacco streak virus (TSV): This virus was found to infect cannabis in studies conducted in both Colorado and New York[9,10] and has shown seed transmission rates between ~7% to 48% in other crops[11].
- Alfalfa mosaic virus (AMV): AMV has been identified in cannabis[12] and shows a seed-borne transmission rate up to 90% in other types of plants[13].

Other viruses that do not currently pose an immediate threat to outdoor cannabis cultivation due to seed-borne transmission include:

- Lettuce chlorosis virus (LCV): Not seed-borne, and no published reports of incidence in the United States[14].
- Cannabis cryptic virus (CanCV): Asymptomatic, with no confirmed impact on plant health[15].
- Tobacco mosaic virus (TMV): No reported natural infections in cannabis, and forced laboratory inoculation studies show no induced symptoms[16] .
- Citrus yellow vein-associated virus (CYVaV): Reported to infect cannabis is several studies[10,17], but no evidence of seed transmission[18].

Testing for BCTV in cannabis seeds followed by TSV and AMV are important steps to ensure a healthy crop. However, LCV, CanCV, TMV and CYVaV are unlikely to cause major economic issues due to seed-borne transmission and are therefore not priorities for screening prior to planting.

Seed-borne Fungal Pathogens in Cannabis

Seed-borne fungal pathogens pose a significant risk to cannabis growers, as they can be present both internally and externally on seeds. Internally infected seeds may carry fungal pathogens that cause disease from within, while externally contaminated seeds can transfer pathogens to seedlings during germination. Once infected plants exist in a field, fungal pathogens can spread quickly through water-run off, insects and sporulation in the air, making these pathogens a major risk to entire crops.

Additionally, many fungal pathogens produce mycotoxins or cause dangerous infections in immunocompromised individuals which can be harmful to human health[19]. Because of this, ensuring high-quality, disease-free cannabis/hemp seed is not only essential for a successful harvest but also for consumer safety.

Critical Seed-Borne Fungal Pathogens

The following fungal pathogens can infect the interior of seeds, leading to damping off, root rot, wilting, and rapid plant death in seedlings[20]. These pathogens may also persist on the seed coat, increasing the risk of disease transmission[21-27].

- *Fusarium spp.*
- *Rhizoctonia solani*
- *Sclerotinia sclerotiorum*
- *Alternaria spp*.
- *Stemphylium vesicarium*
- *Rhizopus Spp*

Seeds infected with these pathogens often exhibit low germination rates and may introduce persistent fungal contaminants into the growing environment. Spores from many of these fungi can survive in soil for years, making it critical to prevent their introduction through rigorous seed screening.

Externally Contaminated Seeds & Secondary Transmission

Other fungal pathogens, while less likely to be present internally, can contaminate the exterior of seeds and transfer to seedlings during germination. A recent study on hemp seed found that up to 75% of seeds were surface contaminated with fungal pathogens[23], including:

- *Penicillium spp.*
- *Cladosporium spp.*
- *Pythium spp.*
- *Chaetomium spp.*
- *Aspergillus spp.*

These fungi can proliferate in seedlings and soil, increasing the risk of crop loss and long-term contamination. Seed sterilization prior to planting is critical to prevent fungal outbreaks and ensure healthy germination.

Seed-Borne Bacterial Pathogens in Cannabis

Bacterial diseases in cannabis are less common than fungal or viral pathogens but can still cause significant crop damage. While many bacterial diseases have been reported in outdoor cannabis and hemp, their prevalence is not well understood. Among bacterial pathogens, seed-borne bacteria transmitted by beet leafhoppers are a significant concern due to the widespread presence of these insects in the western United States. These pathogens include both phytoplasmas and *Spiroplasma citri*.

Spiroplasma citri appears to be significantly less common than phytoplasma pathogens. Recent studies indicate that while phytoplasmas are detected in approximately 21% of symptomatic cannabis plants, *Spiroplasma citri* is identified in only about 3% of cases[28,29] . However, if beet leafhoppers are highly prevalent in the region where the seed was sourced, the risk of *Spiroplasma citri* infection should still be considered.

Phytoplasmas are cell wall-lacking bacteria that inhabit the plant phloem and are primarily transmitted by insect vectors such as the beet leafhopper. However, they can also be spread through vegetative propagation and seed[30]. Phytoplasma infections can cause stunting, small and malformed leaves and highly branched stems (aka “witches broom”). Multiple phytoplasma species that have been identified in cannabis/hemp[28,31,32] including:

- *Candidatus Phytoplasma asteris*
- *Candidatus Phytoplasma trifolii*

While phytoplasmas can be transmitted via seed, infected mother plants often produce low-quality, malformed, or reduced seed yields, making it less likely infected mothers will contribute to seed lots. However, increased risk of seed transmission can arise when seeds are sourced from outdoor-grown plants in regions where the primary vector of phytoplasmas, beet leafhoppers, is endemic namely; Arizona, California, Colorado, Idaho, Oregon, Utah and Washington. If sourcing seed from outdoor cultivators in these areas, phytoplasma screening of seed lots is advisable.

The Bottom Line

Screening for seed-borne pathogens is critical to safeguarding crops. The most prevalent and damaging seed-borne pathogens in cannabis include:

- *Hop Latent Viroid (HLVd)*
- *Beet Curly Top Virus (BCTV)*
- *Alfalfa Mosaic Virus (AMV)*
- *Tobacco Streak Virus (TSV)*
- *Fusarium spp.*
- *Rhizoctonia solani*
- *Alternaria spp.*
- *Stemphylium vesicarium*
- *Candidatus Phytoplasma asteris*
- *Candidatus Phytoplasma trifolii*
- *Sclerotinia sclerotiorum*

For cultivators facing budget constraints, prioritizing pathogen screening is essential to maximizing crop protection with limited resources. **Among the seed-borne pathogens listed, HLVd, BCTV, *Fusarium*, *Alternaria*, *Rhizoctonia solani* and *Sclerotinia sclerotiorum* pose the greatest threat, as they are common, have the potential to cause widespread infection quickly, and can lead to catastrophic crop loss.** HLVd silently spreads through propagation material, leading to stunted, low-yielding plants, while BCTV can quickly devastate entire fields through insect transmission during times when beet leafhoppers are common. *Fusarium*, *Alternaria*, *Sclerotinia sclerotiorum,* and *Rhizoctonia solani* are aggressive fungal pathogens causing poor germination, seedling collapse and plant death and can persist in soil for years, making them particularly difficult to eradicate once introduced. Given the potential economic impact of these diseases, allocating resources to test for these high-risk pathogens is a strategic investment in the long-term success of a cultivation operation.

Why Test Seeds?

Outdoor cannabis growers make a significant investment at the start of each season when sourcing genetics and seeds. The quality and profitability of the final harvest largely depend on selecting high-quality, disease-free genetics that grow into vigorous, high-yielding plants. Planting seeds contaminated with pathogens can jeopardize the entire season, reducing plant health, yields, and overall profitability. Consequences of planting diseased seeds include:

Reduced Germination Rates

Seed-borne pathogens can significantly reduce germination rates, leading to wasted seeds, increased replanting costs, and uneven field establishment. Fungal pathogens such as *Fusarium, Alternaria,Rhizoctonia solani* and others can prevent germination altogether or cause damping-off, a condition where seedlings germinate and then quickly collapse due to root or stem rot. Poor germination not only reduces plant counts but also disrupts production schedules and increases labor and material costs.

Weakened Plant Vigor and Reduced Yield

Even if infected seeds manage to germinate, they often produce weak, stunted plants with poor root systems. Early pathogen exposure can weaken plants making them more susceptible to secondary infections common in the environment, such as *Pythium*, *Botrytis* and others. Hop latent viroid, which is not reported to impact germination rates, is seed transmitted and can exist in plants asymptomatically throughout vegetative growth, only to cause dramatic yield loss and reduced cannabinoids in flower.

Rapid Spread of Pathogens Across the Field

Pathogens introduced through infected seeds can quickly spread to an entire field. Pathogens can move from plant to plant through water run-off, soil, air, insects, and on tools and equipment; making containment difficult once an outbreak begins. Even if only a minority of seeds carry an infection, the resulting spread can lead to widespread crop damage, significantly reducing the overall success of the harvest.

Long-Term Soil Contamination

Certain pathogens, such as *Fusarium* and *Rhizoctonia*, can persist in soil for years, making them difficult to eliminate once introduced. Contaminated soil can act as a long-term reservoir for disease, affecting future cannabis crops and limiting planting options. Some seed-borne diseases are highly pathogenic across multiple crop types or can transfer into asymptomatic host plants, such as native weeds, creating a persistent disease reservoir. To manage soil-borne pathogens, growers may consider strategies like crop rotation or leaving some fields empty. However, these approaches may not be practical for all cultivators and could negatively impact farm profitability.

Investing in Seed Testing for Long-Term Success

Given these risks, testing seeds before planting is a crucial step in protecting both current and future harvests. A small upfront investment in disease testing can prevent substantial financial losses and ensure a successful, high-yielding crop at the end of the season. Confirming that seed batches are free from harmful pathogens reduces the risk of crop failure, prevents the introduction of persistent soil-borne diseases, and ensures strong, uniform plant growth. By screening seeds for pathogens prior to planting, cultivators can safe-guard their investment, enhance plant vigor, and ensure sustainability for future crops.

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How to Test Cannabis Seed for Pathogens

Best Practices for Testing Cannabis Seeds for Pathogens

Testing cannabis seeds for harmful pathogens before planting is a critical step in ensuring a successful and profitable harvest. Undetected seed-borne diseases can lead to poor germination, stunted growth, and long-term soil contamination, making proactive testing an essential part of any grower's strategy. To maximize the effectiveness of seed testing, cultivators should follow these best practices.

Verify the Health of Mother Plants

The first step in seed testing is gathering information from the seed supplier. Growers should inquire whether the mother plants that produced the seeds were tested for pathogens, which specific pathogens were tested for, when the testing was conducted, and which laboratory performed the analysis. Requesting actual test results ensures transparency and helps growers assess the potential risks associated with a given seed batch. A reputable seed producer should be able to provide this data and demonstrate a commitment to pathogen-free production.

Source Seeds from a Limited Number of Mother Plants

Whenever possible, growers should source seeds that originate from a minimal number of mother plants. This practice reduces the overall risk of pathogen transmission and increases the likelihood that a pathogen, if present, will be detected through PCR testing. Seed producers who divide their seed lots according to specific mother plants can further minimize losses if a pathogen is detected in a particular batch. By maintaining traceability, seed producers and growers alike can isolate infected lots, preventing further spread while preserving healthy seed stocks.

Understand the Statistical Approach to Seed Testing

Seed testing is not about testing every single seed in a batch; rather, it is about testing a statistically significant subset to provide confidence that a given pathogen is absent. Most testing is conducted to ensure, with 95% confidence, that if a pathogen is not found in the tested subset, it is unlikely to be present in the entire population. Determining the number of seeds that need to be tested requires statistical calculations. To simplify this process, we have created a seed testing calculator and detailed instructions that growers can use to determine the appropriate sample size based on their desired confidence level and pathogen occurrence rates.

By implementing smart seed testing strategies, cultivators can significantly reduce the risk of introducing seed-borne pathogens into their operations. Verifying mother plant health, sourcing from a limited number of mother plants, and utilizing statistical sampling methods ensure that growers can make informed planting decisions. This proactive approach provides peace of mind and increases the likelihood of a healthy, high-yielding crop, ultimately supporting a more profitable and sustainable cultivation process.

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Surface Sterilization of Seed

Chlorine (Bleach) Seed Treatment

Bleach treatment removes viroids, viruses, fungi, and bacteria from the surface of seeds but does not eliminate pathogens inside the seed. In TUMI Genomics studies, bleach sterilization did not significantly impact germination percentage. However, it should not be used on seeds that have been fungicide-treated or hot water-treated. Bleach treatment is typically performed immediately before planting. While there is no specific data available for cannabis, seeds from other crops have shown reduced germination when stored after bleach treatment. Cultivators who have not previously surface-sterilized seeds should first practice on a small batch to ensure they can successfully complete the process before treating large quantities.

Preparation and Application

1. Prepare the bleach solution by mixing one part household bleach (5–7.5% active ingredient: sodium hypochlorite) with nice parts water. Add two drops of dish detergent per quart of solution. Use a fresh solution for each batch.
2. Submerge seeds in the bleach solution, stirring occasionally, for 60 seconds. Small seeds can be placed in paper towels, coffee filters, or a tea strainer for easier handling if necessary.
3. Rinse seeds with clear water (tap water is fine) for 5 minutes. A handheld mesh strainer works well for this purpose. Once clean, lay seeds out in a single layer to dry.

References

1. Adkar-Purushothama, Charith Raj, Teruo Sano, and Jean-Pierre Perreault. "Hop latent viroid: A hidden threat to the cannabis industry." *Viruses* 15.3 (2023): 681.
2. Punja, Zamir K., et al. "Symptomology, prevalence, and impact of Hop latent viroid on greenhouse-grown cannabis (Cannabis sativa L.) plants in Canada." *Canadian Journal of Plant Pathology* 46.2 (2024): 174-197.
3. Mehle N, Gutiérrez-Aguirre I, Prezelj N, Delic D, Vidic U, Ravnikar M. Survival and transmission of potato virus Y, pepino mosaic virus, and potato spindle tuber viroid in water. Appl Environ Microbiol. 2014 Feb;80(4):1455-62. doi: 10.1128/AEM.03349-13. Epub 2013 Dec 13. PMID: 24334672; PMCID: PMC3911042.
4. Punja ZK, Kahl D, Reade R, Xiang Y, Munz J, Nachappa P. Challenges to *Cannabis sativa*Production from Pathogens and Microbes-The Role of Molecular Diagnostics and Bioinformatics. Int J Mol Sci. 2023 Dec 19;25(1):14. doi: 10.3390/ijms25010014. PMID: 38203190; PMCID: PMC10779078
5. Atallah OO, Yassin SM, Verchot J. New Insights into Hop Latent Viroid Detection, Infectivity, Host Range, and Transmission. Viruses. 2023 Dec 23;16(1):30. doi: 10.3390/v16010030. PMID: 38257731; PMCID: PMC10819085.
6. Rivedal HM, Funke CN, Frost KE. An Overview of Pathogens Associated with Biotic Stresses in Hemp Crops in Oregon, 2019 to 2020. Plant Dis. 2022 May;106(5):1334-1340. doi: 10.1094/PDIS-11-21-2415-SR. Epub 2022 Apr 4. PMID: 34894753.
7. Melgarejo TA, Chen LF, Rojas MR, Schilder A, Gilbertson RL. Curly Top Disease of Hemp (*Cannabis sativa*) in California Is Caused by Mild-Type Strains of *Beet curly top virus* Often in Mixed Infection. Plant Dis. 2022 Dec;106(12):3022-3026. doi: 10.1094/PDIS-04-22-0856-SC. Epub 2022 Nov 17. PMID: 35549320.
8. Anabestani, A.; Behjatnia, S.A.A.; Izadpanah, K.; Tabein, S.; Accotto, G.P. Seed Transmission of Beet Curly Top Virus and Beet Curly Top Iran Virus in a Local Cultivar of Petunia in Iran. *Viruses* **2017**, *9*, 299. https://doi.org/10.3390/v9100299
9. Ellison S. First Report of Tobacco Streak Virus in *Cannabis sativa* in New York. Plant Dis. 2023 Dec 19. doi: 10.1094/PDIS-09-23-1810-PDN. Epub ahead of print. PMID: 38115564.
10. Chiginsky, Judith & Langemeier, Kaitlyn & MacWilliams, Jacob & Albrecht, Tessa & Cranshaw, Whitney & Fulladolsa, Ana & Kapuscinski, Marylee & Stenglein, Mark & Nachappa, Punya. (2021). First Insights Into the Virus and Viroid Communities in Hemp (Cannabis sativa). Frontiers in Agronomy. 3. 10.3389/fagro.2021.778433.
11. Sharman M, Persley DM, Thomas JE. Distribution in Australia and Seed Transmission of Tobacco streak virus in Parthenium hysterophorus. Plant Dis. 2009 Jul;93(7):708-712. doi: 10.1094/PDIS-93-7-0708. PMID: 30764380.
12. Kegler H., Spaar D. On the Virus Susceptibility of Varieties of Cannabis sativa L. Arch. Phytopathol. Plant Prot. 1997;30:457–464. doi: 10.1080/03235409709383198
13. Li J, Shang Q, Luo Y, Wei S, Zhao C, Ban L. Transmission from seed to seedling and elimination of alfalfa viruses. Front Plant Sci. 2024 Jun 6;15:1330219. doi: 10.3389/fpls.2024.1330219. PMID: 38903432; PMCID: PMC11187482.
14. Hadad L, Luria N, Smith E, Sela N, Lachman O, Dombrovsky A. Lettuce Chlorosis Virus Disease: A New Threat to Cannabis Production. Viruses. 2019 Aug 29;11(9):802. doi: 10.3390/v11090802. PMID: 31470681; PMCID: PMC6784094
15. Righetti, L., Paris, R., Ratti, C., Calassanzio, M., Onofri, C., Calzolari, D., Menzel, W., Knierim, D., Magagnini, G., Pacifico, D., & Grassi, G. (2018). Not the one, but the only one: about Cannabis cryptic virus in plants showing 'hemp streak' disease symptoms. *European Journal of Plant Pathology, 150*(3), 575–588
16. McPartland, J. M., Clarke, R. C., & Watson, D. P. (2000). *Hemp diseases and pests: Management and biological control*. CABI Publishing.
17. Jarugula, S., Wagstaff, C., Mitra, A., Crowder, D. W., Gang, D. R., and Naidu, R. A. 2023. First reports of Beet curly top virus, Citrus yellow vein-associated virus, and Hop latent viroid in industrial hemp (*Cannabis sativa*) in Washington State. Plant Dis. 107:2897. https://doi.org/10.1094/PDIS-12-22-2981-PD LinkGoogle Scholar
18. Y. Zhou, H.M. Chen, X.F. Wang, Z.A. Li, M. Tang, C.Y.Zhou. Lack of evidence for seed transmission of *Citrus yellow vein clearing virus* despite its frequent detection in seed tissues. J Plant Pathol, 97 (2015), pp. 519-521

19. Sanche, S. E., Sutton, D. A., & Rinaldi, M. G. (2003). Dematiaceous fungi. In E. J. Anaissie, M. R. McGinnis, & M. A. Pfaller (Eds.), *Clinical mycology* (pp. 367–394). Churchill Livingstone.
20. Punja ZK, Collyer D, Scott C, Lung S, Holmes J, Sutton D. Pathogens and Molds Affecting Production and Quality of *Cannabis sativa* L. Front Plant Sci. 2019 Oct 17;10:1120. doi: 10.3389/fpls.2019.01120. PMID: 31681341; PMCID: PMC6811654.
21. Gwinn, K. D., Hansen, Z., Kelly, H., & Ownley, B. H. (2022). Diseases of *Cannabis sativa* caused by diverse *Fusarium* species. *Frontiers in Agronomy, 3*, Article 796062.
22. Sorrentino, R., Lahoz, E., Battaglia, V., Sorrentino, M. C., & Cerrato, D. (2023). First report of seedling damping-off of industrial hemp (*Cannabis sativa*) caused by seed-transmitted *Alternaria rosae* in Italy. *Plant Disease, 107*(1), 1636.
23. Dumigan, C. R., & Deyholos, M. K. (2022). Cannabis seedlings inherit seed-borne bioactive and anti-fungal endophytic bacilli. *Plants, 11*(16), 2127
24. Summerell, B. A., Salleh, B., & Leslie, J. F. (2003). A utilitarian approach to *Fusarium* identification. *Plant Disease, 87*(2), 117–128
25. Tiourebaev, K. S., Paulitz, T. C., & Mukhambetzhanov, S. K. (1997). First report of *Fusarium oxysporum* on Cannabis sativa in Kazakhstan. *Plant Disease, 81*(10), 1212.
26. Roberts, R. G., & Punja, Z. K. (2021). The Fusarium solani species complex infecting cannabis (*Cannabis sativa* L., marijuana) plants and a first report of *Fusarium (Cylindrocarpon) lichenicola* causing root and crown rot. *Canadian Journal of Plant Pathology, 43*(4), 567–581
27. Crosier, W. F. “RHIZOCTONIA SOLANI IN SEEDS OF SMALL GRAINS AND OTHER PLANTS.” *Proceedings of the Association of Official Seed Analysts*, vol. 58, 1968, pp. 111–17. *JSTOR*, http://www.jstor.org/stable/23432233
28. Schoener, Laura, and Shouhua Wang. "Hemp abnormal growth is attributed to mono-, di-, or tri-infections of *Spiroplasma citri*, 'Candidatus Phytoplasma trifolii', and beet curly top virus." *PhytoFrontiers* (2023)
29. Rivedal HM, Temple TN, Thomas W, Ocamb C, Funke C, Skillman V, Jones G, Shrestha G, Kc A, Dung JKS, Frost K. First report of *Spiroplasma citri* associated with disease symptoms in field-grown hemp (*Cannabis sativa* L.) in the Pacific Northwest. Plant Dis. 2023 Sep 8. doi: 10.1094/PDIS-07-23-1419-PDN. Epub ahead of print. PMID: 37682222
30. Satta, E., Calari, A., and A. Bertaccini. "Phytoplasma Transmission through Seeds: A Critical Review." *Phytopathogenic Mollicutes* 9.1 (2019): 87–96.
31. Raj, S.K., Snehi, S.K., Khan, M.S., and Kumar, S. '*Candidatus* Phytoplasma asteris' (group 16SrI) associated with a witches'-broom disease of *Cannabis sativa* in India. 2008. Plant Pathology 57(6):1173.
32. Hu J. First Report of 'Candidatus Phytoplasma trifolii' Related Strain Associated with Yellowing and Witches'-Broom of Industrial Hemp (Cannabis sativa) in Arizona. Plant Dis. 2021 May 25. doi: 10.1094/PDIS-04-21-0847-PDN. Epub ahead of print. PMID: 34032489.
33. Rivedal HM, Temple TN, Thomas W, Ocamb C, Funke C, Skillman V, Jones G, Shrestha G, Kc A, Dung JKS, Frost K. First report of *Spiroplasma citri* associated with disease symptoms in field-grown hemp (*Cannabis sativa* L.) in the Pacific Northwest. Plant Dis. 2023 Sep 8. doi: 10.1094/PDIS-07-23-1419-PDN. Epub ahead of print. PMID: 37682222