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PEACH LEAF CURL OF PEACH "TAPHRINA DEFORMANS" DISEASE AND CONTROL MEASURES (REVIEW)

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ABSTRACT----------

Peach (Prunus persica) is one of the fruit trees of world economic importance. One of the main diseases that reduce its yield and fruit quality is peach leaf curl disease, the causative agent of which is the fungus Taphrina deformans. The disease mainly manifests in leaves, leading to their wrinkling, bending, and color change; in severe cases, leaves fall prematurely, and the tree's photosynthetic capacity sharply decreases. This leads to a decrease in yield, a decrease in the quality and storability of fruits.

The fungus overwinters on tree branches and buds, and its infection becomes more active in spring under moist and cool weather conditions. Precipitation, fog, and high air humidity are decisive factors in the development of the infection. The disease can be observed in almost all peach varieties, but the degree of susceptibility varies among cultivars.

The system of control measures is based on integrating agrotechnical, chemical, and biological methods. In agricultural techniques, it is important to plant resistant varieties, perform sanitary cleaning, and prune branches in a timely manner. For chemical control, copper-based preparations and dithiocarbamates (for example, Bordeaux mixture, copper oxychloride, ferbam, ziram) are primarily used prophylactically, before leaf emergence.

Thus, although peach leaf curl disease poses a significant threat to yield, its development can be effectively controlled through comprehensive measures, taking into account the biology and epidemiology of the fungus.

KEYWORDS: *Peach, Prunus Persica, Disease, Leaf Curl, Fungus, Taphrina Deformans----------*

INTRODUCTION

Peach (Prunus persica) is one of the most important fruit crops in the world. The economic value of its sweet and fresh fruits is high, and it is reported that the annual harvest of peaches and nectarines in the world is close to 25 million tons (USDA FAS, 2024). Peaches also occupy a special place in the agricultural sector in Uzbekistan - for example, in the first seven months of 2025, the country exported 87.9 thousand tons of peaches and earned more than $80 million (FreshPlaza, 2025). However, high peach yields and fruit quality are seriously threatened by various diseases. One of them is leaf curl, a fungal disease known as "Taphrina deformans," known in international literature as Peach Leaf Curl. Its relevance lies in the fact that the disease occurs in many orchards year after year, which can significantly reduce yields and negatively affect the condition of trees (McManus and Hudelson, 2024). Timely detection of this disease, caused by the fungus Taphrina deformans, and taking measures to combat it is very important for successful peach farming.

ETIOLOGY OF DISEASE

The etiology of the disease depends on its causative agent - the fungus Taphrina deformans. This fungus belongs to the genus Taphrina of the Ascomycota division and is classified as an ascomycete (Fonseca and Rodrigues, 2011). The morphology of Taphrina deformans is unique: in its development cycle, the conidial stage is absent, and only asci - ascospores - are formed (Fonseca and Rodrigues, 2011). The fungal mycelium develops among infected plant tissues (in the intercellular space) and can also live vegetatively (Fig. 1). That is, the fungus Taphrina deformans can also multiply in dimorphic form. Often during autumn and winter, the fungus persists in the trunk, branches, and buds of the tree in the form of mycelium or spores (Betaren, 2023). During the wintering period, ascospores are resistant to severe extreme conditions: high summer temperatures and drought (Agrio, 2021).

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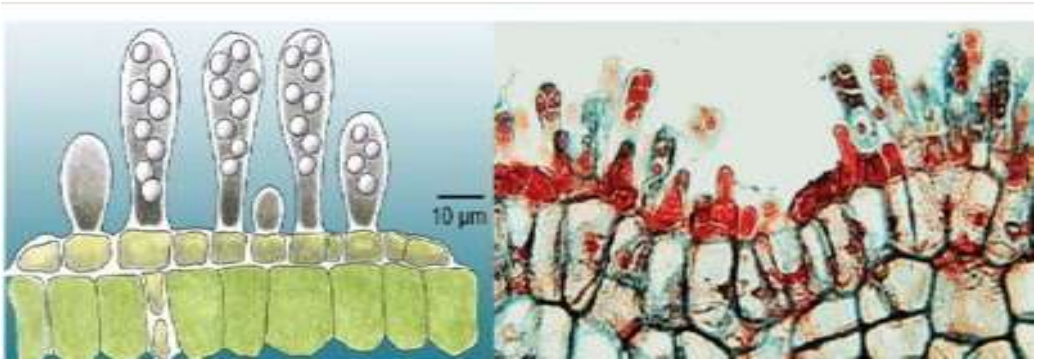

Figure 1. Asci formed by the fungus Taphrina deformans on the leaf surface[1]

The development cycle of the fungus Taphrina deformans becomes primarily active during the spring period. When trees emerge from winter dormancy, the humid and cool air activates the sporulation of the fungus (Rossi et al., 2006). In spring, as peach flower buds and leaf buds swell, fungal spores on the bark and branches begin to develop under the influence of environmental precipitation or irrigation water. As the buds develop, the spores penetrate the tissue of the newly swollen leaves and begin to grow beneath the epidermis (Agrio, 2021). Upon entering plant cells, the fungus stimulates their division and growth - resulting in excessive growth and hyperplastic tissues (Fonseca and Rodrigues, 2011). Consequently, the cells in leaf and shoot tissues become larger and more numerous than normal, leading to leaf curling.

The generative reproduction of the fungus occurs on infected leaves. By late spring, a thin whitish layer appears on the surface of the infected leaf - this is actually a collection of the fungus's sac-like spores (a a cluster of asci (sac-like structures)). Once these ascospores mature, they rupture the cuticle layer on the leaf surface and disperse into the air (Betaren, 2023). Ascospores can be scattered around the garden by wind or water droplets. These spores settle in cracks in the tree trunk, within the resinous substances of the bark layer (cambium sap), or on newly emerging buds. There, they grow into mycelium and overwinter in this state (Betaren, 2023). The following spring, the infection process repeats in the same manner. Thus, Taphrina deformans in its developmental cycle primarily overwinters as closed ascospores, transforms into intercellular mycelium in spring to carry out infection, and subsequently forms ascospores again, demonstrating a cyclical pattern (McManus and Hudelson, 2024).

SYMPTOMS AND SPREAD OF THE DISEASE

The first signs of the disease become noticeable in spring, as soon as young leaves begin to appear in a swollen state. Initially, small, dotted reddish or light jasmine-colored smooth patterns appear on the surface of newly emerging leaves. These dots quickly grow, causing the leaf tissue to elongate, become convex, and wrinkle (McManus and Hudelson, 2024). Affected leaves thicken abnormally, turning red, brown, or yellowish. The leaf blade can undergo complete deformation - it curls inward, taking on a folded and crumpled shape (Fig. 2). On the underside of the leaf tissue, these bulging areas appear slightly sunken in contrast (Betaren, 2023). Due to these characteristic symptoms of the disease, the leaves become quite unsightly and their photosynthetic capacity decreases. When fungal spores mature on the surface of infected leaves, a whitish-brown cotton-like mold appears - these are the ascospores of Taphrina deformans (McManus and Hudelson, 2024). After some time, the diseased leaves dry up and fall off as early as early summer.

[1] *https://www.researchgate.net/publication/326207059_Mycology/figures?lo=1*

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Figure 2. Leaf curl in peach trees[2]

Young peach shoots can also be affected by the disease. In such cases, the shoots and bark grow abnormally: they develop in an uneven, curved manner, sometimes lagging in growth, with shortened internodes (Betaren, 2023). The formation of rosette-shaped leaves at the shoot tip in a single node is a severe symptom of the disease. Affected bark usually has a pale green or yellowish color and may dry up during summer or die in winter due to cold susceptibility (Betaren, 2023). Disease in peach flowers and fruits is relatively rare; however, in severe infections, flowers may fall prematurely, and fruits may develop indistinct swellings. On infected fruits, bumps and sutures form, creating rough protrusions on the fruit surface, which hardens and becomes prone to cracking (UC IPM, 2023). Such fruits become small, flavorless, and prone to early dropping (Betaren, 2023). Additionally, trees severely infected over several years have been found to form significantly fewer flower buds for the following year - indicating that the disease also adversely affects the following year's yield potential (Betaren, 2023).

Leaf curl disease can affect almost all peach and nectarine varieties. Similarly, apricot, almond, and stone fruit trees (plums and sweet cherries) also have similar leaf blistering diseases caused by fungi of the genus Taphrina. However, peach is the most susceptible host plant, and the disease is named after this tree (Agrio, 2021). The spread of the disease is observed in many fruit-growing regions of the world. In particular, in the eastern and central regions of the USA, Europe, Russia, and Central Asia - peach-growing regions - "leaf curl" is noted as one of the most common problems (McManus and Hudelson, 2024; Betaren, 2023).

In peach orchards of Uzbekistan, this disease can also intensify in years when spring is particularly cold and humid. When two main factors - humidity and cool air - are present, and agrotechnical measures are inadequate, the spores of Taphrina deformans, which cause the disease, are more likely to spread widely and infect neighboring trees (McMahon, 2024). Therefore, to prevent the spread of the disease, it is recommended to take preventive measures at the orchard level and in cooperation with neighboring orchards (McMahon, 2024).

EPIDEMIOLOGY

Factors influencing the development of the disease. The epiphytotic outbreak of peach leaf curl disease primarily depends on weather conditions and horticultural practices. The most favorable conditions for fungal infection development are cool and humid spring weather. Studies have shown that Taphrina deformans spores grow rapidly in laboratory conditions at around ~20°C, with a minimum growth temperature of ~9°C and a maximum temperature threshold of 26-30°C (Rossi et al., 2006; UC IPM, 2023). Thus, days with high air humidity (rain or prolonged dew) and spring air temperatures of 10-20°C are very favorable for the fungus. Conversely, if the weather warms up quickly and becomes dry, the disease cycle can be interrupted - even if infection occurs at high temperatures or in a dry climate, clear symptoms may not develop on the leaves (Rossi et al., 2006).

Water droplets are crucial for fungal spores: if the leaf surface remains moist for 12 hours or more, fungal spores can easily penetrate the leaf, initiating infection (Rossi et al., 2006). The highest infection rate is observed when the tree remains continuously moist for 48 hours or more (UC IPM, 2023). Therefore, in years with prolonged

[2] *https://www.insectimages.org/browse/image/5569195*

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rainy or foggy days, the disease can intensify, leading to epiphytotics. Conversely, if the weather is hot and dry during the flowering of spring fruit trees, the disease will be insignificant.

A warm winter season also creates conditions for a greater outbreak of the disease in the following season. This is because the fungus has a higher survival rate during warm winters (McManus and Hudelson, 2024). For example, typically severe cold winter conditions can kill some Taphrina foci, but in mild winters, such natural "disinfection" does not occur, and the disease becomes more pronounced in spring. Therefore, in subtropical regions with relatively warm winters (for example, around the Mediterranean Sea, the Caucasus) and in some southern regions of Uzbekistan, there is a high probability of peach leaf curl becoming severe.

The specific conditions of the garden can also be a contributing factor. For example, in orchards with densely planted peach trees, air circulation decreases and microclimate humidity increases - this situation provides additional impetus for fungal spread. Factors such as excessive soil moisture, poor air circulation, and failure to carry out appropriate sanitary cleaning in the orchard increase disease pressure over several years (Betaren, 2023). Conversely, strong and healthy growth, adequate nutrition, and proper care make peach trees more resistant to disease - for instance, even when damaged, they can quickly produce new leaves and compensate for the damage (McManus and Hudelson, 2024). Varietal factors are also important: not all peach varieties are equally susceptible, and it is known that some varieties are relatively resistant (UC IPM, 2023). Therefore, from an epidemiological perspective, the proportion of resistant varieties in the orchard, agronomic practices, and weather conditions influence the dynamics of disease development.

ECONOMIC DAMAGE AND IMPACT

Leaf curl disease can cause significant economic damage to peach orchards. The direct harm of the disease is a decrease in the quality and quantity of the harvest. As a result of premature leaf fall, the tree loses its nutritional and photosynthetic activity. Consequently, the tree cannot provide the initial nutrition for this year's fruit, and the fruits may fall off or fail to develop (McMahon, 2024). In cases of severe damage, there is a risk of complete crop loss (McMahon, 2024). For example, in the US experience, if the disease is not controlled in spring, the annual peach fruit harvest is almost completely damaged and becomes unmarketable (Peter, 2017).

The overall impact of the disease is so great that orchard owners often incur expenses every year for its prevention. According to analyses conducted in California, 90% of peach orchards in the state receive annual preventive treatment - otherwise, the risk from the disease is assessed as very high (USDA, 1999). If the disease is left uncontrolled year after year, the productivity of the orchard can sharply decrease within 2-3 years due to the weakening of trees and the drying of branches (USDA, 1999). Also, if young seedlings are severely affected, there is a possibility that they will completely die (McManus and Hudelson, 2024). Furthermore, the costs of combating the disease also become a burden on the agro-system - the annual application of fungicides in the autumn/winter period, labor costs, and others. According to some data, the cost of disease treatment per acre (0.4 ha) of peach orchards in the USA is around 50-100 dollars, which constitutes a large expense depending on the size of cultivated areas (CropLife, 2020). If the disease is not controlled, there can be losses of tens of millions of soums in annual yields per hectare of orchard; therefore, preventive costs are justified (USDA, 1999).

In Uzbekistan, there have been instances where this disease has caused significant damage to peach orchards in certain years. For example, local agronomic observations indicate that in regions with heavy spring rainfall, orchardists have lost up to half of their harvest (Bakhsilloev & Umurzakov, 2022). Consequently, neglecting leaf curl disease reduces fruit quality, decreases export potential, and severely jeopardizes the orchard's stability. Therefore, not only treating the damage but also preventing the disease in advance is economically beneficial. Each investment made creates an opportunity to earn more income through disease-protected crops.

CONTROL MEASURES: AGROTECHNICAL, CHEMICAL, AND BIOLOGICAL METHODS

A comprehensive approach is required in combating peach leaf curl disease. The most effective strategy is to combine preventive and agrotechnical methods with chemical treatments.

Agrotechnical Prevention: First and foremost, cultivating resistant varieties is of great importance. Some peach varieties (for example, 'Frost', 'Indian Free', 'Q-1-8' and 'Redhaven' hybrids) have been found to be resistant to leaf curl, thus posing less risk to the harvest (UC IPM, 2023; McManus and Hudelson, 2024). In contrast, varieties like 'Redskin' are highly susceptible and have a greater likelihood of contracting the disease. Therefore, selecting the most resistant varieties when establishing orchards is one of the long-term effective measures against the disease. Additionally, proper tree care also reduces disease incidence: peach trees should be pruned annually and shaped to improve air circulation. Thinning dense branches is important to prevent moisture retention inside the

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tree (Betaren, 2023). It is also recommended to prune affected branches and twigs in late autumn or early winter and dispose of them outside the orchard - this will limit the overwintering of the fungus from infection sites (Betaren, 2023). Collecting and burning or burying fallen diseased leaves is also practiced by some gardeners; although the fungus primarily overwinters in buds, eliminating spores from the leaves is still beneficial (McMahon, 2024).

Another important agrotechnical measure is to care for trees and improve their overall health. If there are too many fruits on a diseased tree, it is necessary to remove some of them and create conditions for the healthy growth of the remaining ones. This serves to ensure that the affected tree is able to ripen the remaining fruits even when it has shed its leaves and grown new ones (McManus and Hudelson, 2024). For example, in the USA, as soon as disease symptoms appear, gardeners recommend providing these trees with additional liquid fertilizer (nitrogen-based) and helping the tree's continued growth by increasing irrigation during dry periods (McMahon, 2024). This method also increases the tree's resistance to winter frost, as a tree that has been weakened by disease and enters winter in this state can easily freeze.

Chemical Control: Preventive treatment with fungicides is the most reliable and widely used method for controlling leaf curl disease. Typically, fungicide is applied at the end of autumn or winter, after the tree has shed its leaves (McManus and Hudelson, 2024). This treatment is called dormant season prophylaxis and is carried out to thoroughly cover all branches and bark. This single application is often sufficient. However, if a rainy winter-spring is expected in the region, a second application is advisable: it is recommended to do this during the swelling of flower buds, but before leaf emergence (UC IPM, 2023). Among the fungicides used, copper-based preparations have historically been the most widespread. For example, Bordeaux mixture (copper sulfate + calcium hydroxide), copper chloroxide, and copper hydroxide have been proven effective through many years of experiments (UC IPM, 2023). Copper-containing preparations form a protective layer on the plant surface, preventing spores from penetrating the tissue. However, they only have a preventive effect - meaning they are ineffective after infection has occurred. Additionally, annual use of large quantities of copper can lead to its accumulation in the soil and have toxic effects on microorganisms, therefore it should be used at appropriate rates (UC IPM, 2023).

In addition to copper, synthetic fungicides are also used. Widely used substances include chlorothalonil, ziram, ferbam, and captan (McManus and Hudelson, 2024; Agrio, 2021). For example, chlorothalonil has been used in nearly 30% of orchards in the USA during years with high rainfall (USDA, 1999). Ziram and other contact fungicides are also effective and are sometimes applied in combination. In newer regions, modern systemic fungicides such as dithianon and difenoconazole can also be used (Agrio, 2021). An important aspect is the alternating use of preparations and adherence to application schedules. To prevent fungicides from negatively affecting the fruit or human health, the final spraying should be completed before leaf emergence (McManus and Hudelson, 2024). With consistent and proper chemical control, the disease can be fully managed, and symptoms may be completely absent in the trees.

Biological and Integral Methods: In recent years, research has been conducted on the use of biological agents against leaf curl disease. For example, some studies have shown success in reducing the disease incidence by using antagonistic fungi such as Trichoderma harzianum or bacteria like Pseudomonas fluorescens (Kumar et al., 2017). However, these methods have not yet been widely implemented in practice. Another biological approach is to enhance the plant's own immunity. Studies have demonstrated that spraying chitin and its derivative, chitosan, can increase resistance to leaf curl (Cesare et al., 2023). This is because chitosan stimulates the plant's defense reaction, allowing it to respond quickly when a pathogen invades. Additionally, some studies have shown that peach trees' disease resistance increases if compost tea, EM solutions (based on microorganisms), and plant extracts are sprayed every two weeks during the growing season (Philadelphia Orchard Project, 2020). Of course, these biological methods cannot fully replace chemical fungicides, but they could be used in the future as supplementary measures within an integrated pest management program.

As a final recommendation, the most effective approach to combating peach leaf curl is a comprehensive one. First and foremost, it is essential to select resistant varieties, plant healthy seedlings, and adhere to quarantine regulations. It should become routine practice to perform sanitary cleaning in the orchard every autumn and apply a single spray of copper or an effective fungicide during the dormant period. In spring, if the weather is humid and cool, it is advisable to conduct an additional second spraying. If disease symptoms appear, the tree can be saved by immediately intensifying agronomic measures - irrigation, fertilization, and fruit thinning. Simultaneously, gardeners will only break the chain of reinfection among surrounding trees if they cooperate and carry out treatment practices in their orchards at the same time (McMahon, 2024).

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CONCLUSION

Peach Leaf Curl disease is a significant disorder caused by the fungus Taphrina deformans and widely prevalent in peach orchards worldwide. It severely damages the leaves of peach trees, seriously affecting both the quality and quantity of the harvest. Understanding the etiology and development cycle of the disease reveals that the pathogen primarily spreads through airborne droplets in spring and proliferates rapidly in cool, humid weather. Symptoms include curling and wrinkling of leaves, reddening of foliage, and premature leaf fall. Branches may also exhibit defective growth, and the tree might gradually experience partial dieback. If this condition persists for several years, it reduces the orchard's economic efficiency and can even lead to tree mortality. The most effective approach to prevent and mitigate damage is implementing integrated control measures. Planting resistant varieties and regularly performing agronomic practices (pruning, cleaning, maintenance) reduces the risk of disease occurrence. It is also crucial to maintain annual preventive fungicide spraying - a single application of fungicide during the dormant period often provides complete disease control. Indeed, in developed countries where orchard treatment during dormancy is not neglected, this disease does not pose a significant problem, allowing for full preservation of the harvest (USDA, 1999).

New technologies and biological methods may also find their place in the future. Modern research continues in areas such as increasing peach immunity against leaf curl disease and the application of biofungicides. Additionally, work is being carried out to develop varieties completely resistant to diseases through genetic selection (Svetaz et al., 2017). In general, combating leaf curl disease requires constant attention and a comprehensive approach. For highly skilled horticulturists and scientists, understanding this disease, conducting in-depth studies of its epidemiology, and implementing the most effective control measures are urgent tasks. Only then will it be possible to ensure stable and high yields of peaches, maintain fruit quality, and preserve export potential.

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