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# A COMPREHENSIVE REVIEW OF SIGNIFICANT BACTERIAL DISEASES AFFECTING WHEAT

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**A B S T R A C T**

Wheat is considered an essential source of food grains for humans and is regarded as a basic food commodity worldwide. Wheat is a staple food for a significant part of the world's population, especially in regions like Asia, Europe, & North America. Wheat is also considered an essential source of fiber and vitamins. In wheat, a protein content of up to 11-14% is present. However, it also has a concentration of some essential amino acids, such as lysine. The bacterial diseases are responsible for a 10 to 40% reduction in wheat production. Bacterial diseases of wheat can lead to significant yield losses and also affect the quality of wheat grains, which results in discoloration, shriveled kernels, reduced grain weight & poor milling properties. Major bacterial infections such as Bacterial Leaf Streak and Black Chaff caused by *Xanthomonas translucens* pathovars; Bacterial Leaf Blight & Basal Glume Rot caused by *Pseudomonas syringae* pathovars; & diseases of minor importance because there is less research available on these diseases, such as Spike Blight of Wheat, Bacterial Mosaic of Wheat, & Gumming disease of Spike caused by genus *Clavibacter* pathogens. Researchers and scientists have focused on various aspects of managing bacterial disease in wheat, such as disease resistant varieties, cultural practices, pathogen detection, disease characterization & biological control methods. While significant progress has been made in the management of bacterial disease in wheat, there are still several gaps, such as a lack of integrated management strategies, sustainable disease management practices, extension and farmer education, rapid and accurate diagnostic tools & limited disease resistance, that need to be addressed. Continued research, collaboration & knowledge exchange among stakeholders are essential to overcome these challenges and protect the wheat crop from bacterial diseases. This review provides an up-to-date comprehensive description of symptoms, disease cycle, and epidemiology & management strategies for bacterial diseases of wheat.

**Keywords**: *Clavibacter* Pathogens, Management Strategies, *Pseudomonas Syringae*, Wheat, *Xanthomonas translucens.*

## INTRODUCTION

The cultivation of wheat started in South Western Asia, and gradually its cultivation spread to other countries in Asia, Africa and America. It belongs to the family Poaceae and is used to produce domesticated cereals such as barley, rye, & several important forage grasses (Gaut, 2002). The wheat production in the years 2021-2022 was 778.6 million metric tonnes. However, this major crop is under continuous risk due to many constraints (abiotic & biotic), leading to a significant reduction in production of wheat (Limbalkar *et al.*, 2018). It has been reported that 31 pests were found to reduce about 21.5% of the economic yield loss in wheat (Savary *et al.*, 2019). Therefore, it is proposed that through a combination of different strategies that may include increasing grain crop production by combating disease, reducing food demand, & maintaining productive capacity, the predicted food demand in 2050 could be achieved (Keating *et al.*, 2014). Bacterial diseases of wheat, including bacterial leaf streak or black chaff, basal glume rot and bacterial leaf blight are mainly reported on wheat. These diseases affect normal leaf development and contaminate the seeds due to spiked infection or sometimes contamination by pathogens that

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come from non-resistant genotypes (Maraite *et al.*, 2007). However, a researcher gives no such importance to bacterial disease as compared to fungal disease, probably because of its resemblance to stress related damage. Also, these diseases appear epidemically only when various environmental conditions are favorable, thus mostly in sporadic form. Moreover, pesticide application is not a practical option for management. So, resistant cultivars and the production of seed free from pathogens are possible solutions (Maraite *et al.*, 2007).

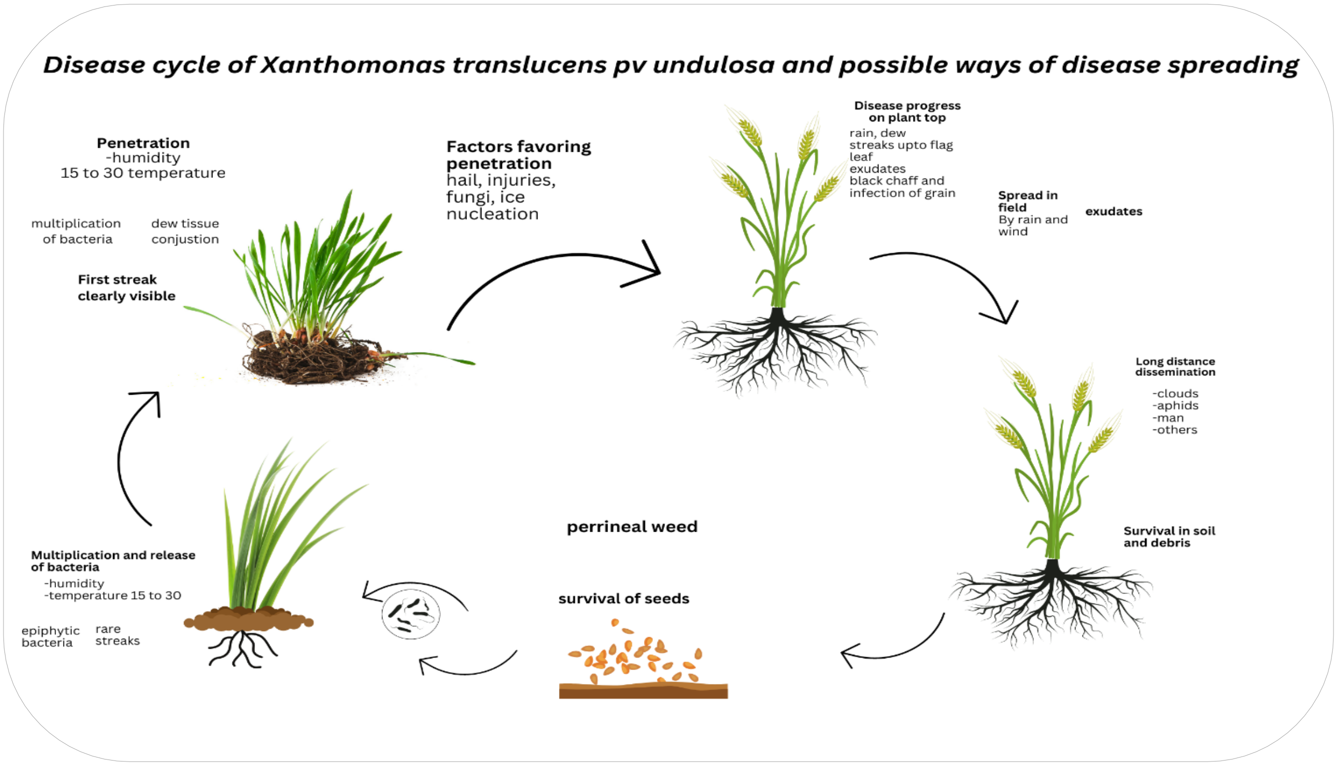
This review provides general knowledge to identify wheat bacterial diseases in addition to methods to identify important bacterial pathogens. However, it is complex and requires integrated approaches to control bacterial diseases. Therefore, we have given general principles and guidelines to control bacterial diseases.

**Major Bacterial Pathogens: Bacterial Leaf Streak and Black Chaff:** Bacterial leaf streak or leaf stripe disease (BLS) is caused by *Xanthomonas Translucens* pv*, undulosa.* Bacterial leaf streak is also called black chaff disease because it occurs in glumes. The black chaff of wheat is caused by *Xanthomonas Compestris* pv *translucens* & disease was first reported in Washington state in 1985 (Schaad and Forster, 1985). The black chaff also resembles abiotic stress, also known as pseudo-black chaff (Hagborg, 1936). Bacterial leaf streak was first reported in 1919 in the United States (Smith *et al.*, 1919). In North America, Bacterial Leaf Streak was first reported in barley and then in wheat farms in the Midwestern United States (Jones *et al.*, 1917). The disease is known to occur on wheat in South America (Argentina, Paraguay, Peru, Brazil & Uruguay) (Duveiller *et al.*, 1991). Bacterial leaf streak disease of wheat has been confirmed in 34 countries worldwide based on the recent global database of the European Plant Protection Organization (Paul and Smith, 1989). Like other countries, BLS has now become a major problem in Pakistan; it was first reported in 1985 in Pakistan (Akhtar and Aslam, 1985). Even though it is a widely spread disease, current data or research does not find it, probably because of the variation in disease importance in different growing areas due to cultivars grown and environmental conditions (Sapkota *et al.*, 2020). Yield losses reported due to Bacterial leaf streak are about 10%, but on highly susceptible varieties, yield losses may be as much as 40% (Waldron, 1929). In Mexico, 20% of yield losses occurred due to leaf streak severity (Duveiller and Maraite, 1993b). A bacterial leaf streak severity of 100% on flag leaves results in a yield reduction of about 34% (Shane and Baumer, 1987). A reduction in yield due to bacterial leaf streak severity can be characterized by a reduction in the weight of seeds and the number of seeds per head (Tillman *et al.*, 1999).

**Symptoms:** A characteristic symptom of the bacterial leaf streak occurs on the spikes and on the leaves of the wheat plant. The disease cycle is initiated with water-soaked necrotic streaks that eventually convert into translucent lesions. These lesions are several centimeters long & at first distinct, and gradually merging to form large solid areas. When temperature & relative humidity become favorable, yellow honey-like exudates ooze out from the surface of the infected leaves (Duveiller and Maraite, 1993a). The black-chaff disease is seed-borne, and that causes restrictions on trade in wheat germplasm internationally & all over the world (McMullen and Adhikari, 2011). Black chaff is often confused with pseudo-chaff or brown melanosis, a condition caused by abiotic stress (Hagborg, 1936). Seed is considered a critical source for primary inoculum, & its vast spread is because of its seed-borne nature (Tsilosani *et al.*, 1977). Until now, the exact location of bacterial pathogens in wheat grains has not been determined. Nevertheless, in most cases, it survives in seed coats (Duveiller *et al.*, 1992).

**Epidemiology:** The pathogen disseminates to other countries, with outbreaks and epidemics appearing in the southern and eastern regions of the United States (Tubajika *et al.*, 1998). The pathogen survives better in soil when crop debris is present (Boosalis, 1951). The bacterial leaf streak causes bacteria to survive in a vast temperature range (15-30°C) (Duveiller *et al.*, 1991) and the temperature at which they grow best is more than 26°C (Forster *et al.*, 1986). Recent research shows that temperature is a critical constraint in epidemic development, as pathogen multiplication is proportional to temperature (Duveiller and Maraite, 1995).

**Disease Cycle:** It has been reported that bacteria move from the seed surface to the aerial portion, affecting the plumules through injuries or stomata on the coleoptile. It starts multiplication at an optimum temperature range (15-30°C) and the release of bacteria takes place initially when streaks are rare. These new bacteria then attack the plumule, extend to the surrounding leaves, and infect them before the 1st leaf appears from the seed coleoptile (Wallin, 1946). At this stage, streaks become clearly visible. The pathogen persists in warmer, progressive wheat growing areas. When precipitation is low & humid, conditions at night are sufficient to infect parenchyma. After head emergence, infection occurs in kernels and glumes. Once the pathogen penetrates the leaf, it still multiplies, & even under dry conditions, moisture on the leaves does not affect bacteria growth. The pathogen's survival does not depend on the host, but it may survive on a tomato leaf (a non-host species) for many weeks. It also survives on perennial weeds. (Timmer *et al.*, 1987). Over short distances, it may disseminate through splashing water, rain, plant-plant contact, and insects. For long distances, infected seed is the method, which is also the primary source of inoculum (Boosalis, 1951).




**Disease Management:** As this bacterial disease is seed-borne, use certified seed free of pathogens. For management, seed lots should be tested by seed wash testing by seed producers for black chaff detection before planting (Duveiller, 1997). Another way is crop rotation, but on this measure, no such research is present. As bacteria can survive in plant debris and induce field infection. It has been reported that the viable number of pathogens is low in overwintering plant debris & largely reduced when the plant debris is buried in the soil (Boosalis, 1951). When wheat is rotated with a non-host crop, pathogen survival is almost impossible, which also results in high vulnerability for this bacterium (Schaad and Forster, 1985).

**Bacterial Leaf Blight:** Bacterial leaf blight is caused by *Pseudomonas syringae Pv, Syringae* (Sellam and RD, 1976). The taxonomy of these bacterial pathogens has not been clearly determined. Various types of *P. syringae* may cause symptoms on wheat spikes or leaves. These pathogens can be identified by using the taxonomic classification of Bradbury (Bradbury, 1986), basal glume rot caused by *Pseudomonas syringae* pv. *Atrofaciens* (Young *et al.*, 1978), leaf blight by *P.syringae* pv. *Syringae,* and black bacterial nodes that induce symptoms on leaves & spikes by *P.syringae* pv. *Japonica* (Dye *et al.*, 1980). This disease has been reported in Argentina (Falahi Charkhabi *et al.*, 2015); Pakistan (Akhtar *et al.*, 1986); South Africa (Smith and Hattingh, 1991); Italy (Varvaro, 1983) & the USA (Nebraska, North Dakota, South Dakota (Otta, 1974).

**Symptoms:** Wheat plants infected with bacterial leaf blight exhibit small, water-soaked spots that extend into the immense lesion and streaks mainly when humid and rainy conditions are common (Bockus *et al.*, 2010). When humidity is low, these lesions become a characteristic grey-green. In less than three to four days, these lesions merge to form blotches of a nonuniform shape and turn into a white color. Necrosis continues until (75 to 100%) of the leaf blade is damaged (Otta, 1974). In some cases, oozy material has also been observed. Overall, the leaf becomes necrotic, while spikes and lower leaves are symptomless (Bockus *et al.*, 2010).

**Epidemiology:** An environmental condition has a major impact on the severity and economic loss of these diseases. Because these diseases appear sporadically, they occur under severe humid conditions in the spring and summer seasons. The diseases are usually considered of less importance, as only in a few instances do they cause huge losses. For example, in South Dakota, leaf necrosis for a period of 7 years causes 75% or more necrotic leaves (Otta, 1974). This pathogen is widespread and has a widespread host range, including many herbaceous & woody plants such as maize, sorghum and lilac. *Pseudomonas syringae* strains that induce necrosis consist of an extensive, diversified group with a broad host range as compared to, *P. syringae* that have induced water-soak symptoms (Ovod *et al.*, 1997). The disease's severity is dependent on specific climatic conditions. When high humidity prevails for many days with cool temperatures (15-25 °C) and enough rainfall, the disease is mainly observed (Kietzell and Rudolph, 1997). The booting stage of the host plant is the most vulnerable stage for infection. Bacterial leaf blight has less importance because of lower yield losses. However, in South Dakota, the disease appeared in epidemic form (high infection), resulting in necrotic spots occurring on the leaves (75% or more) (Otta, 1974). In the epiphytic population, the bacterial inoculum is present in large amounts, and weather conditions are crucial for disease appearance. In areas where abundant moisture is present, this disease is more prevalent (Scharen *et al.*, 1976) and also depends on the wind-driven precipitation during (May-June) (Otta, 1974) and it is also reported in fields that are heavily irrigated (Smith and Hattingh, 1991).

**Basal Glume Rot:** Basal glume rot is caused by *P. syringae* pv*. atrofaciens,* (Young *et al.*, 1978). The disease was first reported in 1925 in New Zealand (Wilkie, 1973). The disease on the spike has been observed in the USA, Canada (Knežević *et al.*, 2016), New Zealand (Wilkie, 1973), Australia (Noble, 1933) & different parts of the world. However, in most cases, the disease is not symptom-specific. The weather condition is crucial for disease severity and economic losses because of these diseases. In Germany, yield losses due to this disease are more than 50%. Also, the pathogen infection results in a reduction in the grain quality of bread wheat (Mavridis *et al.*, 1991).

**Symptoms:** Infected glumes have a dull, brownish-black appearance at the base. Generally, just the lower third of the glume or less is infected. The inner side of the glumes shows more clear symptoms than the outside (small & water-soaked areas are present) (Toben *et al.*, 1989). In diseased grain, color varies from charcoal black to brown, and symptoms first appear at the basal or glume end (Knežević *et al.*, 2016). The infected grains may become wrinkled when water-soaked dark green lesions form, which become necrotic later (Kietzell and Rudolph, 1997).

**Epidemiology:** The pathogen has important epiphytic (occurring on the plant surface) stages (Hirano and Upper, 1983). The pathogen inoculum is present in large amounts; weather conditions are important for disease development. For instance, in many areas of Germany, the pathogen was isolated from (10-48%) of leaves showing no symptoms (Kietzell and Rudolph, 1997). After heading, wet weather conditions support the disease's development. Periods of extended humid, cool weather are crucial for disease epidemics. Controlling moisture at the heading is crucial to control the disease (Toben *et al.*, 1991). Initially, leaves are free from pathogens, and then pathogens effectively attacked the topmost part of the plant & finally reached the flag leaf without causing the characteristic symptoms of basal glume rot, because of non-conducive environmental conditions (Fessehaie, 1993). Scientific studies have shown that this pathogen has a high ability to cause epiphytes (Sultanov *et al.*, 2016). This pathogen also has the ability to colonize the host plant and the aerial region of the plant with microbes. Furthermore, the primary source of infection for the plant is forming an epiphytotic population, which also causes a high amount of damage when favorable environmental conditions occur (Donati *et al.*, 2020; Taghavi and Keshavarz, 2003; Tarkowski and Vereecke, 2014).

**Management strategy:** Since these pseudomonas strains are weak pathogens, control measures are not so important. Under extremely humid conditions, the diseases have been observed in most countries. Therefore, no traditional measures have been established (Bockus *et al.*, 2010). Since the contaminated seed serves as a transmission vehicle for the dispersal of inoculum, these seeds should not be used for sowing. Seed treatment that considerably disinfests the seed is not available (Kimber, 1987). Usually, a resistant variety is the most effective management technique. Hence, research has been done with this technique to detect resistant cultivars of wheat (Akhtar *et al.*, 1986; Toben *et al.*, 1991). To control these diseases, cover the entire plant or a single wheat head with a polythene bag. This may increase the inside temperature of the plant and humidity to the required range. The thermal death point of the bacterial blight pathogen is 48-51 °C (Starr, 1959).

**Minor Bacterial Pathogens: Genus "*Clavibacter*" Pathogen:** This genus includes a bacterial mosaic of wheat, the gumming disease of wheat, & spike blight Pathogens. These diseases cause low economic losses. Less data and research are available about these diseases because these bacterial pathogens require extreme weather conditions, which are present in a few areas.

**Spike Blight of Wheat:** Spike blight of wheat was first reported in 1917 in India as being caused by *Rathayibacter tritci*, which is also considered the causative agent of Tundu disease (Bockus *et al.*, 2010). Spike blight of wheat is also known as yellow ear rot and is also infectious to numerous types of grass, such as barely. Spike blight of wheat is a complex disease because it is intermingled with the nematode, "*Aguina tritici*", the causative agent of seed galls, also recognized as ear cockle disease, in some wheat cultivars (Bamdadian, 1973). The disease is present in different countries, i.e., Afghanistan, Australia, China, Cyprus, Egypt, Ethiopia, Iran, Iraq, India, Morocco, Pakistan & Zambia (Paruthi and Bhatti, 1985).

**Symptoms:** The spike blight of wheat includes similar yellow or white stripes that usually occur in the leaf veins. These stripes have lately developed into a sticky mass, yellow gummosis on the wheat head. Spikes & peduncles are mostly contorted while coming out of the whorl. Also, the initial leaves are twisted and shrunken. Once this sticky mass becomes dry, gummosis forms pale-yellow flecks on the leaves. This hard, gummy mass distorted the leaves, spikes, and peduncles (Bockus *et al.*, 2010).

**Mode of Infection:** The bacterial pathogen survives in crop debris in moist soils. To infect the wheat plant, the pathogen has to be transformed by the *A. tritci* into a whorl enclosure. Usually, the cells of bacteria contaminate the juveniles of *A. tritici* in the soil. This prevents the pathogen from being distributed on seeds, seed galls, and inside the soil. The nematode and this bacterium can survive in seed galls for more than half a decade (Riley and Reardon, 1995).

**Bacterial Mosaic of Wheat:** A bacterial mosaic of wheat was first reported in 1976 in the USA, caused by *Clavibacter tesselarius,* & taxonomically classified in 1982. Diseases were also reported in North America (Carlson and Vidaver, 1982) & Canada (Paul and Smith, 1989). The pathogen is host-specific (wheat) but found to be linked to *C. michiganensis* (Carlson and Vidaver, 1982). The disease occurs in a sporadic manner every year and is also found in triticales. The economic losses caused by this disease are yet to be determined.

**Symptoms:** Bacterial mosaic is a foliar disease with symptoms of a mosaic of small yellow lesions that have similarities to viral symptoms. These small lesions merge to form streaks (Duveiller, 1997). Under a temperature of 20-22 °C in a greenhouse, by artificial inoculation, young seedlings may develop mosaic-like symptoms in 3-5 days (Carlson and Vidaver, 1982). The pathogen is seed borne, so it is recommended to avoid contaminated seeds and develop resistant or tolerant cultivars as control strategies. The available wheat cultivars have different responses to the pathogen, indicating that genetic resistance improvement is possible (Duveiller, 1997).

**Gumming Disease of Spike:** *Clavibacter iranicus* is the causal organism of this disease and has only been reported in Iran (Postnikova *et al.*, 2009). The scientific name of this disease initially was *Clavibacter iranicum,* then *Clavibacter iranicus* by (Davis *et al.*, 1984), while (Zgurskaya *et al.*, 1993) suggested the name of this pathogen as *Rathayibacter iranicus*. Also, no management strategies have been proposed in the literature so far. This *C. iranicus* resembles *Rathayibacter tritici*, but they are different (Bockus *et al.*, 2010).

**Disease Management:** The management of these diseases caused by the *Clavibacter* genus is not completely understood. However, the cultivation of wheat on well-drained soil effectively reduces the pathogen. Management of *A. tritci* is also helpful in decreasing disease incidence. Crop rotation with a 2 to 3-year span for the non-grass crop is yet another suitable control measure.

**Summary:** The occurrence of bacterial diseases in wheat is sporadic and restricted to small ecological regions due to favorable environmental constraints. Nevertheless, due to severe climate change, these bacterial diseases might be more prevalent. These bacterial diseases have been reported worldwide (in temperate and subtropical zones) & in a few cases, yield losses caused by bacterial pathogens have been reported. These bacterial diseases can adversely impact the quality of wheat grains, leading to problems like discoloration, reduced grain weight, shriveled kernels and poor milling properties. Major bacterial pathogens such as *xanthomonas translucens* pathovars are responsible for bacterial leaf streak and black chaff, Whereas *Pseudomonas Syringae* pathovars are responsible for basal glume rot and bacterial leaf blight. In addition, there are lesser known diseases caused by *Clavibacter* pathogens such as spike blight of wheat, bacterial mosaic of wheat and gumming disease of spike, for which limited research is available. Hence, environmental constraints are more crucial for pathogen dissemination than just the presence of an inoculum. These pathogens cause a high amount of damage only when a high bacterial concentration is present in the field. However, lots of seeds contaminated with these pathogens should not be used for planting. In the future, there is a need to develop wheat varieties with enhanced resistance to bacterial diseases, crop rotation that will reduce the buildup of bacterial pathogens in the soil, develop detection methods such as (rapid and reliable diagnostic tools & remote sensing and imaging technologies) and integrated disease management & sustainable practices that will be helpful in managing the diseases.

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