Review Article

Bacterial Leaf Blight of Rice: An Overview of Epidemiology and Management with Special Reference to Indian Sub-Continent

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Abstract | This is a status review article on the destructive bacterial blight disease of rice, caused by *Xanthomonas oryzae* pv. *oryzae*, in rice producing areas. This article comprehensively reviews the etiology, symptomatology, pathogen biology, disease development, disease cycle, epidemics and epidemiology, geographical distribution and strategies for the disease management viz., exploitation of host plant resistance, cultural, physical, chemical and biological control. Studies on pathogen variation have revealed that breeding with single major gene for resistance may be unsuccessful due to breakdown in resistance. Up to this extent, multi cropping using resistant varieties appears to be better option for the disease's management. Evidence from my laboratory suggest that biological control is the best option having ecofriendly activities for the management either using botanicals or through some biological agents. Formulations of various botanicals along with biological agents may be commercializing to help farmers to combat the disease. There is a need to use environmentally safe approaches to overcome the loss of grain yield in rice due to this disease. Climate change has a serious effect on this disease because in current scenarios cropping pattern has been changed and the stakeholders has shifted to some other crops rather the practicing ones. Since, farming community has adopted rice crop in non-core areas of Indian Sub-continent where it was out of question before this. Climate change has a drastic effect for the development of this disease and still there are no remedies to tackle this problem. Environmental issues are also needed to be addressed in the future research agenda of this disease.

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Introduction

Bacterial leaf blight of rice is among the most devastating pathosystem of rice in nearly all the rice growing localities in tropical and temperate regions especially in Asian countries. The pathogenicity of bacterial leaf blight has confirmed that the causal bacterium is *Xanthomonas oryzae* pv. *oryzae*. Comprehensive studies were performed on the etiology, epidemiology and biological management of the disease in Multan. Up till now researchers gave less importance on the biological management especially using plant extracts. The management of the crop plant diseases by utilizing the plant extracts are considered relatively secure as the plants products are economically cost effective, simply biodegradable and prove themselves as environment friendly with their response (Mariappan, 1995). The present research is based on the screening, estimation of phenolics contents; epidemiology and biological control of bacterial blight of rice by plant extracts and detailed reviews of work done previously by the scientists on

this issue are being reported in this chapter.

Disease development and symptomatology

The pathogenic bacterium invades the rice crop plants through the water pores using the fresh wounds of 24 hours (Mukko, 1957). The pores for water percolation are present on leaf edges of the higher area of leave; so, lesions normally start at leaf margins on the upper part near the top area. Firstly, small water-soaked lesions appear which later turned to yellowish white color expanding from the equal sides in a square form to produce elongated circular to quite uneven lesions. Lesions edges were adjoining the healthy areas on the leaves and showing the most characteristic symptom of the disease i.e. the wavy margins, which can be clearly seen on the leaf blade. The lesions normally start on one or both margins of leaves or can be observed on the fresh infected leaf veins under humid conditions. The environment played a key role for the development of the disease and the appearance of the symptoms in the field. The disease could be characterized mainly into two distinct phases; leaf blight phase, and the "Kresek phase" which is the destructive one for the epidemic of disease (Reddy and Ou, 1976; Ou, 1985).

Leaf blight phase

This phase of the disease becomes visible very early in the temperate regions of the rice growing countries with the initial symptoms on the leaf blades after the tillering gain its peak position and usually initiated at lower parts in plants and gradually proceeds towards to the upper areas of the plants (Goto, 1992; Cha, 1982). The severe symptoms of the disease could be observed on vulnerable genotypes when grown under the impact of extreme nitrogen fertilization. The upper portion of leaf or total area of the leaf blade turned pale yellow before drying up due to the severity of the disease (Mizukami and Wakimoto, 1969). In severe attack of the disease yellow to white stripes appeared just inside the margins of the leaf blades which later on turned to pale yellow and become necrotic (Ou, 1985).

Kresek phase of disease

The word "Kresek" is derived by the Vernacular term in Java, meaning "the sound of dead leaves" stroked with one another (Wakimoto, 1969). This stage of the disease was firstly accounted in Indonesia considering a different disease of rice in the mid twenty centuries (Reitsma and Schure, 1950). Later, after a long time of consecutive studies, the pathogen of the distinct disease was identified and named (Mizukami, 1956). The "Kresek" phase of bacterial leaf blight disease was characterized mainly by the systemic infection due to this phase the symptoms of disease usually appear 1-2 weeks after transplantation of the nursery into the field. Under severe conditions leaves of the rice plant become grayish green to whitish and suddenly withered and sometimes "Kresek" phase of the disease happens on mature plants (Goto, 1992; Watanabe, 1975). In this phase usually, symptoms appear on foliar parts, related those on younger plants yet the rotting of the stem also reaches the upper part of the leaf.

Disease cycle

The bacterium remains in roots of the weed "*Leersia haxandra*" form where in the rice growing season it reaches the rice nursery beds and further spreads in the channels by the irrigation water applied to the young plants. Besides this, infected straw present in the field or the infected seeds may also introduce the pathogen into the rice nursery (Mizukami and Wakimoto, 1969). After reaching the young rice seedlings, the pathogen starts to accumulate on the root surface and progress upward towards the crown by utilizing the metabolites for their multiplication, which usually ooze out from roots of rice plants (Mizukami, 1957, 1959, 1961). Mizukammi (1961) and Dath (1983) described that the pathogen might be transmitted to basal parts of the leaf sheath through the contaminated roots or by the lower leaves which encounter contaminated water and becomes the source of infection for the rest of crop period. Tabei (1967) reported that the pathogenic bacterium entered into stomata on coleoptiles and leaf sheath of rice seedling under the moist conditions and multiplied in the intercellular spaces of parenchyma and attacked the vascular system of the plant. It was also assumed that the disease sometimes might be transmitted by the insect of rice crop i.e. rice bug *Leptocorsia acuta* when transmitted mechanically to the crop plants (Mohiuddin et al., 1976).

Etiology of the disease and proof of a microbial entity

The study of bacterial blight of paddy rice was started first time in 1901 in Japan (Tagami and Mizokami, 1962). Early studies showed that the disease was a physiological problem due to the acidic soils in rice growing areas favoring the occurrence of disease (Yoshida and Muko, 1987). This theory was further supported by the recordings that whenever the Soy bean was used as a fertilizer, it oftenly increased

the disease incidence by acidifying the soil nature (Maruyama, 1908, 1909). Nishida (1990) observed that the disease infected leaves when applied with ammonium sulphate in the field; exuded acidic dew drops in response, whereas the drafts showed from quite healthy leaves in the same field were not acidic in nature. Bokura (1911) confirmed that the disease was due to the bacterium and not by the issue of acidic nature soils; he named the bacterial agent as *Bacillus oryzae*, later it was known to be *Pseudonomas oryzae*. Migulas taxonomic system stated that the casual microbe was *Bacterium oryze* (Yoneyama et al., 1969). Afterwards Nakaia (1927) interpreted the bacterium as *Phytomonas oryzae* and then Magrou (1937) described the bacterium as *Xanthomonas oryzae*. The International Committee on Systemic Bacteriology (ICSB) released the final approved list of the bacterial names which showed the bacterium with the name *X.oryzae*; the name of the phyto pathogenic bacteria (Skermn et al., 1980). To escape out the inconvenience of the newly adopted system to plant pathologist, the Committee of Taxonomy of phyto pathogenic bacteria of the International Society for Plant Pathology presented international standard for the naming of pathovars and a comprehensive list of pathovar names to be used for classifying plant pathogenic bacteria at the infrasubspecific level. In the lists, the name *X. oryzae* was revised with the addition of pathovar name as *X. oryzae* pv. *oryzae* (Ishiyma, 1922; Dye, 1978; Dye et al., 1980).

Geographical distribution and economic importance

Bacterial leaf blight of rice was reported first time by farmers of Fukuoka Prefecture, Kyushu Island of Japan in 1884-1885. The disease disseminated gradually in 1950s throughout Japan, particularly noted from Kyushu Island (Yamanuki et al., 1962; Tagami and Mizukami, 1962). The onset of bacterial leaf blight was further observed from several neighboring countries of Japan, i.e., Malaysia and Indonesia (Reitsma and Schure, 1950), Korea (Takeuchi, 1930), Taiwan (Hashioka, 1951) and Cambodia (Nishiyana, 1977) as a Kresek disease. The disease was not only reported from rice growing countries especially in Southeast Asia, but also had been reported from many African countries like Mali, Mauritania, Gambia, Burikana, Guinea, Ghana, Nigeria (Awoderu et al., 1991; Herger et al., 1988). In the United States of America, the disease was first time reported by Lozano (1977) while in Northern Australia, the disease was also found to occur in many cultivars of rice (Aldrick et al., 1973). Bacterial leaf blight of rice had been a most serious issue in Southeast Asia especially from the promotion of high yielding dwarf varieties (Seneviratne, 1962; Fekain, 1971). The disease caused great yield losses during the current years. In Japan, yield losses recorded ranged between 25-35%, often increasing up to 60% (Ou, 1985) while in Philippines and Indonesia, losses were recorded very high. The order of losses recorded in Philippines were 24.50% in moist to 7.21% in completely dry season in vulnerable crops and 9.50% to 1.08% respectively, in healthy crops (Exconde, 1973), while in India and Bangladesh, the heavy yield losses has been reported 12-32% (ShahJahan, 1992). Similarly, in East India, reported losses of the yield were 7-62% and 82% at same genetic resources (Srivastav, 1967; Singh et al., 1980; Srivastav and Kapoor, 1982).

Breakthrough of bacterial blight in Pakistan and its pathogen dispersal

Bacterial leaf blight disease was reported first time in Pakistan at Kala Shah Kaku, Rice Research Institute, and nearby farmers' fields during 1977, afterwards, frequency of disease was reportedly present in paddy rice cultivars IRRI 6, Paalman and Basmati 1998 (Meo and Majid, 1977; Ahmed and Majid, 1980). The increasing incidence of the disease was reported at various farmers' field viz., 11-16, 16-22, and 21-26%, in Sindh, Punjab and Khayber Pakhtun khuwa, respectively (Akhtar and Sarwar, 1986). Bacterial leaf blight gradually increasing incidence 41-52% was noted in Fakanda-Abad, Dhing fields, whereas 71-81% and 90-95% disease infestation was recorded in some nearby fields of villages. Mean incidence of disease calculated in most areas of the Punjab province were 64, 63, 43, 36, 34, 28, 41, 55, 45, 55, and 48% in Hafizabad, Sargodha, Shekhupura, Narowal, Gujranawala, Gujjrat, Sialkot, Lahore, Okara and Kasoor respectively, (Akhtar et al., 1997). Akhtar et al. (2003) reported that the mean incidence of bacterial leaf blight disease was 25, 28, 15, and 29% in the month of September 1999 in Hafizabad, Sheikhupura, Gujarnwala and Gujrat areas, respectively. In Khayber Pakhtoon Khaw, mean incidence of disease was recorded in the range 0-90%, 0-100% and 0-0% in Malakand, Lower Dir and Mansehra, respectively, whereas the severity of disease ranges from 0.2-6, 0.3-7, 0.4-9% in Sawat, Malakand Agency, Lower Dir and Mansehra, respectively. As for as, Sindh Province is concerned, mean incidence of bacterial leaf blight was 0.00, 0.01-5.0, 5.0, 1.0,

2.0, 0.1-5.0, 0.2-5.1 and 0-5% in Dadu, Shikarpur, Larkana, Nawabsha, Thatta, Jacobbanad, Badin and Usta-Mohammad, respectively; while the severity of disease was 0.01, 0.1-1.0, 1.1, 0.1, 1.0, 1.1, and 0.0-1.1% in Larkana, Daddu, nawabash, Shikarpur, Thatta, Badin, Jacobabad and Usta-Mohammad, respectively. As for as Balochistan is concerned, mean disease incidence percentage were recorded 0.0-6.0% whereas in Jammu and Kashmir, bacterial leaf blight was totally absent (Ali et al., 2009).

Identification of pathogen through biochemical tests

Di et al. (1991) observed the maximum recovery of the *X. oryzae* pv. *oryzae* yellow viscous colonies on nutrient agar after the inoculation of diseased samples rather the contaminated seeds because of the presence of some saprophytic bacteria and other microbes on the surfer of seeds. He performed the KOH test to determine that the isolated bacterium is gram negative and could cause the disease in crop plants. Munir et al. (2007) reported *X. oryzae* pv. *oryzae*, a gram-negative rod for gram reaction, negative for oxidase and lecithinase test whereas starch hydrolysis, tween-80, anaerobic nature and acid production from carbohydrates on solid agar-based media varied among the various isolates of the bacterium.

Jabeen (2011) conducted six biochemical tests of the bacterium to characterize the 17 locally collected strains of the bacterium and observed the findings of gram staining which showed bacterium a gram-negative, rod shaped while potassium hydroxide (KOH) test also confirmed the gram staining results and revealed that the bacterium was gram negative; the egg yolk reaction was also found to be negative for the seven locally collected isolates while oxidase test for seven isolates was also negative whereas starch hydrolysis test showed positive reaction.

Cultural and physiological studies of X. oryzae pv. oryzae

Morphological characterization: Ishiyma (1922) observed that the bacterium was short and rod-shaped, gram-negative and non-spore forming with round ends; 0.5-0.8 × 1.0-2.0 µm in size, possessing monotricus flagellum of 6.2-8.1 µm in length. Besides this, microscopic observation showed that the size of the bacterial cell wall was 0.56-0.71 × 1.25-2.16µm in the culture plate and 0.44-0.51 × 0.66-1.39µm in the host plant tissues. Yoshimura et al. (1970) described the ultrastructure of the bacterium which possess a cell wall that encircles the cytoplasmic covering and nuclear stuff of fibriliar emergence while polysomes, ribosomes like structure and granules in cytoplasm were also reported to be present of two types. The outer surface of the bacterium is enclosed by viscous capsule like substance which is composed of hetero polysacchrides, help the bacterium to protect from unfavorable environmental conditions. Swings et al. (1990) reported that the cells of the bacterium were straight rods, 0.5-0.8 × 1.5-2.10µm, gram negative, having one polar flagellum for motility existing either individually or in pairs and sometimes they form chains of filaments.

Physiological characterization: Ishiyama (1922) described that the *X. oryzae* pv *oryzae* is an aerobic, do not use nitrate or methylene blue, not liquefy gelatin, normally digests the milk with coagulation, reddens the litmus milk and do not form gas from sugar. Mucoo and Isaka (1964) studied the *Xoo* isolates from Japan and showed results in contradict with Ishiyama (1922) interpretation. He described that the isolates with high level of pathogenicity normally tend to reveal more concentrated gelatin liquefaction and production of hydrogen sulfide with the digestion of milk. Similar studies were performed with the same results from Philippines and Malaysia isolates (Goto, 1964). Lo and Haung (1964) studied seventy different isolates of the bacterium collected from Thailand and organized them in eleven pathotypes according to their distinctive physiological characteristics. The results of the study were in line with the Ishiyama (1922) and Muco and Isaka (1964). Shekhawat and Srivastav (1968) recorded the differences in the physiological characteristic and the virulence found among isolates collected from India. All isolates were assembled in two different pathovars based on their physiological characteristics and virulence among the tested isolates. Hifni et al. (1975) investigated thirty Japanese and Taiwan isolates to study their physiological characteristics and thus found some differences in their properties including the liquefaction of gelatin. Reddy and Ou (1976) observed that there were no distinguished biochemical groups in a collection of forty different isolates which were collected from nine Asian countries. It was therefore understood that incongruity found in wording might be to the reason of cultural infectivity or differences in experimental methods due to the human error.

Ezuka and Kaku (2000) reported the bacterium as obligate aerobes having the ability to use the carbon

sources by oxidation, showed positive response for catalyase activity but negative for urease on d-xyolse, sucrose, trehalose, d-fructose, d-galtacose, d-cellobise and sodium fumarate, but not on lactose, sarbitol, and dulcitol, guainine, refinol insulin, methanol, ethanol, cytosine, and thiamine. In response of the reaction, acid is produced by many sugars viz., d-glucose, cellobyoles, d-galactose and d-fructosee. Milk of litmus was not acidified yet Esquiline, tween-20 and tween-40 were completely hydrolyzed by the bacterium. Besides this, pathogen growth was limited on the media having (w/v 0.001) tetracycline.

Inshikawa and Maria (2001) described the bacterium as aerobic, ability to digest starch, positively involved in the formation of indole ketogluconate whereas the results of oxydase, urease, nitrate reduction and egg yolk reaction, were found negative among the tested isolates which used the carbon sources as oxidatively not fermentatively. Starch was hydrolyzed after seven days of incubation at 30°C. The best growth of the tested bacterium was observed on solid agar based media with the addition of dezyolze, d-glucose, sodium succinate, trehalose, sodium fumarate, d-fructose, d-necelobise, sucrose, sodium lactate and sodium oxalyate, but the bacterium grew poorly on the solid media supplemented with L-arabonse, D-ribose, L-rahamonse, menthanol, N-propoanoll, ethanedial, mesoinoceitol, lactose, refinose, insulin, sorbitol, dulsitol, adenine, sodium potassium tartrate, sodium Gwolllyxye-2-keto-glutenonic acid, guainine, cytosine, thiamine, tanic acid, hydroxybenzolic acid, hydrocuknon, fluroglucinol, resousinol, arbutinin and ersoculine. Poor growth of the bacterium happens at 6-37°C in the occurrence of 5% sodium chloride, esquline, tween-40 and tween-80.

Cultural characterization

The bacterium causing bacterial leaf blight (*X. oryzae* pv. *oryzae*) can easily be isolated and purified by the ordinary serial dilution method from infected tissue. Wakimoto (1955) reported the most commonly used artificial medium for the multiplication and preservation was purple potato semi synthetic agar medium. Watanab medium was useful for physiological experiments as it proved best for the physiological studies (Watanabe, 1966). Peptone sucrose agar (PSA) medium and the Suwa medium was also found to be the most favorable media for the development of single cell or single colony isolation of the phytopathogenic bacteria (Suwa, 1962). Xos medium was developed for the selective isolation of the pathogen which gave excellent results when the isolation was done from the rice seeds (Di et al., 1991). Tagami and Mizukami (1962) reported that the hydrogen ion concentration (pH) ranged for the good growth of *X. oryzae* pv. *oryzae* was 4.5-7.5 while the best growth of bacterium was obtained at the optimum pH of 6.0-7.0. The temperature range for the good growth of the pathogen was 24-34°C which proved as the optimum temperature and showed ideal growth in watery conditions whereas 53°C was the death temperature for the developing cells on the artificial media.

Watanabe (1963) reported that sucrose was the most beneficial carbon source for the good growth of pathogen followed by mennose, galactose, glucoses, and maltose. The succinic acid was also a best carbon source for the lush growth of pathogen while considering the nitrogen sources, l-glutamic acid was one of the most favorable one followed by l-cysteine.

Watanabe (1975), Naqvi et al. (2016) demonstrated that the best carbon sources were sucrose and glucose followed by mannitol, galactose, fructose and mennoase whereas xylose, starch and lactose were not good carbon sources as the pathogen could not show good growth on these carbon sources. Among the nitrogen sources, ammonium oxalate was the best inorganic compound tested while glutamic acid, aspartic acid, cysteine and methionine were favorable for bacterial growth among acids. Tanaka (1964) reported that the best carbon sources for the bacterial growth were sucrose and glucose after that fructose, manitol, galactose and manose while xylose, lactose and potato starch were the poor carbon sources. The investigations revealed that the bacterium grew well on media (nutrident agar, nutrient sucrose agar, yeast nutrient agar) amended with glucose and sucrose as the major carbon sources. Peptone and sucrose agar medium were found to be best sources for the bacterial growth.

Dye and Lelliott (1974) conducted the experiments to determine the optimum temperature for the growth for *X. oyrzae* pv. *oryzae*, which showed 25-27°C as optimum temperature for the good growth of pathogen while it was observed that the pathogen could grow up to 30°C; whereas absolutely no growth was recorded at 5°C and 40°C. Nishiyana (1977) demonstrated the modified freezing techniques as the

best for the short-term preservation of the pathogen while Isaka (1966) suggested another assay by using the distilled water, column top layered and liquid paraffin to provide a reliable support to maintain the bacterial colonies in its virulent form in the laboratories under strictly controlled conditions. Tsuchiya et al. (1982) recorded the colonies of pathogen of bacterial leaf blight of rice i.e., *X. oryzae* pv. *oryzae* as slightly raised, circular, flattened, convex having a bright yellow color on nutrient agar medium, occuring singly or rarely in aggregates. Gomathi (1991) investigated the various pH levels for the good growth of the bacterium which showed artificial media with the pH of 7.0 sustained the best development of the bacterium while the pathogen failed to grow at the pH of 3.0 to 4.0 and the pH of 9.0 to 10.0.

Thimmegowda (2006) studied the various isolates regarding their cultural and physiological studies, which showed that among the five different isolates tested for their good growth on different solid media; yeast extract glucose agar (YGA) and potato sucrose agar (PSA) supported the excellent growth of the bacterium through maximum recovery of colonies of the bacterium while nutrient agar and beef extract medium were least effective in supporting the good growth of the pathogen.

Suresh et al. (2013) conducted the experiments for the cultural and physiological studies of the tested bacterium i.e., *X. oryzae* which showed beyond the five differential solid media tested for their *in vitro* efficacy for the growth of bacterium, nutrient agar (NA) significantly supported the best development of bacterium which could be observed by the recovery of maximum bacterial colonies. Bacterial colonies were observed to be circular, slightly raised, convex, flattened, with yellow to bright on any medium tested, temperature of 30°C was observed to be optimum for the maximum growth of the pathogen as witnessed by the highest recovery of bacterial colonies (154.33 x 10^5 cfu/ml) and the pH of 7.0 was found optimum for the best growth of the pathogen with the maximum bacterial colonies as compared to the other pH level (159.50 x 10^5 cfu/ml).

In-vivo studies for leaf blight resistance by screening of paddy rice germplasm

Srivastava and Rao (1963) found that among 128 rice varieties tested against mixed inoculmns of five virulent isolates of *X. oryzae* pv. *oryzae*, two *Indica* and eleven *Japonica* type varieties were found resistant against the disease while it was observed that age of rice plant also influenced the severity of bacterial leaf blight disease.

Watanabe (1976) investigated the relationship between the host plant age and the resistance in crop plants to bacterial blight in two rice genotypes. The resistant varieties were more susceptible to the disease at their vegetative stage of growth while the resistance of resistant genotypes increased and exceeded that of susceptible cultivar at the reproductive growth stage of the crop plant. Philip and Devadth (1980) evaluated the resistance of 428 rice genotypes at the nursery and adult plant stages and observed that some genotypes showed resistance against the disease at the adult stage of their life.

Cha et al. (1982) reported from Korea that the higher incidence of bacterial blight was recorded on plants of younger age than on the older ones when they were inoculated with same concentrations of inoculums of *X. oryzae* using clipping method under the same circumstances in the field. Ezuka and Horino (1976) interpreted the type of resistance found in rice crop plants might be called adult plant resistance.

Akhter and Sarwar (1986) surveyed the three provinces of the Pakistan to determine the maximum bacterial blight incidence and severity in all the rice growing areas. The results showed the maximum disease incidence was observed in Punjab followed by Khayber Pakhtoon Khaw and Sindh.

Noda et al. (1989) described that the expressions of adult plant resistance mainly depends not only on the age of crop plants but also on the age of individual leaves. Mew et al. (1979) reported that the lesion length on the leaf blade gradually lessens with the gradual increase in the age of the plant by the inoculation of 40, 60 and 80 days after sowing of the nursery. Akhter et al. (1997) carried out a study during the cropping year to monitor the paddy leaf bligth incidence and its severity in Punjaab, Sindh, Balochijstan, Khyber Pakhtoon khaw and Jammu and Kashmir rice belts to find out disease free area specifically regarding the bacterial leaf blight of rice, however, they reported a serious issue of this disease during the year 2002 and showed maximum disease incidence and severity in Punjab during the rice cropping year 2002-03 due to heavy air stream, rain splashes and storm during the panicle initiation and blossoming.

Kihupi et al. (2001) surveyed the twenty-nine farmer's field in various rice growing areas during the rice cropping season and reported the occurrence of disease after the 45 to 90 days of sowing as per the perceptions of the farmer's vision. Twenty-four rice genotypes and some near isogenic lines were tested against the infection dynamics of bacterial leaf blight of rice at five different locations. The reactions of the near isogenic lines and rice genotypes showed a zonal effect on the severity of the disease. Akhter et al. (2003) determined the sources of resistance in various rice genotypes against the destructive disease of rice i.e., bacterial leaf blight, and found that none of the varieties showed response of resistance towards the virulence of the pathogen. He described that unavailability of resistance in rice germplasm having the typical basmati background was a serious issue to be addressed on the urgent basis as the disease had already posed significant loses to the crop.

Satya et al. (2005a) evaluated five virulent isolates that were collected from various parts of the North Western India against forty-eight aromatic (basmati) genotypes to find out the variability in their virulence and to determine that the response of aromatic genotypes against the tested isolates as they show significant difference in disease progress. Haq et al. (2006) surveyed the two districts of Punjab viz., Gujranwala and Sialkot to determine the incidence of holistic disease of paddy during August, September and October on six cultivars. Maximum incidence of the disease was noted on the Basmati super followed by Basmati 385, Basmati 386, Basmati 2000, basmati Pak and IRRI-6 respectively in both of Districts.

Akhtar and Rafi (2007) determined the virulence of six locally collected *X. oryzae* pv. *oryzae* isolates against six paddy cultivars and found that all basmati varieties were the most susceptible to the disease as compared to the other varieties because lesions of maximum length were observed on all basmati cultivars which had already shown a susceptible response against the disease in many research experiments. Muneer (2007) screened seventy-eight genotypes of rice against a big collection of seventy-eight (78) locally collected isolates of the pathogen from various locations and found none of rice variety was resistant against the virulence of isolates. All the isolates showed virulent response against the disease except the few which failed to produce the characteristic symptoms of the disease on tested cultivars. Khan et al. (2009) screened a total of fifty (50) rice genetic resources against the destructive disease of rice in 2003-04, 2004-05, 2005-06, 2006-07 and found that during all four rice cropping seasons none of the variety was found to be resistant against the disease and showed susceptible to highly susceptible response which is an indication for future that pathogen has broken all the resistance in all varieties, so the disease might be disastrous in coming years if proper management strategies could not be adopted.

Khan et al. (2009) evaluated forty-two rice genetic resources under the field conditions against the *X. oryzae* pv. *oryzae* and found that none of the entries showed resistance against the virulence of the pathogen. Maximum disease incidence of 80% was observed in Sheikupura followed by Mureed ke with 70% disease incidence. Manan et al. (2009) screened a total of twelve rice genetic resources against the virulence of fifty-two locally collected isolates of the bacterium and observed that any single tested line was not found to be resistant against all the virulent isolates of the pathogen occurring in Pakistan and they might become a serious threat for the rice industry in the coming years. Thimmegowda (2006) screened seventy one rice genotypes under the natural epiphytotic conditions, results of the study showed none of the variety to be resistant towards the disease, while some paddy varieties namely Ajaya, TKN-6 and IRRI-8 were established as resistant whereas only some varieties were moderately resistant in their response, some were found moderately susceptible, some were susceptible and fifteen found to be extremely susceptible against the disease in response of their resistance. Shehzad et al. (2012) evaluated twenty (20) commercial rice varieties along with the susceptible check of basmati super and IRRI-24, against the devastating disease of paddy rice under the inoculated conditions and found some of the local varieties to be moderately resistant against the disease. In famous basmati varieties, a varietal response ranged from moderately resistant for Kashmir basmati to highly resistant for the super basmati variety. Although basmati varieties were found good yielding cultivars, yet they were found to be the most susceptible genotypes against the devastating bacterial disease.

Jabeen (2011) and Naqvi et al. (2015) evaluated highly virulent bacterial isolates selected after a series of nine biochemical tests, collected from all over the Pakistan from rice growing zones, against

the eight commercially available rice genotypes. The results showed that out of the eight tested varieties all the basmati cultivars were highly susceptible to susceptible to the disease while the others showed the moderately resistant response against the tested isolates. Sharma and Poon et al. (1977) evaluated a total of thirty rice genotypes against the bacterial leaf blight under inoculated conditions which showed that two varieties i.e., Nigeria 5, AC 19-1-1, were found to be resistant against the bacterial leaf blight disease while few were moderately resistant, and some were found to be susceptible against the disease.

Rafi et al. (2013) surveyed all rice growing zones in Pakistan and showed the highest disease incidence was recorded in Khayber Pakhtoon khaw with 36-80.2% followed by 37.6- 74.6, 12.67- 46.68 and 13.21%, respectively in Punjab, Sindh and Balouchistan during the cropping season in 2005-2007.

Estimation of phenolic contents

Retig and Chet (1974) observed that the phenolic contents increased when catechol was applied to the tomato plants under *in vitro* conditions which resulted in the suppression of symptoms caused by *F. oxysporum* f. sp. *lycopersici*. Blodgett and Stanosa (1997) studied the changes in phenolics compounds resulting from water stress and colonization by *Sphareopics sapinea* in a growth chamber on the tree parts which showed that the parts inoculated with the fungi produced more severe symptoms and showed higher concentration of phenolic compounds as compared to the control. The results of the field experiments showed the increased phenolic contents in shoots of stressed trees inoculated with isolates of the *S. sapinea* and concluded that increase in phenolics contents was clear to be involved in response to infection by the *S. sapinea*.

Dapkevicius et al. (1998) determined the phenolic compounds in some almond hybrids varying in resistance to *Pseudomonas amygedalil*, healthy young leaves were analyzed, which showed higher phenolic contents in resistance and susceptible almond hybrids after artificial inoculation with *P. amygedalil*. Sedlarova and Lebeda (2001) reported that the intensive and rapid accumulation of autofloresent phenolics with the onset of hypersensitive resistance was the main cytological feature of resistance to lettuce downy mildew in *lactusa* spp. Meena et al. (2013) studied the infection dynamics of groundnut plant after inoculation with *Cercosporidium personatum* which resulted in the increase in phenolics contents after accumulation of the pathogen at the inoculation sites. The accumulation of the phenolics contents in plants at the site of infection happens due to the host-pathogen interactions (Garden et al., 1978).

Tiaz and Zeigar (2002) reported plants were able to synthesize secondary metabolites, which include phenolics, fluavinides, lignin, and tannins that play important role in reduction of disease severity. Wahid and Ghazanfar (2006) described that pheonlics and flavonoids were among the most frequent and widely distributed secondary metabolites in the resistance against different types of pathogens. Gorinsteina et al. (2004) conducted a study on the comparison of the main secondary metabolites and their antioxidant activity in white grapefruit and its new hybrid regarding yield potential. The total phenolic contents were estimated by the Folin-Ciocaltu reagent assay and the antioxidant activity was evaluated which revealed a higher concentration of total phenolic contents in those varieties with the higher antioxidant properties. The fruits containing a relatively higher concentration of natural secondary metabolites do not show higher antioxidant activity until or unless a pathogen attacks the crop plants.

Plank (1960) described that citrus peel rich in flavanon, glycosides, and polymethoxy flavons. The results of studies showed that higher concentration of phenol contents was observed in those varieties, which showed higher incidence of the disease severity on citrus fruit.

Agrios (2005) reported that many scientists have worked on the role of phenolics in relation to resistance in plants and showed certain phoenolic compounds which proved themselves toxic against the diversity of pathogens; produced and accumulated at faster rate after infection especially in resistant varieties. Abid et al. (2008) screened fifteen varieties of citrus to find out the resistant resources against citrus canker disease instigated by *X. axonopodis* pv. *citri*. Results showed that resistant varieties viz., Succari, tangaring and jafa showed the higher concentration of phenolics than the sucesptible varieties. There was higher accumulation of phenolics contents in the leaves of those varieties, which showed relatively less disease. The resistant varieties produced more phenolics than the sucesptible varieties and phenolics played an important role in resistance in citrus against the

citrus canker. Results showed that the accumulation of phenolics in the leaves of eight varieties increased significantly with the increase in disease incidence.

Sawaddiwong et al. (2008) investigated the total phenolics contents along with their antioxidant activities in *O. sativa* under the inoculated condition with *X. oryzae* pv. *oryzae* in field. This was very much obvious that seeds of rice grown well when soaked under water at 27°C and showed maximum phenolics contents with their antioxidant properties which were found out by DPPH and ABTS-radical scavenging action.

Koca and Karadeniz (2009) described flavonoids are known for their antioxidant qualities, very little is known on how various flavonoids are distributed in crop plants and how they distribute among plants relates to the tissue's antioxidant potential especially in black berry and blue berry fruits normally grown in black sea region in Turkey. Vichapong et al. (2010) determined the phenolic compounds in rice varieties after the inoculation with the tested bacterium (*X. oryzae* pv. *oryzae*) in greenhouse, results of the study showed higher concentration of phenolic compounds in resistant varieties while less concentration of phenolics was calculated in susceptible varieties.

Management of bacterial leaf blight of rice

The devastating disease of paddy rice can be managed significantly through adopting some sanitary measures, using resistant varieties, application of chemical and by the biological control tactics.

Cultural control

Tabei (1960, 1967) described that cultural practices are normally the use of healthy seeds, removal of diseased stubbles, straw and weeds from the field, by keeping the nursery beds above from the water level, by the avoidance of excess application of (NPK) nitrogenous compounds, using modern irrigation system and by making the drainage systems as better as recommended.

Physical control

Srivastava and Rao (1963, 1964) reported the 95 to 100% eradication of the bacterial blight pathosystem was attained in rice seeds by twelve hours soaking in 0.07% solution of agrimycin then moving seeds into water bath at 54°C for a time of 30 half an hour which gave better results as compared to the control treatment.

Jain (1970) reported that physical control is normally being used for the seed disinfection before the nursery sowing e.g., hot water treatment of rice seeds for about 30 minutes at 52°C proceeded by 8-10 hour of presoaking in water which was found to be the most effective against the bacterial leaf blight of rice.

Zhang et al. (1996) reported that two to three washing of paddy seeds in distilled water after that cleaning either by the brine solution also minimized the bacterial leaf blight disease frequency and enhances the germination percentage of the crop. The presoaking of paddy seed in 50 ppm suspension of zhonheshengmycin also minimized bacterial leaf blight disease severity during the field experiment. Haq et al. (2006) also determined the effectiveness after paddy seed washing to minimize the frequency of deadly pathosystems of rice. Several seven varying actions viz., seed at farmer filed, clean seed, unnecessary seed, washed seed of farmer with water, paddy seed washed through 15% water suspension were evaluated in the experiment which showed that the washed seeds with simple distilled water or by the brine solution significantly reduced the bacterial leaf blight incidence in the field.

Chemical management

Wakimoto (1962a) described that management of bacterial disease through the chemistries or the antibiotics is considered one of the most significant counter measures hostile to the disease. Basically, the evaluation of chemistries towards the control of bacterial leaf blight was initiated with the zone of inhibition technique. Although the fact was clear later on that the results of laboratory experiments performed in controlled conditions could never in line through the field researchs (Kakei et al., 1960; Kido et al., 1953; Wakimoto, 1962a; Yoneyama et al., 1969).

Yamanuki et al. (1962) reported that at the initial stages of the development of the devastating disease of paddy rice, four to five subsequent applications with Bordeaux mixture revealed a curatic result but fungicidal chemistry proved toxic to paddy rice plants when tested after the experiment (Kuwattsuka, 1944; Hori, 1973). Padmananbhan and Jain (1966) observed that the positive control of bacterial leaf blight disease was attained by the application of chlorine and reported that a serious foliar damage occurred by the increasing toxicity due to the subsequent application of chlorine which significantly reduced the yield

potential of the crop (Palaniswami and Ahmed, 1979).

Jain (1970) recorded the antibiotic drug namely Agrimycin 100, teramycine and streptomycin sulphate showed moderate or lower degree management of bacterial leaf blight through various spraying on the plants of varying age in different conditions whereas no significant results were obtained by the treatments in India (Devadth and Dath, 1970). Hori (1973) first time introduced the chemical fungicide namely dithionone from Germany for the control of paddy devastating disease by testing its efficacy under *in vitro* and field conditions. Besides dithionone, nickel dimethyl dithiocarbamate also significantly reduced the disease severity of this holistic disease in many countries particularly reported from India and Taiwan (Jain, 1970; Lee, 1975; Mukherje et al., 1976). Chand et al. (1979) reported that the application of sodium hypochlorite powder to the stagnant water at the rate of 20 ppm chlorine could significantly minimize the disease in the field conditions while the systematic chlorination of the stagnant water in the paddy rice fields with 30% chlorine using the 2-ppm sodium hypochlorite powder greatly reduced the frequency of the devastating paddy rice disease in the field. Tanaka et al. (1984) reported that the fungicidal and bactericidal chemistries described so far were found to be effective for the control of bacterial leaf blight disease somewhat, yet the effectiveness was observed to be imperfect. A new fungicidal chemistry 2-amino, 3, 4-thiadiazole reveled better efficacy against tested bacterium (Yakushiji and Wakes, 1971; Nishimura et al., 1971; Nakanishi et al., 1972; Hori, 1973; Krishnappa and Singh, 1977).

Biological control

It is very much clear that all the fungicidal chemistries have the adverse effects on the ecosystem as well as on the farmers and consumers health, that's why control of crop plant diseases through bio control agents and naturally occurring plant extracts has become a need of time and being investigated in the recent era.

Hsieh and Buddenhagen (1974) described that the inoculated plants remained healthy and could not produce the characteristic symptoms of the disease when they were inoculated with the tested bacterium along with *Erwinia herbicola* as bio agent. Poon et al. (1977) described that the artificial inoculation of endophytic bacteria along with the *X. oryzae* significantly control the development of disease symptoms of the disease in the control conditions as compared to the individual or various other populations of the bacteria either they were saprophytic or the antagonists in nature. Sands and Melntyre (1977) studied the efficiency of tartrate and nitrate (1000 mM, pH 3.5) aqueous solutions to test their antimicrobial activities. Results showed that the consecutive applications of these solutions have a good bactericidal effect on the disease and retarded the development of symptoms along with the lesions on leaves of cowpea produced under the stress of *P. syrgine*. Phillips and Devadth (1980) observed the antagonistic effect of two fungal species viz., *Penicillium* and *Aspergillus*, while conducting a study on various rice cultivars and concluded that the phyloplane mycoflora were found to be the antagonists against the bacterial blight disease.

Anuratha and Gnanamanickam (1987) observed that the roots of the rice plants possessed different isolates of the *P. fluroresense* which possessed the antagonistic activity against the disease. They isolated the various strains of the *P. fluroresense* and studied their antagonistic activity against the *X. oryzae* under *in vitro* conditions; *P. floresence* strains significantly controlled the growth of tested bacterium. Similarly, when they sow rice seeds after a presoaking treatment in the suspension of *P. fluroresense,* which provided a coating on the deed coat. After the seedling emergence they were sprayed with the *P. floresence* again and finally inoculated with the tested bacterium using the clipping method, this treatment considerably reduces the severity of the paddy bacterial blight in comparison with the non-treated control. Sakthivel and Mew et al. (1993) conducted a study after the collection of 150 strains of *X. oryzae* to find out the production of bacteriocin next to various pointer isolates of the bacterium. A further study was conducted for the ratio of bacteriocin production among the isolates and to generate the nonpathogenic bacteria through the genetic change by repeated sub culturing and mutagenesis. Treatments with nonpathogenic bacteriocin generating bacteria showed significant reduction for the control of paddy blight frequency 32-100% in screen house and 12-75% in green house.

Liu and Wang (1998) reported that several Chinese researchers performed an experiment in greenhouse and under *in vivo* conditions for the control of paddy blight using a virulent strain of the bacterium i.e., Du 728 strains. First application of the Du 728 with

(10^5 cfu/ mL) suspension significantly controlled the disease upto 50%. Similarly, the control efficiency increased up to 60% when the mutant Du-728, was used in combination with salicylic acid (12 mg/ mL). Likewise, in the *in vivo* studies similar effect of the disease suppression was attained up to 70% when three applications of the suspensions were performed after the one-week interval.

Biocontrol with plant botanicals

Biological management of diseases of plants with the botanicals extract is best because of their nature as easily biodegradable having ecofriendly activities. Bio chemical properties of crude plant extracts have been studied and reported by many research scientists that the plant botanicals possess antimicrobial activities next to the diseases occurred on crop plants under the stress caused by many bacteria, fungi, nematodes, insect pests and many viruses. This fact has now been established by many studies performed under *in vitro* and field conditions that the plant botanicals have their impact for the reduction of plant diseases. Heavy brain storming of the literature on agricultural plant disease management cleared the reality that enough data is present on management of crop plants disorders with botanicals, yet a little work equal to none is found on the biological management of bacterial blight pathosystem of rice. The extracts of different plant species showed excellent efficacy against fungal disease. Different plant parts containing higher concentration of antifungal compounds; which inhibit the growth of fungi. Garden et al. (1978) assessed different plant botanicals against the control of bacterial blight pathosystem under *in-vitro* experiment. Investigations showed all the plant extracts controlled the pathogenic bacterium significantly at different concentrations. Photochemical and TLC analysis showed the presence of terpinoids, flavonoids, coumarine, tannin, saponin, and lignin as the active pinriciple ingredients of the plant extracts.

Bhatt and Saksina (1980) investigated the extracts of seeds of *Albizzia amara, Ipomea purpurea* and *Derrus robusta* by using various aqueous, ethanolic, methanolic and ether solvents to determine their efficiency next to plant and human pathogens. Results showed that the plants extract as good antimicrobial agents against the pathogenic bacteria. Mukharjee and Biswa (1981) evaluated twenty-five different plant botanicals against the two bacterial pathogens viz., *E. carovotaora* and *X. compaestris oryzae* pv. *oryzae* at the rate of varying concentrations under an *in vitro* experiment. All the tested botanicals showed higher efficacy against the tested botanicals. Besides this the extracted plant oil from all the plant botanicals powder to test against some fungal and bacterial pathogens showed significant effect for the suppression of disease. Tiwari and Dath (1984) reported the leaf extract media of 23 plants favored sporulation/ sclerotial production of *Pyrecularia oryzae* and *Corticium saski*. One or more pathogens could not grow in the leaf extracts media of *Ocimum sansetum*, *Lawsonia inerimis* and *Piperbetel*, which showed botanicals extracts having the strong antifungal activity. Rafiq et al. (1984) studied the aqueous botanicals extracts of *Anagallis arvensis* which significantly retarded the actions of *Helminthosporium turcicum*, *H. carbonum, H. maydes and H. oryzae*, under *in vitro* experiments, whereas the extracts stem parts of *A. arvensis* proved a higher antimicrobial and antifungal activity towards *H. oryzae* under the controlled conditions. While, none of plants extracts, revealed the antimicrobial actions towards *Alternaria brassica* and *A. linea*.

Tanaka et al. (1984) reported *in-vitro* antimicrobial and antifungal activities of some *Sternbergia* species. All the ethanolic extracts of *Sternbergia* species and lycorine, which were isolated from these species showed antimicrobial activities under *in vitro* conditions against gram-positive *Staphyloncus aurueus*, *Staphyloccus facelis* and gram-negative *E. coli* and *P. aeuroyginosa*) bacteria and fungus *Candida albucians* with micro dilution broth metal. Ark et al. (1986) investigated the antibacterial and antifungal activities of alcoholic plant extracts of barley and wheat seeds which significantly checked the growth of the tested bacterium. They also evaluated the plant extracts of 65 species of the 34 families against the fourteen different phyto pathogenic bacteria which showed good antibacterial activities against all the tested bacterium. Rode et al. (1989) studied some of the potential botanical extracts in different solvents of *Allium ampeloprasum* and *A. sativum* under *in vitro* conditions against some phytopathogenic bacteria and fungi which showed significantly higher results as compared to the un-treated control as these extracts have already been used and showed antimicrobial sensitivity for the control of many human as well as plant diseases. Bensal and Sobiti (1990) recommended that the *Azadirachta indica* (Neem) extracts from the various parts of the plants found to be an inexpensive and easily available remedy for the management in various

diseases of crop plants because the neem extracts possessed the strong antimicrobial and antifungal activities against the various pathosystems. Treatment of neem leaf extracts found to lessen the frequency of groundnut disease caused by *Aspergillus niger* upto 2.88% under the *in vitro* conditions. Anila et al. (1991) treated the opium seeds in *A. indica* leaf extracts by soaking overnight, which proved significant results by enhancing the germination percentage of the seeds upto 76% and avoiding the wilt diseases caused by *Pythium* and *Phytophthora* species. They also found that the oil cakes of *Ponogamia galabara* and *A. indica* were also very effective for the control of opium poppy mildew. Hughes and Lawson (1991) also extracted plant oil from *Corriandum sativum, Elacis*, *Sapiandus* specie and *Tara aketogeno* dried seeds successfully which significantly protected the plants from their respective pathogen with a varying degree. Tubers of the plants were also protected due to the subsequent application of the oil of *Madhiuca indica* along with *Symbopogan* sp. Similarly, it has also been reported that plant extracts of some other available plant botanicals viz., *C. equistifloia* and *C. sativum*, and *Piper betlea* were found to be quite successful under the field conditions as well. Kazmi et al. (1991) used different plant extracts for controlling the growth of *Rhizoctonia solani* and found aqueous extracts of neem seeds, 30% neem and garlic bulb 4% showed antifungal activity whereas neem oil at 0.1% was found more effective against tested fungi than benomil.

Ali et al. (1992) tested three neem products viz. neem oil, neem leaf extracts, neem pericarp dust, and two mould inhibitors, Teco-60 and boric acid were evaluated in-vitro at 0.4, 0.6, 0.8% concentration against post-harvest fruit rotting fungi of tomato viz., *P. italium*, *A. alternata*, and *A. niger*. All the neem products except neem oil were less effective as compared to Tacto 60 in checking the growth of these fungi. Daffy et al. (1995) reported an aqueous preparation of leaves extract of *Reynoutria sachalinensis*, (giant knot weed) applied after seven days interval at the concentration of 15% provided control of *Sphearotheca fuligine*, a cause of powdery mildew on English cucumber as effective as benomyl. Datar (1995) showed neem leaf extract to be effective against six fungal species, *Curvalaria lunata*, *A. tenuis*, *Fusraium* sp., *Sclerotium rolfschi*, *Macrophamina phaseolina*, and *Elsinoamblina*. After four days of inoculation, maximum inhibition of 45.1% was found in *Alternaria tinuis*.

Akhtar *et al*. (1997) studied the *in vitro* efficacy of 208 plant decoctions in different solvents using the agar diffusion technique to find out the better efficacy of decoctions against *X. campestris* pv. *citri*. Results showed that diffusates of plant viz., *Accacia nilotica, Terminalia cheeblua, Phyllantus embilica,* and *Spindur mukororri* were found to be significantly effective against the tested bacterium. The plant diffusates were collected from various sources viz., spices, food legumes, vegetables, forest trees, shrubs, fruit trees, fodder, herbs and oil seeds. Leksoombon et al. (1998) evaluated the different aqueous and solvent extracts of two hundred species of the plants which were gathered from different locations against many phytopathogenic bacteria. Results showed that among all the extracts few were found to be effective against the growth inhibition of pathogenic bacteria.

John and James (1999) investigated various commercially available plant botanical formulations and essential oils to fumigate the soil for the proper management of *F. oxysporum* in soil and greenhouse conditions. They used different combinations for the treatment of soil from aqueous formulation of 90% neem oil + 70% clove oil, similarly 90% neem oil + 50% pepper/ mustard oil in a separate experiment which showed significant response for the suppression of fungal growth under *in vitro* experiment and observed treatments with significant differences. Hence, proposed that due to the healthy crop stand after subsequent applications of the different formulations of plant extracts oils in green house and substantial decrease in the inoculums level revealed that plant botanicals as well as oils of the botanicals powder could perform well in bio control-based strategies for the management of holistic pathogens of the crop plants. Kagle et al. (2004) described antibacterial activity of various plant extracts for the management of bacterial leaf blight disease under *in-vitro* conditions. All the extracts showed promising results for the control of bacterial growth under *in-vitro* conditions, which significantly controlled the growth of bacterial colonies. Seed treatment with *A. indica* was most effective in reducing the disease incidence as compared to the control. Kumar (2006) evaluated ten medicinal botanicals extracts against the major pathogens of rice crop viz, *X. oryzae* pv. *oryzae, H. oryzae* and *P. oryzae*, which showed *Eucalyptus citrodora* (Safeda) and *Mentha piperita* to control all the holistic pathogens of the rice crop and particularly inhibited the bacterial growth significantly under *in-vitro* conditions (Naqvi et al., 2018). Wilson et al. (1967) evaluated sixty-five different medicinal

plants species against the conidial germination of *A. brassiciola*, among them thirty-nine plant extracts showed substantial inhibition against the germination of conidia of the pathogen. The extraordinary results were attained among all the extracts used in the experiment from *P. perfoliatum* (speed weed). The zone of inhibition attained from all the plant extracts significantly influenced the treatment of anion exchange, while it was incompletely decreased by the cations exchange which showed the existence of such substances having a strong inhibitory effect on the plant pathogens.

Lgbinosa et al. (2009) investigated the activity of ethanolic, methanolic and aqueous extracts of the bark of *Jatropha curcus* under *in vitro* conditions to determine the antifungal and antibacterial activity against some phytopathogenic bacteria and fungi. All the extracts of the *J. curcus* significantly controlled the fungal and bacterial growth under *in vitro* trail and proved this bio fuel plant to have antimicrobial properties and could be utilized in the biological based management system of the crop plants.

Lalitha et al. (2010) evaluated aqueous and solvent extracts of *Solanum torvurm* leaves for antimicrobial activity under *in-vitro* condition against some important seed borne pathogens of rice. Aqueous extracts of leaves of *S. torvurm* at 25% concentration showed best inhibition of the test pathogen especially for *X. oyrzae* pv. *oryzae* and *Bipolaris oryzae*. Khalil (2001) determined the effect of twenty-five botanicals extracts on vegetative growth and germination of spores of two plant pathogenic terrestrial species viz., *Saprolegniea parasitica* and *A. solani*. *Euginia aromatica* extracts completely retarded the germinating spores of *A. solani and* showed significant growth reduction of the fungal mycelium. Besides the *E. aromatic,* botanicals extract of *E. rosterta, Capsicum frustesens* and *Alium cepa* also showed outstanding effect on both fungi under *in vitro* conditions. Jabeen (2011) evaluated the antibacterial potential of 25 species of various indigenous curative plants using the disc diffusion technique against the devastating pathosystem of bacterial blight of rice, out of the 25 medicinal plants, *Amomum subuladum*, *T. chebula*, *A. indica, Anethum graveolens* decoction revealed considerable action. Effectiveness of the plant extracts of six outstanding plants were tested again by the glasshouse, field and detached leaf assays. The plant extracts of *T. chibula* proved the significant response for the control of bacterial leaf blight under *in vitro* and *in vivo* conditions. Jabeen (2011a) investigated different diffusates of various plant species in hot water to check their antifungal and antimicrobial activities against the virulent strain of *X. oyzae,* which is a holistic pathosystem for the paddy blight. Seven plant species viz. *Linum usitatissimum*, *Mangifera indica, Citrus lemon*, *T. indica*, *P. domestica, C. longa* and *T. arjuna* performed well against the bacterium by significantly suppressing its growth under *in vitro* conditions.

Govindapa et al. (2011) investigated five plant botanicals to manage the bacterial blight pathosystem under *in-vitro* environment; efficacies of botanicals were determined by antibacterial activity performing the seed treatment and knowing enhancement of germination of seeds and seed vigor. *A. indica* leaf extracts significantly controlled the bacterial leaf blight under controlled condition. Treatment of seeds also proved very effective in the reduction of incidence of disease in field conditions. The investigations showed that the leaf extract of *A. indica* have the potential to initiate the accumulation of host plant defense enzymes, that might belong with the stimulation of resistance in the crop plants. Kavitha and Satish (2011) screened nine medicinal plants viz., *A. nilotica*, *Carum copticum*, *Acorus calumus*, *Eupatorium odaritum*, *Emblicka ofcinalis*, *Hyptis suaveolens*, *Ocimium graticium*, *Pedalium muras*, *Millingtonnia hortensis* for their antimicrobial activity against important plant pathogenic bacteria such that *X. compastresis* pv. *vesicatoria*, *X. axonopodis* pv. *malvacearum*, *X. oryzae* pv. *oryzae* and *E. cartovora*, results showed that methanol extracts of *E. oficsenalis*, *A. nilotica* and *C. copticum* significantly controlled the bacterial growth under *in-vitro* conditions.

Bhatt and Saxena (2012) investigated the antimicrobial activity of *Ocimum sanctum* (tulsi), methanolic extracts against various strains of gram-positive and gram-negative bacteria. The results of the plant extracts showed excellent antifungal and antibacterial activities next to three species of bacteria viz., *B. subtilis* (Gram+ bacteria) and *E. coli* (Gram-) as well as against *X. oryzae* pv.*oryzae* which is also a phytopathogenic bacterium. Meena et al. (2013) investigated different plant extracts against paddy bacterial blight under *in vitro* conditions. Results showed datura metal to produce significant reduction in bacterial blight severity either used singly or in combination with other plants extracts.

Epidemiological factors conducive for the development of bacterial leaf blight of rice

Maruyama (1908) described that the topographic and changing climatic conditions greatly influenced the development of the disease severity and incidence. The causal bacterium of the disease was severely affected by the discrete sunshine hours during rice cropping season and excess of dryness. It has been reported that paddy bacterial blight is normally present within those areas having monthly rainfall of 220mm while the optimum temperature for the development of disease is 25-30°C. Besides such environmental conditions soil type also favored the development of disease such that acidic soils are assumed to be the important factor enhancing the disease severity during the early days of rice crop. Kuwazaku (1942) examined the prevalence of disease in those areas where the annual mean temperature during the month of July was more than 24°C and the annual rainfall during the month of July was more than 210mm, both the conditions favored the development of disease and significant correlation was observed between the development of disease with the two most important environmental factors i.e., wind and rainfall during June to September 1948 to 1953 in accordance with the climatic information gathered.

Goto et al. (1955) suggested after a series of experiments that favorable environmental conditions for the development of bacterial blight were high temperature during August till September and humid autumn were found to be best suited regarding the disease epidemic development. It was also generally considered that a little sunshine after the heavy rain fall along with the robust winds during the months of May to August particularly augmented the development of bacterial blight. Muco et al. (1957) described that climatic conditions greatly influenced the development of bacterial blight disease of rice. The promising factors for the development of epidemic were high relative humidity, rainfall, temperature, typhoons and strong winds through paddy development season. Fujikawa et al. (1957) described that a significant correlation was found among the high temperature, relative humidity of the morning for the development of disease and particularly highlighted the role of heavy rainfall and typhoons followed by the few hours of sun shine strongly favored the development of disease in the rice growing areas. Van Derplang (1960) developed the first temporal model for the epidemic progress and has since provided the fundamentals for the modeling of crop plant diseases (Campbell and Madden, 1990; McCartney, 1997; Naqvi et al., 2016). The plant pathologists generally have the same opinion that environment is the diverting power for epidemics development of disease (Rabbing and Bastiaans, 1989; Hardwick, 1998). All the environmental variables such that temperature, relative humidity, rainfall, wind speed and sun shine hours have been considered effective for the development of different crop plants disease epidemics in different seasons as the wind speed and high rainfall favored the dispersal of pathogens, high relative humidity supplied excess moisture at the host plant surface to favors the sporulation of most plant pathogens to infect the crop plants similarly sunshine provided favourable temperature for the successful development of disease (Ingold, 1971; Lacey, 1996; Francl and Panigrahi, 1997; Walters and Hardwick, 2000).

Yoshimura (1963) suggested that the average minimum temperature of 24°C during the month of September appeared to increase the epidemic development of disease under the high population of inoculums in the field. A ruthless wind along with the typhoons severely accelerated the disease development if a high population of bacterium was available in the field. Hence, these plant extracts were found to be very effective with different application methods under *in-vitro* and *in-vivo* conditions for the control of various bacterial strains which are specifically phytopathogenic. Different concentrations of these botanicals were evaluated and found to be very effective in suppressing the pathogens under and the disease severity. So, these plant extracts can be applied on the various standing field crops for the control of diseases particularly the bacterial leaf blight of rice. It is concluded from the research reviewed that these plant extracts can be applied for the control of bacterial leaf blight of rice.

Conclusions and Recommendations

It is evident from the present literature that bacterial leaf blight pathogen has become a devastating disease in rice growing areas of Pakistan. No variety has been reported to be resistant against the disease. Regarding the management of disease, plant extracts revealed an encouraging level of efficacy against the bacterial leaf blight disease under *in-vitro* and in field conditions. The higher efficacy of these plant extracts against the disease confirmed the plant extracts to be a better alternate in place of bactericides. In this

concern, formulations of various plant extracts which are environment friendly may play a positive role to check the disease.

Taking into considerations the above review, the following recommendations are forwarded: The farmer's community should avoid the mono cropping of rice and prefer the multi cropping system to cope with epidemics and severe losses in terms of yield. An integrated management approach could be developed to minimize the losses to the crop by the holistic disease. It is suggested that the use of plant extracts rather than synthetic chemicals against the disease which will surely help in reducing the severity of disease and will improve the rice production. The active ingredients of the plant extracts should be determined for the development of effective bio products.

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Authors Contribution

Conceived the idea, wrote abstract, article and overall management of the article.

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