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Recent Advances on Coffee Leaf Rust

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Abstract

Coffee Leaf Rust (CLR) is a major constraint for coffee production in the world. Ever since its first outbreak as the famine of coffee in Ceylon, CLR has already been recorded in Lake Victoria of Kenya. Till date, more than forty five races of Hemileia vastatrix, the fungus causing CLR disease, have been identified. Nine CLR resistance genes (S_H1 to S_H9), conferring either independently or jointly, are also been traced in different coffee species. However, the breakdown of host-plant resistance vis-à-vis evolving new races of the pathogen, development of durable CLR resistant varieties without deterring their taste attributes under organic farming condition remained as the biggest challenge in coffee growing nations like Nepal. This review tries to uncover the overall history, setbacks, research progresses and achievements in CLR all around the globe.

Keywords: Physiological Races, CLR Resistance, Coffee Varieties

Introduction

Coffea genus belongs to *Rubiaceae* family. It has over 500 different genus and 6,000 species. *Coffea* genus is originated from the African country, Ethopia. During 15th century, it was distributed by Yemen traders all over the world. In Nepal, it was introduced by Monk Hira Giri in 1938. In 1968, His Majesty of Government extended its cultivation by importing seeds from India. The plantation was significantly expanded in mid hills of Nepal after the establishment of Nepal Coffee Company in 1983. Coffee Development Centre was established in 1984 under Department of Agriculture at Aapchaur of Gulmi District. In 1993, National Tea and Coffee Development Board established as government apex body under Ministry of Agriculture with the aim to facilitate and coordinate on production, marketing and policy related issues.

The first description of a coffee plant was done in 1592 by Prospero Alpini. A century later Antoine de Jussieu (1713) denominated the plant as *Jasminum arabicanum*. Later on Linnaeus (1737) classified it as a separate genus *Coffea*. At that time only one species *C. Arabica* was known. It is a tetraploid (has 44 chromosomes), that derives from ancient forms of two diploid species: *Coffea eugenioides* (22 chromosomes), likely as the maternal progenitor, and *C. canephora* (22 chromosomes), as the paternal progenitor. *C. arabica*, *C. canephora*, *C. eugenioides*, *C. liberica* and *C. excelsa* are major *Coffea* species.

On an experience of farmers, research by scientist and on extension of coffee species and appropriate technology throughout the world, out of four, only two species are commercially adapted worldwide due to its high production, good quality and appropriate growth habits. The species *Coffea canephora* (Robusta) is grown in lowlands while the most cultivated species, *Coffea arabica* is for highlands and recognized as highland specialty

coffee. Arabica species occupies area of cultivation with 75-80% of worlds coffee production (Coffee Research Institute, 2012). Coffee is considered as cash generative crop and provides direct employment to number of workers. It does well on hillside farms where other cash crops are not easily grown.

Coffee is one of the most important plantation crops of Nepal. It is grown at an altitude of 800 to 1800masl, specifically in mid hill region of Nepal. Organic coffee of Nepal is an exportable commodity and fetch good price in international market. Though there are lots of opportunities in coffee business, some constraints at production, marketing and consumer level is still prevailing. Infection of coffee leaf rust, coffee berry disease, Coffee wilt, infestation of white stem borer, lack of suitable varieties for varied agro-climatic zone, improved package of practices, low farm gate price (Price gap) are some major constraint leading meager increase in productivity standing almost constant. Lack of knowledge on after harvest technology is another part. Furthermore, lack of physical infrastructure like coffee collection centre, processing plant as well marketing strategies at local level are additional. With the purpose to mitigate or to provide relevant solution regarding these problems, Coffee Research Program was established in Gulmi district under Nepal Agriculture Research Council. The program has started number of research activities on varieties, appropriate technology generation, postharvest technology and on different aspect from the time of its establishment. In present context coffee leaf rust, a major fungal disease is being a serious threat in Nepal. Its first outbreak has been occurred in 2015 from the district, Lalitpur in Nepal (Upadhya *et al.*, 2016) and then spreading takes place in most of the major coffee producing district like Syangja, Palpa, Makawanpur, Kavre. Till date ten districts in mid hills has been infected. This disease could be a major threat for coffee stakeholder if any preventive control measures will not applied in time. However, high cost of fungicide and importance of organic coffee from nutritional and health point of view, coffee improvement program is being conducted to explore and develop resistance against coffee leaf rust. Considering situation and being based on international CLR research results, reports and article publication, this review has been done. It has clear and defined information on history, viability of the pathogen, races of the pathogen and resistance against coffee leaf rust.

History and Symptomatology

Coffee leaf rust was first mentioned by British explorer in 1861 in Lake Victoria of Kenya of east Africa. It was first recorded in cultivated trees in Srilanka in 1869 (Wellman, 1957). Thereafter, it spread out to many other Asian countries. By 1920 most of the countries in central and east Africa recorded the diseases. In the western hemisphere, coffee rust was first reported from Brazil in 1970. It quickly spread to most of the South and Central American countries. Till 1986, it was reported from Paraguay and Argentina, Nicaragua, Bolivia, Peru and El Salvador, Guatemala and Honduras, Mexico and Ecuador, Colombia and Costa Rica, Venezuela, and Cuba and Jamaica. Now it

is well established in all the major coffee growing countries in Latin America, and countries in the west.

Coffee leaf rust caused by *Hemileia vastatrix* is an obligate parasite having complex life cycle and ingenious one. The organisms asexually produce thousands of tiny spores (reproductive bodies). These spores can travel in water, rain, air and remain viable for long distances (Kushalappa and Eskes, 1989; Gouveia *et al.*, 2005). It can travel even from one continent to another and it mainly occurs through wind current. Once a spore lands on a leaf, it can stand until conditions are right. When the condition becomes favorable, it germinates and enters into leaves through stomata (Muller *et al.*, 2009).

Coffee Leaf Rust manifests itself as yellow pustules on the lower surface of leaves turning orange-yellow with powdery masses of uredeniospores in later stages. Defoliation of affected plants is a common symptom, which leads to loss of yield and quality of coffee. The damage of coffee rust is due to reduction in photosynthetic leaf surface area at the lesion site and also to pathogen induced leaf fall. When the attack is severe, the whole plant may become defoliated, causing dieback of branches (Upadhya *et al.*, 2016). The berry yield is reduced not only during the current year but also in the following year by reducing fruiting branches. Although the plants may become weakened, they normally recover from rust attack, especially when nutrition is adequate, death of plant occurs only with extremely high diseases severity.

Control of CLR by copper based fungicides such as Copper oxychloride and Nordox 75% have exhibited moderate potency. Unfortunately, fungicide use is burdened for organic farming and resource constraint coffee farmers as they are smallholders hence making it economically unfeasible. Among the antifungal botanicals and other bioagents screened in India, *Bacillus brevis* was as good at controlling CLR as the currently recommended fungicide regime of Bordeaux mixture. Spraying of 0.5% Bordeaux mixture solution thrice in a year is found effective in controlling CLR disease in Nepal (Upadhya *et al.*, 2016). Cultural control measures such as pruning, stumping, de-suckering, fertilizer application and coffee tree spacing, have also shown promise although they cannot stand alone if effective control measures does not applied at time (Bigirimana *et al*., 2012).

Incidence and Severity of CLR under Different Management Practices

Incidence and severity of CLR depends upon different management practices. Management practices on coffee orchard has direct and indirect influence on environmental factors affect pathogen by altering spore germination and hyphal growth rates which as a result affect rate of inoculums production. Studies by Hakiza (1997) and Eskes (1983) relate CLR severity directly to prevailing ecological condition such as temperature, rainfall, light, duration of leaf wetness and wind velocity. Temperature and relative humidity are the most important environmental factors that determine spore germination and penetration of *Hemileia vastatrix* (Beer *et al*., 1998). In addition, efficient light penetration under such condition keeps temperature well

regulated. Climate characterized by mild mean temperatures (between 21.6 °C and 23.6 °C) with foliar wetness associated with high relative humidity (>80 %) is the most favorable condition for infection by *H. vastatrix*. Shade management, mulching, pruning, weeding, type of soil, fertilizer application are associated with CLR incidence and severity. Mulching, pruning and fertilizer application are associated with lower levels of CLR severity (Bigirimana *et al.,* 2012).

Mulching mainly comprised of banana leaves, sorghum and rice straws reduce the incidence and severity of CLR. Weeding has also significant role on CLR incidence and severity. Weeded farm has lower CLR severity than unweeded farms. In addition properties of soil influence on CLR incidence. The alternating wet and dry conditions favor high CLR build up and thus leads to high crop losses (Prakash *et al.,* 2005). The higher mean incidence of CLR was found in clay soil than in loam soils. Coffee trees planted in clay soils are very susceptible to CLR. Clay soils are very heavy with excessive water retention and are mostly affected by leaching (McCauley *et al*., 2005 and Waller *et al*., 2007). This in turn affects the ability to retain soil nutrients (Leslie, 2002) are indirectly responsible for plant vigor and the state of readiness of plants to defend themselves against pathogenic attack (Agrios, 2005; Stone *et al*., 2003). Slope of land has also influence on incidence and severity of CLR. CLR severity was found to be highest at very steep slopes and medium slopes and least on gentle slopes. The disease severity decreased when altitude increased. Farms located at higher altitudes (normally from 1800 masl and above) have lesser influence on CLR and those at lower altitudes (mainly from 1400 masl and below) were much more diseased. On the other hand, this high disease incidence is also compounded by the high susceptibility of commercial cultivars grown.

Shade effects on coffee rust are controversial. On one hand, shade helps to prevent high fruit loads, which decreases leaf receptivity to the pathogen. It reduces berry load on coffee trees, which in turn reduces plant stress and consequently translates into increased plant resistance to CLR (Avelino, 2010). On another, it provides better micro-climate for germination and colonization. Higher incidence and severity of CLR was found in partial shade due to presence of optimum microclimatic conditions. It favors CLR pathogen infection and colonization of coffee leaves (Beer *et al*., 1998). Conversely, low light penetration under thick shade restricts levels of CLR incidences and severity. This translates into low temperatures which enhance host recognition by the pathogens and eventually successful infection. A positive relationship has been found in between the number of fruiting nodes and coffee rust incidence and severity (Zambolim *et al.,* 1992).

Viability of Coffee Leaf Rust

Infection is manifested as yellow-orange powdery lesions on the abaxial surface of leaves, and leads to impaired photosynthesis, premature defoliation and reduced floral initiation resulting in tremendous yield loss that may reach as much as 70%. Coffee leaf rust pathogen produces uredinal, telial and basidial stage but only dikaryotic urediospores are responsible for the disease (Silva *et al.,*

2006). The urediniospores produced in these lesions are responsible for the dispersal, survival and infection structure of the pathogen. Teliospores are occasionally produced, germinate to produce basidiospores. However, infection of basidiospores to coffee has not been demonstrated and so far, no alternate host has been found. The pathogen exists in several physiological forms or races and break down the resistance in the host plant in due course by evolving new races. Forty five *H. vastatrix* races have been identified globally. Isolated and identified rust races are maintained on susceptible plants under green house conditions. It requires frequent re-inoculation from old leaves to new leaves in isolated chambers to avoid cross contamination. Maintenance of large number of races requires larger space and manpower. The infected leaves defoliated after few days of infection may cause loss of known races and to re-isolate the same race requires couple of years. The degree of resistance to rust by coffee lines depends on the type of rust race (Rodrigues *et al.*, 1975). Many studies are presently being carried out to understand the molecular basis of the interaction between coffee and rust (Diana *et al.*, 2004). Parallel to this, plant breeders are putting in tremendous efforts to generate introgressed lines that exhibit disease resistance to different races of rust. One major requirement for studies like screening for natural resistance in the host germplasm and screening of fungicides to control rust outbreak is the continuous availability of viable spores. Since, *H. vastatrix* is a biotropic fungus and culture of the fungus on an artificial medium is not possible. *H. vastatrix* cultures are usually maintained by repeated infection on susceptible plants under controlled conditions, which is a tedious and laborious process. An alternative to overcome this problem is to preserve spores under appropriate conditions. Though there is a considerable literature on germination conditions of coffee rust, there are only limited studies on preservation of CLR spores. Preservation of race I and race VIII on cold storage at -20°C and -80°C has enhanced germination in both the races for at least up to 15 days. This easy preservation condition would eliminate the need of cumbersome processes like maintenance culture on susceptible plants or constant supply of liquid nitrogen for storage at -196°C. Coffee rust spores were maintained up to 150 days with high viability in liquid nitrogen at -196°C.

Races of Pathogen

Coffee leaf rust caused by *Hemileia vastatrix* Berk. et Br. has great genetic variability due to which coffee leaf rust has been/being a challenge. Pathogen modification, emergence of new races of the pathogen, as well as occurrence of complex races, illustrates the evolutionary potential of *H. vastatrix* population and its consequent adaptation to resistance (Cabral *et al.*, 2009). Cultivation over large areas offers a favorable environment for rapid evolution of the pathogen, permitting the gradual movement of rust epidemics and distribution of genotypes (Nunes *et al.*, 2009). The mechanisms leading to the emergence of new races of *H. vastatrix* are still not clear. Sexual stage of the fungus has not been encountered yet (Gopal Krishnan, 1951; Varzea and Marques, 2005). However mutation has been hypothesized as the principle

mechanism for variability of the fungus (Varzea and Marques, 2005). Although morphological evidence has indicated the occurrence of karyogamy and meiosis in asexual spores since 1967 (Rajendren, 1967), only in 2011 did an image cytometry study of DNA content reveal the presence of a novel type of sexual reproduction hidden within asexual spores of *H. vastatrix*, called cryptosexuality (Carvalho *et al.,* 2011). According to the authors, this type of reproduction could explain the frequent and rapid emergence of new physiological races of *H. vastatrix.*

The first race differentiation of *H. vastatrix* was carried out by Mayne (1932) in India, who differentiated the local rust samples into four physiological races. No other studies were made on the physiological specialization of *H. vastatrix* until D'Oliveira initiated a world survey of coffee rust races in 1952 (D'Oliveira, 1965). The work carried out at the Coffee Rusts Research Center (CIFC) enabled the characterization of about 45 rust races (D'Oliveira, 1965; D'Oliveira and Rodrigues, 1961; Rodrigues *et al.,* 1965; Bettencourt *et al.,* 1965; Rodrigues *et al.,* 1975; Rodrigues *et al.,* 1993; Várzea *et al.,* 2002a). Molecular studies to detect genetic diversity in *H. vastatrix* were carried out (Nandris *et al.,* 1998). The RAPD (Random Amplified Polymorphic DNA) method revealed polymorphism between individuals. However, a linkage between the molecular markers obtained and pathotypes used was not established. In recent studies at CIFC, using RAPD and MSP-PCR (Microsatellite-Primed Polymerase Chain Reaction), a considerable degree of variability among the populations studied was observed, although no clear relationship was obtained between host, geographical origin and physiological races (Gouveia *et al.,* 2005).

The variability of the biotrophic fungi, including *H. vastatrix,* is usually high. More than 45 physiological races of *H. vastatrix* have been identified from samples collected in different coffee-producing countries (Varzea and Marques, 2005). Among these, race II, which has virulence gene v5, predominates in commercial farming areas (Fernandes *et al.,* 2009). The virulence genes of the pathogen identified were v1, v2, v3, v4, v5, v6, v7, v8, and v9 which were supplanted in whole or part (Bettencourt and Rodrigues, 1988). The majorities of commercial cultivars planted in coffee-producing regions worldwide have the S_H5 factor and are therefore susceptible to race II of *H. vastatrix* (Fazuoli *et al.,* 2005).

About thirty five physiological races have been identified in India. In Brazil, 15 races I, II, III, VII, X, XIII, XV, XVI, XVII, XXI, XXII, XXIII, XXIV, XXV or XXXI and XXXVII have been traced out (Cabral *et al.,* 2009). Race II is the most widely distributed race among identified races in Brazil (Zambolim *et al.,* 2005a). Rodrigues Jr. *et al.* (1975) recorded seven physiological races of *H. vastatrix* which are I, II, III, XVII, XXIV, XI and XX. The diseases surveyed from 2006 to 2007 recorded new rust pathogen, races XXII and XXXIV (CIFC, 2007). Five races XXIII, XXIV, XXV, XXVIII and XXXI were recorded after two years later (TaCRI, 2009). In Tanzania, seven new races XLI (v2, 5, 8), XLII (v2, 5, 7, 8 or v2, 5, 7, 8, 9), XV (v4, 5), XXX (v5, 8), XXXIII (v5, 7 or v5, 7, 9), XXXIV (v2, 5, 7 or v2, 5, 7, 9), XXXIX (v2, 4, 5, 6, 7, 8, 9) has been

reported (Kilambo *et al.,* 2013). Altogether 21 physiological races of *Hemileia vastatrix* has been recorded in Tanzania.

Resistance against Coffee Leaf Rust

Use of resistant cultivar is a safer alternative to overcome the challenge of coffee leaf rust in long run. Several researches from different parts of the world have attempted to obtain durable resistance to coffee rust. The resistance of coffee trees to *H. vastatrix* has been explored by conventional breeding methods. There are known sources of monogenic, oligogenic and polygenic resistance (Alvarado, 2005). Coffee rust resistance is conferred either independently or jointly by genes S_H1, S_H2, S_H3, S_H4, S_H5, S_H6, S_H7, S_H8, and S_H9 (Bettencourt and Rodrigues, 1988). Genes like S_H1, S_H2, S_H4, and S_H5 were identified in *Coffea arabica* (Bettencourt and Noronha-Wagner, 1971), whereas S_H6, S_H7, S_H8, and S_H9 were found in *Coffea canephora* (Bettencourt and Rodrigues, 1988). Genes like S_H6, S_H7, S_H8, and S_H9 were introgressed from *C. canephora* (Rodrigues *et al.,* 1975) and S_H3 from *Coffea liberica* (Prakash *et al*., 2004). Beside these S_H genes, other major and minor genes might condition the coffee rust interactions (Bettencourt and Rodrigues Jr., 1988). The coffee genotypes are classified in physiological groups which are distinguished from each other essentially by responses involving either complete resistance or susceptibility (low and high infection type) to several rust races. Group A, characterized by resistance to all known rust races is found in hybrid between C. *arabica* x C. *canephora*, either spontaneously or man-made (D Oliveira and Rodrigues Jr., 1961; Marques and Bettencourt, 1979). Plants of group A are also found in *C. liberica*, *C. dewevrei*, *C. eugenioides*, *C. congensis*, etc (D Oliveira and Rodrigues Jr., 1961) while E- group characterized by susceptibility to almost all known races, includes the traditional Typica and Bourbon cultivars (Bettencourt and Rodrigues Jr., 1988). Non-specific polygenic resistance has been assessed at CIFC and more extensively in other countries (Kushalappa and Eskes, 1989), mainly under laboratory conditions using different parameters, such as latency period, percentage of sporulating lesions, and spore production per lesion. Holguin (1993) indicated the existence of sources of this type of resistance in *C. canephora* and interspecific hybrids and also in some *C. arabica* genotypes, but the inheritance of this type of resistance remains unknown. The majorities of commercial cultivars planted in coffee-producing regions worldwide have the S_H5 factor and are susceptible to race II of *H. vastatrix* (Fazuoli *et al.,* 2005). The main source of genes for resistance to all races of *H. vastatrix* including race II is currently the Híbrido de Timor (HDT) also called Timor Hybrid. Híbrido de Timor is a plant derived from a spontaneous crossing of *C. arabica* and *C. canephora* (Varzea and Marques, 2005).

Kent was perhaps the first variety to show good resistance to coffee rust in India. However, this resistance was lost after about 10 years of exposure (Rodrigues and Eskes, 2009). This phenomenon of gradually losing resistance has also been noticed in some *C. liberica* and *C. canephora* varieties. Catimor and Icatu show partial

resistance to the rust, but lack many of the taste attributes desired by specialty coffee buyers. Catimor (Cauvery in India) is a cultivar developed from the cross between Caturra and Hibrido de Timor whereas Icatu was developed in Brazil by crossing Robusta and Arabica (Bourbon) followed by backcrossing to Mundo Novo. Sarchimor (Chandragiri in India) is another resistant cultivar developed from the cross between variety, Villasarchi and Hibrido de Timor (Jayarama, 2007).

IPR 107, released in 2010, is a dwarf medium size cultivar with complete resistance to leaf rust and has medium precocity in ripening (Sera *et al.,* 2010a). It was derived from a cross between 'IAPAR 59' x 'Mundo Novo IAC 376-4', performed at IAPAR. The mother plant of 'IPR 107' is 'IAPAR 59', which was derived from a cross between "Villa Sarchi CIFC 971/10" (*Coffea arabica* L.) and "Hibrido de Timor CIFC 832/2" (interspecific hybrid between *C. arabica* and *C. canephora*). 'IAPAR 59' is classified in physiological group A. It is resistant to all rust races of the world and carries at least S_H5, S_H6, S_H7, S_H8 and S_H9 resistance genes. This cultivar is recommended for semi-dense, dense and super dense planting systems in areas with annual average temperature between 18 ºC and 22 ºC. For cultivation with high plant density, the genotypes Katipo, Paraiso MG H419-1, H419-3-3-7-16-4-1-1, Araponga MG1, Catucai Amarelo 24/137, Catigua MG2, Sacramento MG1, Pau-Brasil MG1, Catigua MG3, Oeiras MG 6851 and Tupi present higher level of resistance for leaf rust.

Some Recommended Varieties

Varieties from India were screened for resistance to CLR. Selection 6 was found resistant. Selection 5A was generally resistant but with some individual bushes susceptible, due to the variety being a composite. Catuai x HDT, Colombia, Selection 5B, Chandragiri, and Selection 5A were all resistant to CLR in India. In Kenya Crosses 8, 22, 23, 27, 30 were resistant to CLR and gave high yields. Three CLR resistant varieties were officially released in Kenya, named Batian varieties 1, 2 and 3. Selection 5A and 6 have good cup quality in comparison with Ruiru 11 and SL28 in Kenya. In Uganda varieties NG9257 and Elgon CB, as well as Selections 5A and 6 are resistant to CLR. Selections 5A and 6 gave consistent CLR resistance and Selection 6 was better in quality than the commercial variety BM 139 in Rwanda. Line 13683/35 and Selection 6 were resistant to CLR in Zimbabwe, and were far better than the known resistant commercial variety, Catimor 129. Selection 5A and 6 are early maturing and show potential of being high yielding. Both Selections are tall statured similar to SL28, a tall commercial variety in many countries, but which is susceptible to CLR. A survey made by B. Upadhya in 2016 on mid hill region indicated Catimor, Tekesic and San Roman as tolerant varieties to CLR in Nepal. However their productivity is found low in comparison to Selection-10 and Yellow Catura, commercial varieties of Nepal.

Conclusion

In some last decades, considerable success has been attained in preservation of coffee rust pathogen, identification of rust races, its physiological behavior and development of resistant cultivar to control coffee leaf rust.

The discovery of Hibrido de Timor with good genetic resistance against rust was a breakthrough in coffee research. The existence of genotypes with different levels of resistance allows the opportunity of development and selection of resistant cultivars, improving the costs of production through reduction of need for others technologies, like chemical method of controlling diseases.

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