



AN OVERVIEW OF COMPARISON BETWEEN WHEAT RUSTS MYCOFLORA IN INDIA WITH GLOBAL SCENARIO

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ABSTRACT

Wheat rusts are the oldest plant disease known to human and caused by Puccinia species. Puccinia species are the main constraints in wheat production wherever wheat is grown. Early literatures mention these devastating diseases and their ability to destroy entire wheat crops. These wheat rust pathogens are highly transmissible through air current in both cases, primary and secondary infections. Primary infection occur through alternate host developing spore (Aeciospores) and secondary infection caused by wheat (primary host) developing spore (Uredospores). Secondary infection results epidemics, several time as globally occurrence. Ecologically, the persistence of rusts as a significant disease in wheat can be attributed to specific characteristics of the rust mycoflora. Their ability to spread aerially over the large distance, production of urediospores in enormous number and evolving new pathotypes, makes the management of wheat rusts a very daunting task. These characteristics include a capacity to produce a large number of spores which can be wind disseminated over long distances and infect wheat under favorable environmental conditions and the ability to change genetically, thereby producing new races with increased aggressiveness on resistant wheat cultivars.

KEY WORDS: *Wheat Rust, Puccinia, Rust Mycoflora, Stem Rust, Leaf Rust, Stripe Rust*

INTRODUCTION

Wheat is an important cereal crop and of the first domesticated food crops and from more than 10,000 years has been the basic staple food for most of the world.⁽¹⁾ It is grown in an area of about 222.28 million hectares in a range of environments with 724 million tonnes production worldwide (FAO-2016). India is leading producer of wheat (*Triticum aestivum*) in the world.⁽²⁾ It is the most important winter cereal crop in India and serves as the staple food for more

than one billion population. It contributes approximately 14% to the world wheat basket and holds the global share of 11% area under cultivation of wheat.⁽¹⁾ In India, wheat crop is grown mainly in the northern states, with Uttar Pradesh being the top-most contributor (35%) of wheat with a total production of 25.22 Million Tonnes, followed by Punjab (15.78 MT) and Madhya Pradesh (14.18 MT) (FAO-2016)

Wheat is a synonym to food security in India. However, production of wheat is always subject to



many biotic and abiotic constraints. Among the biotic causes, rusts (*Puccinia*= over 3,000 species) are very devastating pathogens of wheat worldwide⁽³⁻⁷⁾ and have no doubt been present and evolving during domestication of cereal crops as a major segment of agriculture.⁽⁵⁾⁽⁸⁾ *Puccinia* is largest group of rust fungi that parasitize a wide range of host plants in which Wheat (*Triticum* sps.) is chief one. Rust is characterized by megacyclic life cycle including uredo, teleuto, basidio, pycnidio and aecidio stage.⁽⁶⁾⁽⁹⁾ Some are completing their life cycle with single host (monogenetic) and some are sare two hosts (digentic).⁽⁹⁾ In India about 716 species of *Puccinia* have been reported⁽⁹⁻¹⁰⁾ in which wheat crop is subjected to severe attack of all the three rust endemics to India viz., black or stem rust (*Puccinia graminis* f. sp. *tritici*), the brown or leaf rust (*Puccinia triticina*) and the yellow or stripe rust (*Puccinia striiformis*).⁽¹⁾

Yield losses caused by leaf rust epidemic are estimated at around 40% and losses due to stem rust and stripe rust can be as great as 100%. All the rusts of wheat are known to occur in India.⁽²⁾⁽⁶⁻⁷⁾⁽¹¹⁻¹²⁾ Rusts of wheat are shifty pathogens, capable of aerial spread, multiply geometrically and can cause epiphytotics. Alternate hosts are non functional and the rusts spread via repeating spore called urediospores through wheat.⁽⁵⁾⁽⁷⁾ After its germination, a series of essential structures for the establishment of a successful parasite relationship are formed.⁽⁵⁻⁶⁾ This review assessment of wheat mycoflora may be providing a satisfactory result in the research, managing and controlling of their cause.

HISTORY

Rust mycoflora of cereal have probably been a problem since the first cereal crops were grown. Spores of *Puccinia graminis* have been found in archaeological sites in Israel dated 1300 B.C.⁽¹³⁻¹⁴⁾ Rust was observed and recognized as early as the time of Aristotle (384-322B.C.).⁽¹⁴⁾ In 17th century, the French farmers had noticed that black stem rust was much worse in fields that surrounded by barberry bushes. Later, in the Rouen city of France was the first promulgate legislative measures perform in the year 1660 to control barberry bushes. At that time nobody knew that Barberries (*Berberis vulgaris*) were an alternate host of the stem rust life cycle (*Puccinia graminis*). The Italian researcher Fontana and Tozzetti independently provide the first detail report of stem rust of wheat in 1767.⁽¹⁵⁻¹⁶⁾ In 1865, the famous mycologist, Heinrich Anton de Bary discovered the complete life cycle of the stem rust and demonstrated that *P. graminis* required two different hosts (Wheat and Barberry bush) during the different stages of its development and thus discovered

the heteroecious nature of wheat stem rust pathogen. In 1927, the Canadian pathologist Johan Hubert Craigie successfully demonstrated that pycnia are the sexual structure of rust fungi and also designated two mating types (+) and (-) for haploid pycnia (spermatia and receptive hyphae) in wheat black rust (*P. graminis* f. sp. *tritici*).⁽¹⁷⁾ The causal organism of wheat stem rust was termed *Puccinia graminis* by Persoon in 1797. In early records, wheat leaf rust is not distinguished from stem rust.⁽¹³⁾⁽¹⁸⁻¹⁹⁾ However in 1815, de Candolle had shown that wheat leaf rust was caused by a different fungous and named *Uredo rubigovera*.⁽²⁰⁾ The pathogen of leaf rust underwent a number of name changes until 1956 when Cummins and Cald-well suggested *Puccinia recondite*.⁽²¹⁾ Currently the leaf rust of wheat pathogen preferred name *Puccinia triticina* purposed by Mains and Jackson in 1926 and recently by Savile (1984) and Anikster (1997).⁽²²⁻²⁴⁾ The stripe rust of wheat firstly described by Gadd in 1777⁽¹³⁾ and named by Eriksson and Henning in 1896 as *Puccinia glumarum*.⁽²⁵⁾ *Puccinia glumarum* name revived by Hylander et al. as *Puccinia striiformis*.⁽²⁶⁾ In India, the systematic investigations of wheat rusts were initiated by Professor Karam Chand Mehta from Agra College, Agra Uttar Pradesh during the 1922-1923. His outstanding contributions reported that the discovery of the life cycle of stem rust of wheat in India and epidemiology of wheat rusts. Through experimentation and circumstantial evidences, Prof. K. C. Mehta proved beyond doubt that barberry, an alternate host of wheat stem rust pathogen, does not play any functional role in the perpetuation of the rust fungus in India.⁽²⁷⁾ Wheat rust resistance breeding was also started in India during 1934 by Dr. B. P. Pal.⁽²⁸⁾

TAXONOMY

The rust mycoflora belong to family Pucciniaceae, order Uredinales of class Basidiomycetes and comprise a large group of obligate plant parasites. About 168 genera and approximately 7000 species are exist as rust pathogens to the plants, whereas more than half of species belong to genus *Puccinia*.⁽²⁹⁻³⁰⁾ The genus *Puccinia* was named in honor Florentian Physician and Teacher by P. A. Micheli.⁽³¹⁾ Among all reported rust fungi, *Puccinia* are the most Agricultural destructive and devastating rust mycoflora that causing different distinctive rust diseases.⁽³²⁾ In India, about 716 species of *Puccinia* have been reported.⁽⁹⁻¹⁰⁾ Three major type of rust mycoflora infects wheat; Stem rust or Black rust, Leaf rust or Brown rust and Stripe rust or Yellow rust. The causative agents of these wheat rust are *Puccinia graminis* f. sp. *tritici*, *Puccinia triticina* and *Puccinia striiformis* respectively.⁽³¹⁾



Systematic Position of Rust Mycoflora (<i>Puccinia</i> sps.)	
Kingdom	Fungi
Division	Amastigomycotina
Sub-Division	Basidiomycotina
Class	Basidiomycetes
Order	Uredinales
Family	Pucciniaceae
Genus	<i>Puccinia</i>
Species	<i>graminis</i> , <i>tritricina</i> , <i>striiformis</i>

HOST SPECIFICITY

Host ranges of rust mycoflora are wider, diversified and considered as one of the most harmful pathogens in agriculture, horticulture, forestry and medicinal plants. Unlike other mycoflora, Rust exhibit one of the most important characteristic of their exceptionally high degree of host specificity.⁽²⁹⁾ Rust disease are caused by highly specific fungal pathogens that commonly known as rust mycoflora. These rust mycoflora are restricted in host specificity. More than 5000 rust mycoflora species are estimated that attack on different crops, grasses etc.⁽³¹⁾ In India, wheat rust has specified host for three different rust mycoflora that all cause different rust pathogenesis. These wheat rust mycoflora are also generally specified on plant parts as causative locality. Wheat rusts are Stem rust caused by *P. graminis* f. sp. *tritici*, Leaf rust caused by *P. triticina* and Stripe rust caused by *P. striiformis*. Primary host of Stem rust (*P. graminis* f. sp. *tritici*) is wheat, barley and triticale with alternate host *Barberis*. *P. triticina* is primarily pathogens of wheat, and its immediate ancestors are manmade crop triticale. Leaf rust population exists in Europe, Asia (India) and Africa that are primarily pathogens of durum wheat.⁽³³⁾ In the life cycle of leaf rust, sexual stage develop (gametes) on alternate hosts *Thalictrum*, *Anchusa*, *Isopyrum*, *Clematis* etc.⁽²⁴⁾ Primary host of stripe rust (*P. striiformis*) is cereals (wheat) and some grasses with any no alternate host, because only telial and uredinal stages are present in their life cycle.⁽³⁴⁾

PATHOGENECITY

The rust mycoflora is a group of fungi that are among the most destructive plant pathogen in the world as well as India. Their sever attacks occur on cereal grain crops. The diverse species may attack many grass hosts, with cereal crop specially wheat.⁽³¹⁾ For the germination and growth of rust pathogens, water on the leaf surface from intermittent rain or heavy dew and temperature are required. To initiation and development of infection, rust require an average temperature up to 35°C with 50-60% relative humidity.⁽²⁹⁾ In optimal condition (Table-1) rust disease infection development completed into 6-8 hrs. and Uredospores capable to causing secondary disease spreading produced in 7-10 days.⁽³⁵⁾ Uredospores are relatively more viable (about 1 year) than other spores of rust pathogens and also highly spreading efficiency because they are produced in large quantity and light in weight so they are extremely efficient and responsible for disease spreading.⁽⁵⁾⁽³⁶⁾ In case of new infection, alternate host not always required because Uredospores are able to initiate infection one year later also.⁽³⁵⁾ Whereas barberry is the most dangerous source of primary inoculum of stem rust in temperate regions. Nearly growing barberry of wheat fields, will be a consistent source of Aeciospores for the earliest infection of wheat during spring.⁽¹⁴⁾ Rusts may debilitate or kill young wheat plants but more typically reduce foliage root growth and yield by decreasing photosynthesis, increasing respiration rate, and decreasing translocation of carbohydrates. They move carbohydrates to the area infected and use them for growth. Uredinia produce the summer rust spores and Telia produce the overwinter spores. The occurrence of rust in spring and summer can continuously re-infect the wheat crop and hence cause epidemics. Severity of wheat rust in India cause epidemic several times (Table-2). Wheat rust has been recorded in India with documented evidence from the years 1786, 1805, 1828-29, 1831-32, 1879, 1887 and 1907. Whereas 17 identified epidemics of wheat rust in India between 1786 to 1956 are reported.⁽³¹⁾



Stage	Temperatute (°C)			Light	Water
	Minimum	Optimum	Maximum		
Stem Rust (<i>P.graminis</i> f. sp. <i>tritici</i>)					
Germination	2	15-24	30	Low	Essential
Germling	-	20	-	Low	Essential
Appressorium	-	16-27	-	None	Essential
Penetration	15	29	35	High	Essential
Growth	5	30	40	High	None
Sporulation	15	30	40	High	None
Leaf Rust (<i>P. triticina</i>)					
Germination	2	20	30	Low	Essential
Germling	5	15-20	30	Low	Essential
Appressorium	-	15-20	-	None	Essential
Penetration	10	20	30	No Effect	Essential
Growth	2	25	35	High	None
Sporulation	10	25	35	High	None
Stripe Rust (<i>P. striiformis</i>)					
Germination	0	9-13	23	Low	Essential
Germling	-	10-15	-	Low	Essential
Appressorium	-	-	Not Formed	None	Essential
Penetration	2	9-13	23	Low	Essential
Growth	3	12-15	20	High	None
Sporulation	5	12-15	20	High	None

Table-1: Optimal environmental condition for wheat rust establishment⁽⁴¹⁾

Rust Epidemic year (in India)	Rust type	Wheat Production Losses (in Million Tonnes)	Value of Losses (in Million US\$)
1945-49	Stem Rust	2.0 MT	296 MUS\$
1971-72	Stem and Stripe Rust	0.8 MT	118 MUS\$
1972-73	Stem and Stripe Rust	1.5 MT	222 MUS\$
1980	Leaf Rust	1.0 MT	148 MUS\$

Table-2: Rust epidemics in India and their effects on wheat crop⁽³¹⁾

LIFE CYCLE

Rust mycoflora have complex life cycles that require two specific different host plant-Primary host (wheat) and alternate host except stripe rust. In their life cycle may have five different stages (spores).⁽³⁵⁾ In case of stem rust and leaf rust has five distinct sporic stages (Fig.-1 and 2) Pycnial stage (0), Aecidial stage (1), Uredial stage (2), Telial stage (3) and Basidial stage (4). Pycnial stage is called stage-0 because before 1927 the role of Pycnial stage in the life cycle of rust was not understood.⁽¹⁷⁾ Stage-0 (Pycnial) and Stage-1 (Aecidial) occur on alternate hosts in their life cycle. Stripe rust consist only Uredial stage and Telial stage in their life cycle (Fig.-3).⁽³⁷⁾

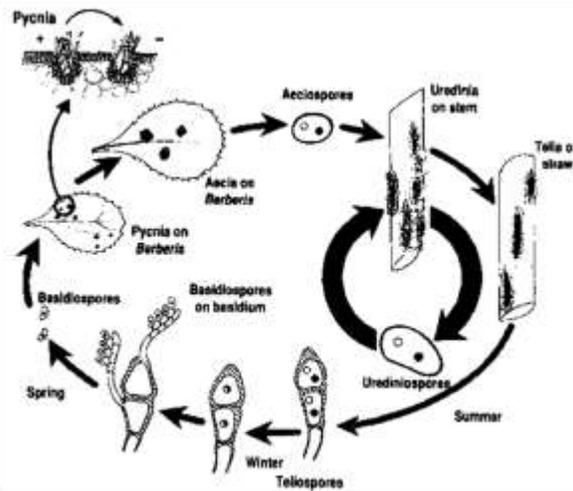


Fig.1 Life Cycle of *Puccinia graminis* (Stem Rust)

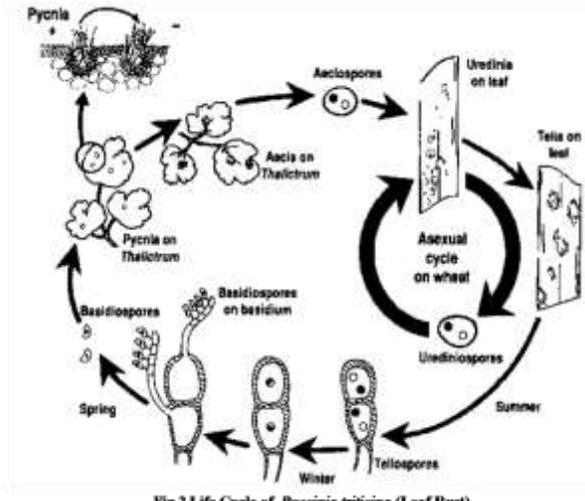


Fig.2 Life Cycle of *Puccinia triticina* (Leaf Rust)

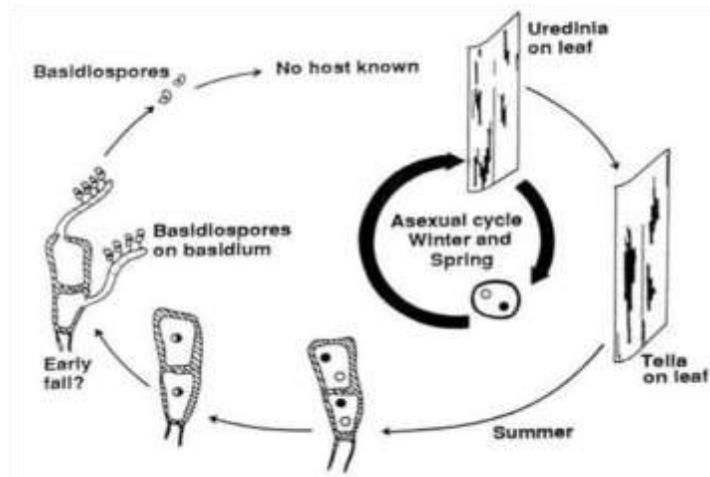


Fig.3 Life Cycle of *Puccinia striiformis* (Stripe Rust)

TRANSMISSION

Rust pathogens are able to spread over long distance. The spreading of rust is takes place by sporic stage through wind.⁽³⁷⁾ In case of all sporic stage, Uredospores are highly viable and transmissible via wind.⁽³⁵⁾ Wheat rust known to survive and carry over to the next generation with the help of Uredospores which are called as repeating spores.⁽¹⁷⁾ An identical biochemical patterns and connective wind from Australia indicate long distance dispersal and deposition of viable Uredospores across 5000 Km. Of ocean from Southern part of Africa to that of Australia.⁽¹⁷⁾ Uredospores are produce in large quantity as well as light in weight that a resion to spread very long distance and infect new host wheat.⁽³⁵⁾ Aeciospores are develop on alternate hosts and also spread via wind in nearly located crop fields and cause early infection to the host plants (wheat).⁽¹⁴⁾

SYMPTOMS

Three rust diseases occur on wheat- stem rust, leaf rust and stripe rust. These disease are caused by particular species of rust mycoflora belongs to *Puccinia* sps. There are all the rust produce mostly similar disease symptoms. The rust infected plant may appear stunted, chlorotic (yellowing) or discolored whereas, disease symptoms includes coloured pustules, witches blooms, stem canker, hypertrophy of affected tissues of formation of galls.⁽²⁹⁾ The name of rust disease also given by their appearance on the host plant (wheat) like stem rust as black rust, leaf rust as brown rust and stripe rust as yellow rust. Infection of rust occurs on only shoot parts of host plant (wheat) and leading to the production of pustules that contains thousands of spores. These pustules give the appearance of “Rust” on wheat.⁽³⁵⁾ Stem rust symptoms (Fig.4) begin as oval to elongate lesions on stem generally (also on leaves,



sheath etc.) as reddish-brown in color. In severe case, pustules produce numerous black sooty spores and many stem lesions may weaken plant shoot and result in lodging.⁽³⁶⁾⁽³⁸⁾ Leaf rust symptoms (Fig.5) begin as small circular to oval yellow-brown spots on upper surface of infected leaves of wheat. Later the spots develop as brown or orange coloured pustules that produce a large number of spores as like brown dust on the leaf surface. In this the pustules dose not develop as

lesions like stem rust.⁽³⁶⁾⁽³⁹⁾ In Stripe rust symptoms (Fig.6) would appear about a week after infection. Sporulation starts about two weeks post infection.⁽³⁷⁾ Stripe rust begin by production of light yellow coloured pustules in stripe of leaves and mature pustules produce yellow-orange spores.⁽³⁶⁻³⁷⁾ Chlorosis or Yellowing of leaves are quit appearance on both leaf and stripe rust and easily detectable.⁽³⁵⁾

**Fig.4 Stem Rust****Fig.5 Leaf Rust****Fig.6 Stripe Rust**

PREVENTION

Only one of the versatile prevention methods for avoiding rust disease or minimizing their impact is to plant a variety with known resistance. It is the most economical method of control. Destroying previous wheat plants and volunteer wheat, by tillage or herbicide, is another important step in the prevention of several disease including wheat rusts. The elimination of green bridge between wheat crops will help in prevents mechanism. Crop rotation is also very helpful to reducing disease carryover because rests are host specific.⁽³⁵⁾ The key points for prevention of wheat rusts has always been to avoid large scale planting of similar varieties (single genotype) and deploy varieties with diverse resistance, if possible then resistance based on more than one effective gene. It will not only delay the epidemics of wheat rusts but also increase the self-life of wheat varieties and discourage the evolution in pathogens (rusts).⁽¹⁷⁾⁽⁴⁰⁾ In the case of stem of wheat, the alternate host (Barberry) played an important role in

sexual variability. However the eradication of barberry has reduced the influence of the sexual cycle of the disease (rust).⁽³¹⁾

GLOBAL SENERIO OF WHEAT RUSTS

Wheat was among the first of the domesticated food crops and for more than 10,000 years has been the basic staple food for most of the world. It is the most widely grown cereal crop in the world and one of the central pillars of global food security.⁽¹¹⁾ Globally the main threads of wheat security is rust that cause several epidemics (Table-3). The world wide scenario of wheat rusts specifying through historical and current evolution (Table-4). Wheat rust is globally present as endemic as well as epidemic hot spots in wheat developing countries covering large areas (Table-5).



Country	Rust Type	Year	Total Epidemic area of Wheat
Pakistan	Stripe Rust	1977-78	10-20%
Mexico	Leaf Rust	1976-77	70%
Ethiopia	Stem Rust	1993-94	90%
South America (Southern Cone)	Leaf Rust	1996	Unknown
Argentina	Leaf Rust	1999 & 2003	Unknown

Table-3: Global epidemics of wheat rusts⁽³¹⁾

Zone	Stem Rust		Leaf Rust		Stripe Rust	
	Current	Historical	Current	Historical	Current	Historical
Africa						
North	Local	Major	Major	Major	Local	Local
East	Major	Major	Local	Local	Major	Major
Southern	Local	Major	Local	Local	Local	Rare
Asia						
Far East	Local	Major	Local	Local	Major	Major
Central	Minor	Minor	Major	Major	Local	Local
South	Minor	Major	Local	Major	Local	Local
Southeast	Minor	Minor	Major	Major	Rare	Rare
West	Local	Major	Local	Local	Major	Major
Europe						
East	Minor	Major	Major	Major	Local	Local
West	Minor	Major	Local	Major	Major	Major
North America	Minor	Major	Major	Major	Local	Local
South America	Local	Major	Major	Major	Local	Local
Australia	Local	Major	Local	Local	Local	Rare

Table-4: Current and Historical Scenario of wheat rusts for the epidemiological zones⁽⁴²⁾

Rust Type	Yield Loss Percentage		Endemic total area of Wheat Percentage	Hot Spots of Rust Disease
	In Endemic	In Epidemic		
Stem Rust	40%	~100%	50%	Kenya, Ethiopia, Brazil, Parana State, South India
Leaf Rust	15-20%	~50%	90%	Mexico, India, Pakistan, Bangladesh, China
Stripe Rust	40%	~100%	33%	South America, East Africa, North Africa, Indo-Gangetic Plains of India and Pakistan

Table-5: Summary of losses caused by rust disease in developing countries⁽³¹⁾

CONCLUSION

In the present article, we are concluding that the wheat rust mainly three types and share specific hosts with may include alternate hosts and their symptoms (Table-6). Rusts mycoflora have an excellent ability to vary via mutation. Some rust pathogen may also vary through sexual reproduction and thus overcome resistance genes. The favorable environmental condition of wheat rusts likewise High temperature for Stem rust, Moderate temperature for leaf rust and Low

temperature for stripe rust to the virulence of infection. Wheat rust transmits through air current. The initiation of infection takes place by primary and secondary whereas, the primary infection caused by Aeciospores that develop on alternate hosts and secondary infection caused by Uredospores that develop on wheat and also a resion to become epidemics. Through the eradication of bushes (alternate host) and crop rotation, is a way to prevent wheat rust effectively. The Control of wheat rusts may apply through biological (through biotic



effect), chemical (fungicides, weedicides etc), and mechanical methods.

Disease	Pathogen	Primary Host	Alternate Host	Symptoms
Stem Rust	<i>P.graminis</i> f. sp. <i>tritici</i>	Wheat <i>Triticum aestivum</i>	Barberry <i>Berberis vulgaris</i>	Isolated Uredinia on upper and lower surface of leaf, stem and spikes
Leaf Rust	<i>P. triticina</i>	Wheat <i>Triticum aestivum</i>	<i>Thalictrum</i> , <i>Anchusa</i> , <i>Isopyrum</i> , <i>Clematis</i>	Isolated Uredinia on upper surface of leaf surface and rarely on leaf sheath
Stripe Rust	<i>P. striiformis</i>	Wheat <i>Triticum aestivum</i>	Unknown	Systematic Uredinia on leaves, spikes and rarely on leaf sheath

Table-6: Summary of wheat rusts⁽⁴¹⁾

REFERENCES

- S. M. S. Tomar et al. (2014) "Wheat rusts in India: Resistance breeding and gene deployment – A review", *Indian J. Genet.* 74 (2): 129-156.
- M. PRASHAR et al. (2015) "Virulence diversity in *Puccinia striiformis* f.sp. *tritici* causing yellow rust on wheat (*Triticum aestivum*) in India", *Indian Phytopath.* 68(2): 129-133.
- Belayneh Admassu and Emebet Fekadu (2005) "Physiological races and virulence diversity of *Puccinia graminis* f. sp. *tritici* on wheat in Ethiopia", *Phytopathol. Mediterr* 44: 313–318.
- C. Manjunatha et al. (2018) "Rapid detection of *Puccinia triticina* causing leaf rust of wheat by PCR and loop mediated isothermal amplification", *PLoS ONE* 13(4): 1-14.
- Marcia Soares Chaves et al. (2008) "The Cereal Rust: An Overview", *Pest Technology* 2(2): 38-55.
- Mogens S. Hovmøller et al. (2011) "Diversity of *Puccinia striiformis* on Cereals and Grasses", *Annu. Rev. Phytopathol.* 49: 197–217.
- S. C. Bhardwaj et al. (2012) "Rust situation and pathotypes of *Puccinia* species in Leh Ladakh in relation to recurrence of wheat rusts in India", *Indian Phytopath.* 65(3): 230-232.
- William R. Bushnell and Alan P Roelfs (1984) "The Cereal rusts", Academic Press, Inc. Vol.1.
- Gautam AK and Avasthi S (2016) "First checklist of rust fungi in the genus *Puccinia* from Himachal Pradesh, India", *Plant Pathology & Quarantine* 6(2): 106–120.
- Gautam AK and Avasthi S (2016) "*Puccinia himachalensis* – a new rust fungus from Himachal Pradesh, India", *Plant Pathology & Quarantine* 6(2): 220–223.
- M. Solh et al. (2012) "The growing threat of stripe rust worldwide", *Borlaug Global Rust Initiative*, 1-10.
- Rupinder Singh et al. (2017) "A review on stripe rust of wheat, its spread, identification and management at field level", *Res. on Crops* 18(3): 528-533.
- William R. Bushnell and Alan P Roelfs (1985) "The Cereal rusts", Academic Press, Inc. Vol. 2.
- Schmann G.L. and K.J. Leonard (2000) "Stem rust of wheat (Black rust)", *The plant health instructor*, DOI: 10.1094/PHI-I-2000-0721-01.
- Fontana F. (1932) "Observation of the rust of grain", P. P. Pirone, transl. Classics No.2. Washington DC, American Phytopathological Society.
- Tozzetti G.T. (1952) "V. Alimurgia: True nature, causes and sad effects of the rusts, the bunts, the smuts, and other maladies of wheat and oats in the field". In L.R. Tehon, transl. *Phytopathological Classics No. 9: 139*. St. Paul, MN, USA, American Phytopathological Society.
- Neha Gupta et al. (2017) "Wheat rust research – Status, efforts and way ahead", *Journal of Wheat Research* 9(2): 72-86.
- Chester K.S. (1946) "The nature and prevention of the cereal rusts as exemplified in the leaf rust of wheat", In *Chronica Botanica*. Waltham, MA, USA, 269.
- Yue Jin et al. (2014) "Population Diversity of *Puccinia graminis* is sustained through Sexual Cycle on Alternate Hosts", *Journal of Integrative Agriculture* 13(2): 262-264.
- de Candolle A. (1815) "Uredo rouille des cereals", In *Flora francaise, famille des champignons*. p. 83.
- Cummins G.B. and Candwell R.M. (1956) "The validity of binomials in the leaf rust fungus complex of cereals and grasses". *Phytopathology* 46: 81-82.
- Mains E.B. and Jackson H.S. (1926) "Physiologic specialization in the leaf rust of wheat, *Puccinia triticina*", *Phytopathology* 16: 89-120.



23. Savile D.B.O. (1984) "Taxonomy of the cereal rust fungi", In W.R. Bushnell and A.P. Roelfs, eds. *The cereal rusts vol. 1, Origins, Specificity, structure, and physiology*, p. 79-112.
24. Anikster Y. et al. (1997) "Puccinia recondite causing leaf rust on cultivated wheat, wild wheat, and rye", *Can. J. Bot.* 75: 2082-2096.
25. Eriksson J. and Henning E. (1896) "Die Getreideroste. Ihre Geschichte und Natur sowie Massregeln gegen dieselben", p. 463, Stockholm, P.A. Norstedt and Soner.
26. Hylander N. et al. (1953) "Enumeratio uredinearum Scandinavicarum", *Opera Bot.* 1: 1-120.
27. Mehta KC. (1940) "Further studies on Cereal Rusts in India" (Vol I). Imperial Council Agricultural Research. New Delhi. Scientific Monograph 14: 224.
28. Tomar SMS, SK Singh, M Sivasamy and Vinod (2014) "Wheat rusts in India: Resistance breeding and gene deployment – A review", *Indian Journal of Genetics* 74: 129-156.
29. Ajay Kumar Gautam & Shubhi Avasthi (2019) "A Checklist of Rust Fungi from Himachal Pradesh, India", *The Journal of Threatened Taxa* 11(14): 14845-14861.
30. Gautam AK and Avasthi S (2018) "A new record to rust fungi of North Western Himalayas (Himachal Pradesh), India", *Studies in Fungi* 3(1): 234-240.
31. H.J. Dubin and John P. Brennan (2020) "Combating Stem and Leaf Rust of Wheat", *International food policy research institute*.
32. Anwesha sah singh and Uma Tiwari Palni (2011) "Diversity and Distribution of rust Fungi in Central Himalayan region", *Journal of Phytology* 3(2): 49-59.
33. Huerta Espino J. and Roelfs A.P. (1989) "Physiological specialization on leaf rust on durum wheat", *Phytopathology* 79: 1218.
34. Eriksson J. nad Henning E. (1894) "Die Hauptresultate einer neuen Untersuchung uber die Getreideroste, Z. Pflanzenkr", 4: 66-73.
35. Mark A. Marsalis and Natalie P. Goldberg (2016) "Leaf, Stem, and Stripe Rust Diseases of Wheat", *New Mexico State University, Guide A-415*.
36. B. B. Mundkur (1967) "Fungi and Plant Disease", *Macmillan and Co. Limited Calcutta Bombay Madras London, Second Addition*.
37. Rupinder Singh et al. (2017) "A review on stripe rust of wheat, its spread, identification and management at field level", *Res. on Crops* 18 (3): 528-533.
38. Arif Abraham et al. (2018) "Pathogenic Variability of Wheat Stem Rust Pathogen (*Puccinia graminis* f. sp. *tritici*) in Hararghe Highlands, Ethiopia", *Advances in Agriculture Volume 2018, Article ID 8612135*, p.7.
39. Saleem Khan et al. (2018) "Evaluation of Wheat (*Triticum aestivum* L) Varieties for Leaf Rust and Yield Attributing Characters", *Agri Res & Tech: Open Access J* 16(4).
40. Subhash C. Bhardwaj et al. (2019) "Status of Wheat Rust Research and Progress in Rust Management-Indian Context", *Agronomy* 9(892).
41. Roelfs A.P. et al. (1992) "Barley stripe rust in Texas", *Plant Dis.* 76: 538.
42. Saari E.E. and Prescott J.M. (1985) "World distribution in relation to economic losses".