SLOW RUSTING MECHANISM IN WHEAT VARIETIES OF PENINSULAR ZONE AND INTEGRATED MANAGEMENT OF LEAF RUST (*Puccinia triticina* Eriks.)

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By

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CERTIFICATE

This is to certify that the thesis entitled **"SLOW RUSTING MECHANISM IN WHEAT VARIETIES OF PENINSULAR ZONE AND INTEGRATED MANAGEMENT OF LEAF RUST (*Puccinia triticina* Eriks.)"** submitted by **Mr. NANDEESH RAVINDRA GOUDA** for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **PLANT PATHOLOGY** to the University of Agricultural Sciences, Dharwad is a record of bonafide research work done by him during the period of his study in this University, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

DHARWAD | **(P.V.PATIL)**
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(SUMA S. BIRADAR)

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1. INTRODUCTION

Wheat (*Triticum* spp.; family: Poaceae) is one of the highest consumed winter cereal food crop in the world, measured either by cultivated area (220 m ha) or by the size of the harvest (752 mt) with an average yield of 3412 kg/ha (Anon., 2017). It has attained a premier position in the world for its unique consumable protein *i.e.* gluten, which is responsible for bread making properties of wheat flour, along with the straw which is a major source of nutritious feed for large population of cattle. Wheat is cultivated in so widly distributed mega environments of the globe, that the crop is harvested in one country or the other all the year around.

In India, wheat is the second most important food crop being next to rice and it contributes nearly 25 per cent to the total food grain production. The total estimated area under wheat cultivation in India during 2016 was 31.46 m ha with the production of 96.64 mt and average productivity of 3,071 kg/ha (Anon., 2016a). It is one of the important *rabi* cereal grown in Karnataka where in all the three cultivated species *viz.*, *Triticum aestivum* L., *T. durum* Desf. and *T. dicoccum* Shrank are grown over an area of 2.01 lakh ha with a production of 2.15 lakh tones and with a productivity of 1069 kg/ha which is low as compared to national average of 3,140 kg/ha (www.indiastat.com, 2016).

Wheat, like any other crop, suffers from many diseases caused by fungi, bacteria, viruses, nematodes and physiological disorders. However, the diseases caused by fungi are responsible for taking heavy toll of the wheat crop in the country. Among the fungal diseases, three rusts *viz.*, stem rust (*Puccinia graminis* Pers.: f.sp. *tritici* Eriks. & E. Henn.), leaf rust (*Puccinia triticina* Eriks.) and stripe rust (*Puccinia striiformis* Westend) are considered to be the most important ones.

Leaf rust (brown rust or orange rust) caused by *P. triticina* Eriks. (Anikster *et al.*, 1997) is considered to be the most serious of three rusts and universal in occurrence. It primarily infects the leaf blades and to a lesser extent leaf sheaths and glumes. Pathogen (*P. triticina*) being obligate after infection produces small white specks (Plate 1a) in susceptible genotypes and later light brown to brown uredial pustules are seen which are spherical to oval shaped (Plate 1b) with numerous uredospores produced by rupturing the host upper epidermis (Plate 1c). The widespread damage results in shriveling of grains and over all yields will reduce even may up to 40 per cent (Saari and Prescott, 1985).

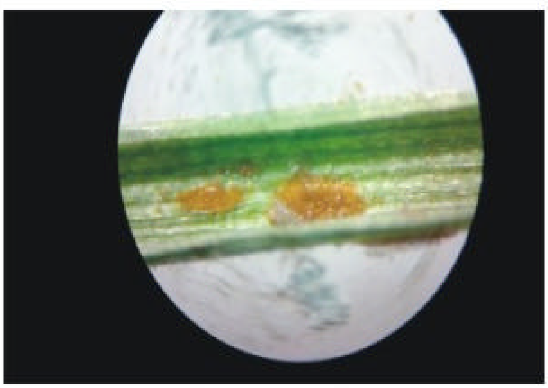
Wheat cultivation in peninsular zone : Research on wheat improvement in India is focused and driven by Indian Institute of Wheat and Barley Research (erstwhile Directorate of Wheat Research), Karnal. Area under wheat cultivation in India is divided in to six zones based on agro-climatic as well as geographic conditions *viz.*, north western plains zone (NWPZ), north eastern plains zone (NEPZ), central zone (CZ), peninsular zone (PZ), northern hills zone (NHZ) and southern hills zone (SHZ) (Plate 2).

Peninsular zone (PZ) comprises of southern states *viz.*, Maharashtra, Karnataka, Telangana, Andhra Pradesh, Tamil Nadu and Union territory of Goa and Dadra/Nagar Haveli. Of these Maharashtra and Karnataka contribute to maximum area under wheat cultivation and consequently maximum production in peninsular zone. All the three cultivated species of wheat *viz.*, aestivum (bread wheat), durum (macaroni wheat) and dicoccum (emmer wheat) belong to the genus Triticum and are cultivated in peninsular zone. *T. aestivum* is cultivated on maximum area (90-95 %) followed by *T. durum* (5-10 %) and *T. dicoccum* (<1 %). Cultivation of *T. dicoccum* (local name 'Khapli' wheat), is confined to very small area in Sangli, Satara, Kolhapur and Pune districts of Maharashtra and in parts of north Karnataka adjoining Maharashtra. *T. sphaerococcum* is sporadically cultivated in Maharashtra and Gujarat only. Maharashtra is the only state in PZ having substantial area under wheat followed by Karnataka having area limited only to 1/4th or 1/5th of Maharashtra. Lower production of wheat in Karnataka may be attributed to the fact that considerable area of wheat cultivation is under rain fed condition. Also peninsular zone is characterized by limited irrigation, area under wheat cultivation is reduced to half in rainfall deficit areas and exposure of wheat crop to terminal heat *i.e.,* high temperature between grain developments to maturity stage (Anon., 2016b).

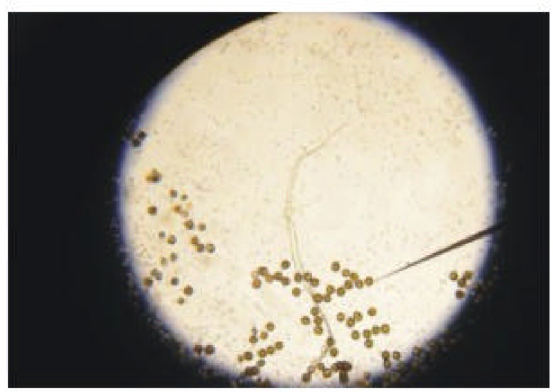
a) Initial leaf rust symptoms on leaves

b) Symptoms on leaf in seedling stage

c) Symptoms on flag leaf



d) Uredium of *P. triticina* (40X)



e) Uredospores of *P. triticina* (100X)

Plate 1: Symptomatology of wheat leaf rust

Plate 2: Agro-climatic zones of India

Slow rusting mechanism: The repeated appearance of new races has made to focus on different breeding approaches that utilize minor genes, conferring horizontal / non-race specific resistance, which is often characterised as slow development of rust disease in cereal crops. Slow rusting resistance in wheat, maize, sorghum, barley, oats, sunflower, groundnut and soybean has been studied in due course of time. The word slow rusting has been first time used by Caldwell *et al.* (1970) for resistance to leaf rust disease of wheat. Slow rusting is partial resistance partitioned in variable proportions between horizontal and vertical resistance. The purpose of using slow rusting cultivars is to substitute the stability of horizontal resistance for the instability often associated with vertical resistance.

The term slow rusting describes the ability of cultivar to retard rust development and is recognized particularly during epidemics of the rust. Slow rusting varieties are important to minimize the rate of spread of the disease and to check possible occurrence of epidemics without causing any adverse effect on the yield. This trait has been used for improvement of cultivars as recognized by infection types (Hayes *et al.,* 1925). Slow rusting or partial resistance is a useful measure of resistance as it is the result of all factors that influence disease development such as difference in environment, cultivars and population of pathogen. In the long run, this might be the cheapest way of controlling the rusts. It is encouraging for plant breeders as its components are predominantly controlled by genes with additive effects and therefore, rapid improvement of resistance is possible through selection. The delay in progress of epiphytotic development is attributed to several factors including increased latent period, number of uredosori per unit area, size of uredosori, rate of sporulation, *etc.* Chances of new variants or pathotypes are minimized due to reduced selection pressure.

In any pathological research, the major thrust areas of crop protection are crop health monitoring survey, understanding the variation in pathogenic population, host resistance and disease management (tillage operations and disease management). Park *et al.* (2011) stated that surveillance of wheat rust pathogens, including assessments of rust incidence and virulence characterization *via* either trap plots or race (pathotypes) surveys have provided information fundamental in formulating and adopting appropriate national and international policies, investments and strategies in plant protection, plant breeding and in rust pathogen research. Evolution of races is a continuous process with a fast thriving fungal obligates such as cereal rusts. Identification of prevalent races of *P. triticina* gives information on evolution of new races, its virulence and spread. Through this we can control possible epidemics and reduce yield loss.

The Coordinated, Wheat and Barley research programme under National Agricultural Research System (NARS) since its inception in 1965 have resulted in releasing more than 400 wheat varieties for different agro-climatic conditions in India. It includes several rust resistant varieties released for cultivation in peninsular zone of India. It includes varieties released during 1970s (HD-2189) which are still under cultivation along with recently released varieties. So there is a need to assess their mode of resistance, components of disease resistance and durability in relation to continuous evolution of new pathotypes of rust pathogen. It is found that the ever evolving leaf rust pathogen can be effectively controlled by three strategies *viz.*, long, medium and short term strategies. Identified slow rusters based on various parameters of slow rusting mechanism along with molecular level confirmation of reported slow rusting genes will offer long term strategy as they allow slow development of the pathogen without exerting selection pressure there by creating less variability of the pathogen. Those varieties which show immune to resistant reaction will act as medium term strategy and new molecules of fungicide chemicals acts as short term strategy for controling of the diseases in all the wheat growing regions.

Since a disease is the outcome of interaction between host, pathogen and environment, integrated disease management system has to be a part of the management strategy in wheat ecosystem which includes effective botanicals, bioagents, ITK's and finally chemicals. In recent days, propiconazole at 0.1 per cent has been recommended for the control of wheat leaf rust, but its continuous use may lead to development of resistance by the pathogen.

Hence, the present investigation was aimed at finding out mechanism of rust resistance in peninsular zone wheat cultivars, pathogenic race pattern and to develop integrated spray schedule for management of the disease. This would provide the basic understanding of components of slow rusting resistance, evolution of race pattern and eco-friendly disease management strategy. In view of the above, field investigation was carried out with the following objectives:

1. To conduct survey for foliar diseases severity in northern parts of Karnataka
2. To conduct screening and understanding the prevalence of races of *P. triticina* on peninsular zone released wheat varieties
3. To study the slow rusting mechanism in peninsular zone released wheat varieties
4. To develop integrated spray schedule for management of the disease

2. REVIEW OF LITERATURE

Among the several constraints towards realizing the potential yield in wheat, the rust disease poses major threat to wheat production worldwide including India. The leaf rust caused by pathogen *Puccinia triticina* Eriks. (Syn: *Puccinia recondita)* is an important foliar disease of common wheat, causing a yield loss up to approximately 63 per cent, if susceptible cultivars are grown (Singh *et al.,* 2005). It's a highly variable pathogen and it has gained additional virulence over a period of time rendering new wheat cultivars grown in India susceptible.

The use of cultivars with major gene resistance permits the selection of mutations at a single locus to render the resistance effectively in a relatively short time. However, due to selection pressure and evolution, new virulent races of the fungus appear which increase the need to develop durable resistance. Wheat rust races vary in virulence's and are capable of infecting different wheat cultivars (Nayar *et al.,* 1997). In order to minimize the crop losses due to sudden breakdown of resistance, variability in *P. triticina* was continuously monitored throughout India especially at primary foci of infection *viz.,* Nilgiri Hills in Tamil Nadu, through various management strategies such as gene deployment, gene cycling and use of slow rusting cultivars. The information on various aspects of present study such as survey, screening, race pattern, slow rusting mechanism and disease management is compiled in brief to present a general picture on the present investigation.

The efforts made to understand the work done by earlier workers in this direction, have been reviewed under the following headings:

2.0 History of wheat leaf rust

2.1 Survey (occurrence of the disease)

2.2 Screening of wheat varieties for leaf rust resistance

2.3 Race pattern of *P. triticina*

2.4 Slow rusting mechanism

2.5 Apparent rate of infection (r), area under disease progress curve (AUDPC)

2.6 Latent period, uredial density and uredial size

2.7 Development of integrated spray schedule for management of the disease

2.0 History of wheat leaf rust

Early records indicate that wheat was affected by blight, blast and mildew, which are now assumed to be at least, or in less part, due to the rust fungi. Excavations in Israel have revealed uredospores of stem rust that have been dated at about 1300 B.C. (Kislev, 1982). In early records wheat rust is not distinguished from stem rust (Chester, 1946). However, by 1815 De Candolle had shown that wheat leaf rust was caused by a distinct fungus and described it as *Uredo rubigo-vera*. The pathogen naming underwent a number of changes until 1956 when Cummins and Caldwell in 1956 suggested *P. recondite*, which is the generally used nomenclature today. In recent days the pathogen is named as *P. triticina* Eriks. as referred by Anikster *et al.*, 1997.

2.1 Survey (occurrence of the disease)

Wheat is susceptible to many diseases including the highly destructive ones like rusts (*Puccinia* spp.), septoria leaf blotches (*Septoria tritici*), fusarium head blight (*Fusarium graminearum*), smut (*Ustilago tritici*) and powdery mildew (*Erysiphe graminis* f.sp.*tritici*). Rusts are the most important diseases of wheat worldwide, in spite of great progress made in their control in many countries and considered as the major diseases of wheat since no other wheat disease could result in greater loss over large area in a given year. The persistence of rust as a significant disease in wheat can be attributed to specific characteristics of the rust fungi. 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 (Hailu and Woldeab, 2015). In this regard survey can detect new virulent phenotypes, provide a historic record of shifts in virulence to specific resistance gene and detect group of genetically similar isolates. Therefore, disease monitoring and surveillance are of paramount significant for sustainable wheat production and tackle food insecurity (Wang *et al.*, 2010).

As many surveys revealed, Karnataka and Maharashtra plays an important role in determination of virulence of the pathogen. The substantial area under wheat cultivation regularly acts as a geographical region of secondary foci of infection and residence for gaining extra virulence by the pathogen.

Navi (1986) reported the incidence of wheat leaf rust in off season wheat crop grown in many parts of Chikkamagalur and Chitradurga districts with severity ranging from traces to 10S.

Nargund (1989) carried out survey for leaf rust incidence in different talukas of Belagavi and Dharwad districts during *rabi* 1987-88 and 1988-89. He reported there was no incidence of leaf rust during *rabi* 1988-89 except in Athani taluk, where in late sown local wheat variety showed severity of 20S. During 1987-88, severe incidence of leaf rust was observed and the variety DWR-39 showed the severity to the extent of 20MS in both districts, whereas HD 2189 recorded TMR in Dharwad. Local varieties showed severity from 40S to 100S and the genotype Khapli to the maximum extent of 60MS.

Hasabnis (1998) reported the incidence of higher level of leaf rust during 1996-97 in Belagavi on varieties *viz.*, Agralocal, Amruth, DWR 162 and Local red up to 80S, 80S, 60S and 100S, respectively. During 1997-98 DWR 162 showed rust severity of 5MS to 90S in Karnataka. Similarly, MACS 2496 exhibited severity of 50S in the Maharashtra state.

Arunkumar (2013) reported variable proportion of rust incidence in northern parts of Karnataka particularly in Belagavi, Dharwad and Gadag with severity range of 10MS-100S, 20MS-100S and 40S-80S, respectively during *rabi* 2010-11 and 10MS-100S, 20MS-100S and 60S-80S respectively during *rabi* 2011-12.

On all India basis Singh *et al.* (2016) reported the overall wheat crop health status during *rabi* 2015-16. The appearance of brown rust was first time observed on 16th December, 2015 in sick plot of G. B. Pant University of Agriculture and Technology, Pantnagar but the severity of rust was maximum in Karnataka followed by Himachal Pradesh and Maharashtra in later stages of the cropping season. In Karnataka the brown rust was first observed on 18th February at Amminbhavi village of Dharwad taluk.

2.2 Screening of wheat varieties for leaf rust resistance

Screening of varieties to diseases is a primary and most important research work carried out in the past and also is continuing presently. Screening of breeding materials, released varieties, land races, germplasms *etc.*, is done for getting resistance source and to check their durability with respect to various agro-climatic zones and climatic conditions.

Navi (1986) screened 155 varieties for leaf rust resistance and found HD 2428, PBW 175, HUW 374, DL 254-2, HS 207, VL 639, DL 230-7, HD 2402, DL 230-6 and HI 1156 were immune to leaf rust whereas, remaining (144) varieties showed different rate of infection ranging from 20S to 80S severity.

Kalappanavar and Yashoda Hegde (2001) screened 100 wheat genotypes at Main Agricultural Research Station, Dharwad and reported that genotypes *viz.*, HD 365, WH 542 and HW 2045 were having less than 5.0 ACI values to both stem and leaf rusts over the years. Some genotypes were showed moderately resistance to rusts. Results indicated that HD 365, WH 542 and HW 2045 can be used as rust resistant source in resistance breeding programme.

Kalappanavar and Julie Nicol (2003) screened 140 wheat genotypes of CIMMYT, Turkey at Main Agricultural Research Station, Dharwad. They reported that around 25 genotypes were resistant to stem rust, leaf rust and leaf blight.

Kalappanavar *et al*. (2003) evaluated 100 wheat genotypes for three years and reported two genotypes PBW 500 and HW 2004 as immune and VL 822 and VL 829 as resistant to leaf rust.

Sinha *et al.* (2004) screened 50 exotic bread wheat genotypes comprising of four Indian genotypes (WH 542, UP 2338, HD 2172 and HD 2329) and rest from other countries for leaf rust at two locations. Most of the genotypes differed in their disease reaction across the two locations. However, a total of seven genotypes *viz.*, WH 542, Oasis/SKauz//*4BCN, KAUZ/KAUZ/STAR, CHIL/2*STAR, MIANYANG 20, CLC89/RABE and URES/JUN/KAUZ, exhibited good level of resistance at both locations.

Singh *et al.* (2004) evaluated 44 wheat lines for resistance to leaf rust. Among which, 14 wheat lines showed seedling resistance, while 30 lines showed seedling susceptibility to race 77-5. The 14 wheat lines possessing seedling resistance against 77-5 also showed adult plant resistance against pathotypes 77-5, 77-2 and 104-2, respectively.

Singrun *et al.* (2004) tested 225 wheat varieties from Kazakhastan, Mongolia and Russia for resistance to powdery mildew and leaf rust disease. They found that 115 cultivars/lines were susceptible to powdery mildew and 32 cultivars/lines showed an intermediate resistance response to leaf rust of wheat. However, 13 lines were completely resistant to all used isolates of the pathogen.

Patidar (2006) screened 1500 bread wheat accessions received from NBPGR, New Delhi against leaf rust during *rabi* 2004-05. Out of 1500 accessions under natural condition only 738 accessions proved resistant with an leaf rust intensity ranging from 0-20 per cent with chlorotic and necrotic lesions and small size of uredopustules. A total of 284 accessions confirmed moderately susceptible reaction with an intensity of leaf rust ranging from 20-50 per cent. Whereas 31 genotypes showed moderately resistant reaction against leaf rust, rest 447 accessions showed susceptible reaction.

2.3 Race pattern of *P. triticina*

In 1894, Eriksson showed that the cereal rust fungus *P. graminis* consists of different biological races that cannot be distinguished morphologically but differ in their pathogenicity to their cereal host; for example, some of them being able to attack wheat, but not the other cereals, such as oats and rye. Soon after, Stakman (1914) established that morphologically indistinguishable races of a pathogen within a pathogen species differ in their ability to attack certain varieties. The pathogen races can be distinguished by their ability to infect different varieties within a set of host differential varieties. Their work helped to explain why a variety that was resistant in one geographic area was susceptible in another, why resistance changed from year to year and why resistant varieties suddenly became susceptible. In all cases the change was due to the presence or appearance of a different physiological race of the pathogen.

In India the evolution of new pathotypes occurs in all the three rusts of wheat, rendering a resistant variety susceptible. There is a report of more than 26 pathotypes in 400 samples of leaf rust from 13 states of India and Nepal during 2010. 121R63-1 was the most predominant pathotype followed by 21R55 in the Indian sub continent. Monitoring of rust being done every year through extensive surveys and planting trap plot nurseries at hotspot locations of the Indian subcontinent (Indu Sharma and Saharan, 2011).

Kulkarni (1978 and 1979) reported common leaf rust race flora as 12, 77, 77A, 77B, 162 and 162A at different locations in Karnataka during late 1970s. Pathogenicity surveys after 1980s revealed the dominance of 77 and 104 race group (Nayar *et al.*, 1985). Farmers grow wheat crop during the off season in the plains of Chikmagalur and Chitradurga districts of Karnataka and in these areas heavy incidence of leaf rust have been reported (Kulkarni, 1984 and Hedge, 1991).

According to Joshi (1986) leaf rust pathogen races 12 and 77 prevailed during period of 1965 to 1980, while race 162 in 1965-75, 162A in 1966-70 and 104 in 1971-80 dominated the population at national level. Nargund (1989) found that the leaf rust races *viz.*, 77 (45R31), 77 (109R31) and 77A-1 (109R23) were the most predominant in Karnataka during 1987-88.

Hasabnis (1998) surveyed different districts in Karnataka and Maharashtra states during 1996-97 and 1997-98 for virulence monitoring. He reported that, pathotypes from group 77 were widely distributed in surveyed areas.

Kiyar (2002) reported the prevalence of leaf rust races 77-5, 77-3 from group 77, races 12-2 and 12-5 from group 12 and race 104-2 in Dharwad and Belagavi districts during the year 2001-02.

Reports are also available on existence of predominant leaf rust races in Karnataka from 1996-97 to 2005-06. The races 17R63, 29R23, 21R63 and 121R55-1 were prevalent during 2001-02 and 2002-03, respectively and race 121R55-1 a new pathotype detected in few samples during 2002-03. In the year 2003-04 and 2004-05 the race 121R63-1 was most predominant. During the year 2004-05 a new pathotype

253R31 was reported from few samples and known to have virulence on *Lr*19. During 2005-06 race 253R31 was most predominant followed by 121R63-1 (Kalappanavar *et al.*, 2006).

In India, during the last 21 years, around 23 *P. triticina* pathotypes were observed with identification of new pathotypes 125R28 and 93R37. Among these 10 pathotypes were observed from group 12 and 13 and group 77. Among these 9 pathotypes (4 of group 12 and 5 of group 77) have combined virulence for both *Lr*23 and *Lr*26 (Bhardwaj *et al*,. 2011).

During the cropping season 2011 and 2012, leaf rust pathotype, 121R63-1 (77-5) was dominant and distributed in 35.71 per cent and 58.90 per cent area, respectively. Occurrences of a diverse population of pathotypes in Karnataka some of which (12,104,162 group of pathotypes) do not occur in Nilgiri hills reveal that the surveyed areas form a different focus of infection (Arunkumar, 2013).

Mc Callum *et al.* (2013) analyzed 110 *P. triticina* uredinial isolates for their virulence spectra (frequency and distribution) collected across Canada, during 2009 using 16 near isogenic wheat lines inoculated at the seedling stage. They identified most common virulence phenotypes TDBJ (28.1 %), MLDS (20.6 %) and TDBJ (15.8 %) and reported around 20 unique virulence phenotypes among 269 isolates.

Recently in the cropping season 2015-16 nineteen pathotypes of *P. triticina* were identified on 232 samples analyzed from 13 states of India, Nepal and Bhutan. The pathotype 77-9 (121R60-1 = MHTKP) was most frequent and observed in 93 samples, followed by 77-5 (121R63-1 = THTTM) and 104-2 (21R55 = PHTTL), which were identified in 46 and 38 samples, respectively. *P. triticina* population was highly diverse in Karnataka and Himachal Pradesh as 19 pathotypes each were observed in these two states. In Karnataka pathotype 77-9 was most frequent followed by pathotype 77-5 and 104-2. In Uttarakhand, pathotype 104-2 was most frequent whereas in Himachal Pradesh pt 77-9 and 104-2 were more predominant. In Chattisgarh, pathotype 77-9 was found in maximum number of samples whereas 77-5 and 104-2 identified only in one and three samples, respectively (Singh *et al.*, 2016).

2.4 Slow rusting mechanism

The term slow rusting describes ability of a cultivar to retard the rate of rust development. Slow rusting is a type of coexistence between the host and the pathogen, wherein the host is neither benefitted nor harmed. It is an intermediate expression of host defense system against the invading pathogen. The rapid loss of race specific resistance (Vertical resistance, VR) to cereal rusts in early 1970's has attracted the attention of plant breeders and plant pathologists to other form of resistance which may be more durable and long lasting such as slow rusting resistance, recognized by slow rate of rust development on cultivars showing susceptible type of infection. It is encouraging for plant breeders as the slow rusting and its components are predominantly controlled by genes with additive effects and therefore, rapid improvement of resistance is possible through selection.

Most of the research works in late 1970's (Ohm and Shaner,1976., Kuhn *et al.*, 1978., Kulkarni and Chopra,1980) on various components of slow rusting resistance revealed that it is race non specific and long lasting with various mechanisms such as, decreased frequency of penetration, slower invasion of the host tissue, reduced infectivity, longer latent period, reduced pustule size, reduced pustule expression, lower sporulation rate, reduced spore deposition, reduced pustule weight and shorter infection period. Soon after many researchers started to identify the cultivars with slow rusting characters and thus are designated as slow rusters based on various above mentioned characters and those with high susceptibility are referred as fast rusters.

Gupta and Singh (1982) rated wheat varieties, UP 310, Janak, WH 147,GLR 1 and GLR 22 as slow-rusting to *P. recondita* f.sp *tritici* in the field during 1976–79 crop seasons, as these varieties allowed lower infection rate as compared to fast rusting varieties Lal bahadur, HI 601 and Kalyansona. These slow-rusting varieties showed longer incubation period, fewer uredospores per pustule and early conversion of uredia into telia on flag leaves as compared to fast rusting Lal bahadur and all the other varieties tested under glasshouse conditions.

Jalinder (1983) studied slow rusting mechanism in 16 varieties of wheat. UP 301, DWR 16, HD 2189 and DWR 26 remained free from infection throughout and varieties WH 147, WL 711, Sonalika, C 306 and HD 4502 were identified as slow rusters, whereas, Agra local, Kalyansona, Narmada, NI 5439 and Lal bahadur were identified as fast rusters.

Shaner (1983) observed linear growth of uredia with time on some slow and fast rusting wheat cultivars infected with *P. recondita*. The average rates for fast rusting Morocco, Monon and Suwon 92 were 0.07, 0.05 and 0.04 sq. mm per day, while for the slow rusting CI 13227 and Suwon 85, 0.03 and 0.02 sq. mm per day, respectively.

Navi (1986) recorded the slow rusting mechanism in eighteen varieties, nine from *T. aestivum* and nine from *T. durum* based on the terminal severity (coefficient of infection). Among aestivum varieties CC 464, DWR 39, DH 2189 and DWR 16 have shown slow rate of rust development (Terminal severity 5MR, 5MR, 30MS and 30S, respectively) and these are classified as slow rusters. Among the nine varieties of *T.durum* Raj 1555, DWR 137, HD 4502 and DWL 5023 have shown the slow rate of rust de velopment with terminal severity 10MR, 10X, 10X and 10MS, respectively.

Nargund (1989) studied slow leaf rusting mechanism in 11 varieties of *Triticum aestivum* L. and nine varieties of *T. durum* Desf. Wheat varieties *viz.*, AKW 65-1, NI 5439, Kalyansona and Lal bahadur of *T.aestivum* and Local red, AP-30-1 and Amrut of *T.durum* were identified as fast rusters and varieties *viz.*, DWR 39, Keerti, HD 2189, WH 147,WH 146 and HI 977 of *T. aestivum* and Kiran, Bijaga yellow, MACS 1967 and Raj 1555 of *T. durum* were identified as slow rusters based on the average coefficient of infection (ACI) values at different stages of crop growth, area under disease progress curve (AUDPC) and grain yield at maturity.

A study (Singh *et al.*, 1991) of spring bread wheat germplasm developed at CIMMYT showed highly significant phenotypic variability for each component of partial resistance (namely, uredial appearance, latency period, uredial number and uredial size differences within the high infection types) to *P. recondita* f.sp. *tritici*. The study revealed that all of these wheat genotypes displayed a longer uredial appearance and latency periods and decreased uredial number and uredial size when compared to the susceptible check cultivar 'Morocco'. Disease progress was negatively correlated with uredial appearance and latency periods, whereas a positive correlation was observed with uredial number and uredial size. Certain genotypes displayed high levels of partial resistance resulting in low disease severity in the field.

Khan *et al.* (1997) reported that out of ten wheat varieties evaluated for slow rusting, the varieties Chenab 70, WL 711 and Pak 81 were fast rusting cultivars with 11.22, 19.73 and 13.88 per cent grain yield losses, respectively. The cultivars LU 26, V 87094 and V 8829 were moderately slow rusters with 8.10, 9.28 and 5.19 per cent yield losses, respectively and Paven, FSD 85 and INQ 91 were slow rusters.

Mahoto *et al.* (2001) analyzed 43 bread wheat varieties from Nepal against fifteen pathotypes of *P. recondita* f. sp. *tritici* prevalent to south Asia. They postulated genes *viz.*, *Lr*1, *Lr*3, *Lr*9, *Lr*10, *Lr*13, *Lr*23 and *Lr*26 in these bread wheat lines some of which conferring slow rusting characters in these lines.

Bhardwaj *et al.* (2005) stated an integrated strategy using a combination of diverse resistance genes, deployment of cultivars by using pathotype distribution data, slow rusting and adult plant resistance to curtail selection of new pathotypes and prevent rust epiphytotics.

Patidar (2006) characterized genotypes HD 2189, HW 2021 as slow rusters. These genotypes recorded low ACI, low AUDPC, considerable more latent period, medium pustule size, pustule density and less rate of infection with good quantity of yield per hectare. However, genotypes DWR 195, DWR 162 and MACS 2496 recorded maximum ACI and relevant adverse values compared to slow leaf rusting genotypes and identified as fast rusters.

Sareen *et al.* (2012) investigated slow rusting resistance in 15 wheat genotypes at pathological and molecular level to characterize slow rusting genes like *Lr* 46 and *Lr* 50 under field condition.

2.5 Apparent rate of infection (r), area under disease progress curve (AUDPC)

Van der Plank (1963) suggested the calculation of apparent infection rate (r) or apparent rate of infection to quantify the rate of disease development. The r value has been used to evaluate data on effectiveness of sanitation, fungicidal application and cultivar resistance (Fry, 1978; Penny packer *et al.,* 1980 and Van der Plank, 1963).

Wilcoxson *et al.* (1975) made evaluation of wheat cultivars for ability to retard development of stem rust. They further observed that the AUDPC value to be reliable and convenient to evaluate varieties under field condition, but not rate of development (r) as it gives instantaneous status of the disease development. Luke *et al.* (1975) observed that slow rusting in some cultivars of oats to crown rust was characterized by slower infection rate as compared to the susceptible cultivars. These cultivars usually showed a lower percentage of infection throughout the growing season.

Shaner and Finney (1980) used modified formula to calculate area under disease progress curve and found that under unfavorable weather, there was little difference in the level of mildew between two cultivars namely, Knox and Vermillion. The AUDPC had a lower error variance, hence a superior measurement of slow mildewing.

Sabharwal (1986) studied the leaf rust development on four wheat cultivars under field conditions. Maximum AUDPC value was found in Lal bahadur followed by WH 147 and least in Arjun. Nargund (1989) employed AUDPC to evaluate bread and durum wheat varieties against leaf rust. The wheat varieties *viz.*, AKW 65-1, Lal bahadur and NI 5439 of *T. aestivum* and Local red and Amrut of *T. durum* recorded higher values of AUDPC with lower grain yield.

Nargund (1989) studied the rate of spread of leaf rust per unit area per day in *T.durum* and *T.aestivum* varieties. The variety, Raj 1555 (0.2377) of *T. durum* and Kalyansona (0.4170) and Sonalika (0.3798) of *T.aestivum* showed maximum rate of spread. Further, he reported no relationship between “r” value and slow rusting nature of varieties and concluded that “r” values are not useful as AUDPC values in studying the slow rusting nature of cultivars.

Nagesha *et al.* (2005) studied the slow rusting characters in nine sunflower genotypes with a more focus on apparent rate of infection ‘r’ and AUDPC. In their investigation they found that the ‘r’ value varied and at times they did not remain constant for a given genotype and also did not show a particular trend which is attributed to genetic character of the genotype. The AUDPC values differed considerably for different genotypes. The highest AUDPC value was observed in Morden (1691.20) followed by NSH 160 (1503.67), Kaveri 618 (1467.17). In general AUDPC values take care of initial rust severity, rate of infection and also the terminal severity. Hence, based on AUDPC values, PAC 36, PAC 304 and GK 2002 could be termed as slow rusters, the intermediate types were DSH 1, MSFH 17 and KHSH 1, whereas the genotypes Morden, NSH 160 and Kaveri 618 were considered as fast rusters and highly susceptible.

Shahin *et al.* (2012) studied the slow rusting resistance in 20 wheat cultivars to yellow rust in Egypt. The slow rusting resistance at adult plant stage was assessed through the determination of infection type (IT), disease severity (DS), relative area under disease progress curve (rAUDPC) and coefficient of infection (CI). The cultivars *viz.*, Giza 168, Gemmeiza 7 and Sakha 94 exhibited the lower CI and rAUDPC and could have slow rusting resistance. The correlation analysis of different parameters also showed strong relationship of CI with rAUDPC (R^2=0.93).

2.6 Latent period, pustule density and size

The above three characters are identified as three stages of pathogenesis in rust pathogen. The effects of slow rusting characters on these stages of pathogenesis may be considered as components of slow rusting (longer latent period, restricted pustule size, fewer pustules per square centimeter area) and these can be effectively utilized for characterization of wheat genotypes for this type of resistance.

Ohm and Shaner (1976) observed the latent period in two slow and two fast rusting cultivars of wheat under glass house inoculations with *P. recondita* f.sp. *tritici*. They observed that the appearance of pustules was protracted on Suwon 85 and P 6028l, the latent period being longer by a factor of 1.2 to 1.8 compared to that of slow rusting, Suwon 92 and Monon.

Kapoor and Joshi (1981) studied slow rusting components in six susceptible wheat cultivars at seedling and flag leaf stage to race 122 of *P.graminis* f.sp. *tritici* under glass house conditions. The cultivar, Sonalika produced fewer flecks and pustules per cm^2 than Agra local and Kharchia. The latent period for Sonalika was 1 to 2 days longer than Kharchia and Agra local. Hence, they opined that latent period and pustule density per unit area of leaf are the important components of slow rusting.

Kulkarni *et al*. (1982) concluded that latent period, infectibility and sporulation were the most important components of slow rusting in wheat with *P.recondita* f.sp. *tritici.* These factors collectively determine the rate of disease development in an additive manner.

Sokhi and Singh (1984) studied the slow rusting in cultivars of *Pennisetum americanum* L. inoculated with *Puccinia penniseti* [*P. substriata var. penicillariae*]. The incubation period in slow rusting lines was 9 days compared with 6-7 days in fast-rusting lines and 13-14 days with fast rusting cultivars. The number and size of uredinia and uredospore production were less in most of the slow rusting cultivars.

Pascual and Dalmacio (1987) studied sorghum genotypes against *Puccinia purpurea* Cooke using resistant (slow-rusting 3755 and BTx623), moderately resistant (CS174) and susceptible (ULP Sg5) genotypes. They showed that resistance significantly lengthened the latent period by 3-7 days (42-100 %), shortened the infectious period by 5-14 days (14-38 %), reduced sporulation capacity by 51-74 %, reduced pustule size by 44-69 % and lowered infection frequency by 49-78 %. Analysis revealed that association among resistance components was strong but the degree of association differed. Latent period duration was the best factor for distinguishing the resistance of genotypes. To select for slow-rusting resistance, it is recommended that plants has to be examined in the field 15-20 days after inoculation, when differences in the density of uredia and the size of pustules between slow- and fast-rusting genotypes would be at their greatest.

Reddy and Khare (1988) while evaluating six cultivars of groundnut differing in susceptibility to *Puccinia arachidis* Speg. found that the resistant cultivars had longer incubation period, lower pustule density and smaller pustules than susceptible one.

Nargund (1989) studied slow leaf rusting mechanism in 11 varieties of *Triticum aestivum* L. and 9 varieties of *T. durum* Desf. Wheat varieties *viz.*, AKW 65-1, NI 5439, Kalyansona and Lal bahadur of *T. aestivum* and Local red, AP-30-1 and Amrut of *T. durum* were identified as fast rusters and varieties *viz.*, DWR 39, Keerti, HD 2189,WH 147, WH 146 and HI 977 of *T. aestivum* and Kiran, Bijaga yellow, MACS 1967 and Raj 1555 of *T. durum* were identified as slow rusters based on the average coefficient infection (ACI) values at different stages of crop growth, area under disease progress curve (AUDPC) and grain yield at maturity.

Wilson (1994) evaluated pearl millet inbreds Tift-383, 700481-21-8 and ICMP 501 for partial rust resistance (*P. substriata var. indica*.) in comparison to susceptible inbred Tift 23 DB. In field trials AUDPC of the three inbreds was less than that of Tift 23 DB when disease pressure was severe. Uredinium dimensions on seedlings at 10 days after inoculation were smaller for the three inbreds than for Tift 23 DB.

Singh *et al.* (2003) studied leaf rust resistance gene *Lr* 34 to confer slow rusting resistance in wheat (*T. aestivum*). Greenhouse experiments were conducted to evaluate the effect of this gene on three components (latent period, uredinium size and receptivity) of slow rusting resistance at seven plant growth stages of the *Lr* 34 near-isogenic lines, Jupateco 73R and Jupateco 73S at three temperatures (13, 18 and 23 ^{0}C). The presence of *Lr* 34 increased the latent period and reduced uredinium size and receptivity. Although effects of *Lr* 34 could be seen at each growth stage, differences in latent period and receptivity between the isogenic lines increased dramatically from the four leaf stage onwards and stabilized by the five leaf stage. The relative effect of the *Lr* 34 gene on latent period decreases and the receptivity increases with increasing temperature. Uredinium size was least affected by temperature and growth stage.

Patidar *et al.* (2007) characterized two wheat genotypes *viz.*, HD 2189 and HW 2021 as slow rusters. These genotypes recorded low ACI, low AUDPC, more latent period, medium pustule size, pustule density and lesser rate of infection with good quality of yield per hectare. However, genotypes, DWR 162, DWR 195 and MACS 2496 recorded maximum ACI compared to slow leaf rusting genotypes and identified as fast rusters.

Sunkad and Kulkarni (2008) studied the slow rusting ability of 21 groundnut genotypes against *P. arachidis*. Ten genotypes *viz.*, Dh 22 (Red), Dh 22 (Tan), GPBD 4, K 134, R 8808, R 9214, R 9227, R 2001-1, R 2001-2 and R 2001-3 showed longer latent period, lesser number of pustules per unit area, smaller pustules, low amount of uredospores per pustule, lesser per cent disease index, rate of infection and AUDPC compared to fast rusting genotypes and were categorized as slow rusters.

Maqsood *et al.* (2012) evaluated 59 spring bread wheat (*T. aestivum*) genotypes for the presence of the *Lr* 34/*Yr*18 linked csLV34 allele using STS marker csLV34 to determine the effect of this gene complex on the components of partial resistance (slow rusting) in wheat to leaf/stripe rust. The components of partial resistance including latency period (LP) and infection frequency (IF) were studied on primary leaf (seedling stage), fourth leaf and fully expanded young flag leaf (adult plant stage). Both the stripe and leaf rust fungi showed a prolonged LP and reduced IF on genotypes carrying *Lr* 34/*Yr*18 gene complex. Generally, a longer LP was associated with a reduced IF at all growth stages. Although significant effect of *Lr* 34/*Yr*18 gene complex on LP and IF was observed almost at all three growth stages, the effect was more pronounced at flag leaf. This suggested that *Lr* 34/*Yr*18 gene complex is more effective at later stages of plant growth.

Sareen *et al.* (2012) studied the pathological and molecular characterization of slow rusting in 15 wheat genotypes. The slow rusting genotypes showed lesser AUDPC and longer incubation period. The genes *Lr* 46 and *Lr* 50 were identified as slow rusters and resulted in longer latent period, reduced uredium size and lower AUDPC in field epidemics.

Arunkumar (2013) identified genotypes UAS 326, UAS 315, VL 616, VL 924, HD 2189, HD 2932, HD 3091, NI 5439, HI 977, HS 420, DBW 16, KRL 210, Pavon 76, RL 6073 and Parula as slow rusters based on low terminal disease severity, less rate of disease development, minimum value of AUDPC, longer latent period, lower pustule density and smaller size of uredinium.

The elite bread wheat genotypes HD 2183 and GW 322 were reported as slow rusters based on the studies on slow rusting components such as low terminal disease severity, slow rate of disease development, minimum values of AUDPC, lower pustule density and smaller size of uredinium (Goolappa, 2015).

Hanamanth and Patil (2016) studied five components of slow rusting resistance *viz.*, latent period, uredial density, uredial size, apparent infection rate (r) and area under disease progress curve (AUDPC) in nine pearl millet genotypes for assessing the nature of slow rusting or partial resistance. Pearl millet genotypes, J 2496 (2786.70), J 2510 (3240.30), J 2517 (3175.55) and 70 SB 13 (3175.55) recorded lower values for AUDPC and increased latent period (11-12 days) and decreased uredial density (5.25/cm^2 to 6.16/cm^2). They also reported that AUDPC, latent period and uredial density per unit area appears to be the significant components in selecting the slow rusting genotypes.

2.7 To develop integrated spray schedule for management of the disease

Integrated Disease Management (IDM) is the optimization of pest control measures in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production whilst minimizing hazards to humans, animals, plants and the environment (Walters *et al.*, 2012). This definition has the merit of stressing the importance of optimization, since there are trade-offs and compromises involved and many different goals to be reconciled. IDM is a sustainable approach to manage disease by combining biological, cultural and chemical tools in a way that minimizes economic, environmental and health risks. Here, IDM is seen as a continuously improving process in which innovative solutions are integrated and adapted locally as they emerge and contribute to reducing reliance on pesticides in agricultural systems.

Fungicides

Fungicides can supplement the use of resistant cultivars to control pathogens when (a) a new race of the rust fungus occurs and the disease threatens to become epidemic (b) the expression of rust resistance depends on environmental factors and weather changes to favor rust development, or (c) the rust epidemic is occasional in areas where the disease is too rare to justify breeding programs (Cook, 1991).

Navi (1986) evaluated six fungicides bayleton, calixin, vigil, rovral, dithane M 45 and dithane Z 78 on leaf rust management. He reported least disease incidence (16.74 %) in plots sprayed with bayleton at 250 g a.i. per ha followed by calixin (18.44 %), vigil (24.04 per cent) as compared to control (71.19 %).

Daniel *et al.* (2000) opines that fungicide application and P fertilization are important management tools for reducing disease and increasing wheat yield. P fertilization increased yield as much as by 60 % compared with no P along with foliar fungicide propiconazole (Tilt) applied @ 0.13 kg a.i. ha^{-1}. Resistant cultivars are more responsive to P. However, fungicide application diminished the magnitude of leaf rust and enhanced yield, especially for susceptible cultivars.

Basandrai *et al*. (2013) evaluated six triazole fungicides *viz.*, propiconazole (tilt 25 EC), triadimefon (Bayleton 25 EC), difenoconazole (score 25 EC), mono- and di- potassium salts of phosphorous acid (topaz), fenarimol (rubigan 12.5 EC) applied @ 0.1 per cent, hexaconazole (contaf 5 EC) @ 0.2 % along with mancozeb (Indofil M 45 @ 0.25 %) against leaf rust using variety sonalika. The least rust severity (0.6 %) was recorded in plots sprayed with difenconazole (0.1 %). However, the plots sprayed with propiconazole @ 0.1 per cent resulted in the higher grain yield (49.1q ha^{-1}) followed by triadimefon (46.9q ha^{-1}), difenconazole (46.4q ha^{-1}) and fenarimol (45.6q ha^{-1}).

Arunkumar (2013) reported that among different chemicals sprayed the combiproduct fungicide pyraclostrobin 13.3 % + epoxiconazole 5 % (opera 18.3 % SE) @ 0.1 per cent with two sprays at an interval of 45 and 60 days after sowing (DAS) was best alternative to the propiconazole @ 0.1 per cent for the control of wheat leaf rust.

Chaudhary and Chaudhary (2013) tested the efficacy of fungicides (systemic and non systemic) and twenty plant extracts in inhibition of uredospore germination of *P. triticina* causing wheat leaf rust. They reported the maximum inhibition of uredospore germination in mancozeb (54.85 %) followed by chlorothalonil (40.89 %) at 1000 ppm. Among systemic fungicides, propiconazole was found to be the best for inhibition of 86.03 per cent uredospores germination followed by hexaconazole and penconazole with 77.40 and 72.29 per cent, respectively.

Utpal *et al.* (2013) reported, tebuconazole 250 EC (4.78 % urediniospores germination) as superior among the eight systemic fungicides evaluated *in vitro* condition against *Puccinia sorghi* at different concentrations. Among the non-systemic fungicides mancozeb + phyton (7.24 % urediniospores germination) was superior followed by mancozeb (24.44 % urediniospores germination) at different concentrations screened *in vitro*. Also the fungicides revealed higher efficacy with the increase in concentration levels.

Commercially available plant based products

Syed (1999) evaluated efficacy of different plant extracts against groundnut rust in field condition with three sprays at 15 days interval. Among the different plant extract treatments neem leaf extract @ 5 % recorded minimum per cent disease severity of 19.96 per cent which was on par with NSKE @ 5 % (20.23 %) followed by *Tridax procumbens* (21.63 %), *Pongamia* (22.68 %), *Datura stramonium* (22.68 %) and *Prosopis julifera* (23.23 %).

Ayoub and Niazi (2001) reported effectiveness of leaf extracts of four poisonous phanerogamic plants in controlling wheat leaf rust. Leaf extracts of *Nerium odorum, Calatrop is gigantean, Azadiracta indica* and *D. stramonium* have 40, 60, 45.45, 56.96 and 81.81per cent decrease of disease severity over control, respectively. Whereas the fungicide baytan decrease the disease severity by 84.84 per cent, which was on par with *D. stramonium.*

Patil (2009) evaluated antifungal activity of commercially available plant products *viz.*, neem oil, margotricure, nimbicidine, neem gold at 0.5 per cent and wanis at 1.0 per cent against soybean rust sprayed thrice at an interval of 10 days starting from the onset of disease. Among these nimbicidine recorded lowest rust severity of 40.74 per cent, followed by neem oil (48.14 %), margotricure (53.08 %), neem seed kernel extract (NSKE) (58.02 %) and wanis @ 1.0 per cent (70.26 %) were found next best and were on par with each other.

Cawood *et al.* (2013) reported the importance of plant extracts in enhancing host plant defense mechanism. Treatment of susceptible and resistant wheat cultivar with *Agapanthus africanus* extract followed by *P. triticina* infection led to the stronger expression of PR2, PR3 and PR9 genes as compared to the control. They also reported the existence of fortuitously identified retrotransposon protein encoding gene after treatment with *A. africanus* extract.

Dey *et al.* (2013) reported the importance of botanicals in rust disease management. Among different commercially available plant based products neemazol F5 % is superior in inhibition of uredinospore germination of *P. sorghi* (per cent spore germination, 6.55 %) followed by nimbicidine (6.83 %) at different concentrations.

Shabana *et al.* (2016) tested the efficacy of eight plant extracts (garlic, clove, garden quinine, Brazilian pepper, anthi mandhaari, black cumin, white cedar and neem) in controlling wheat leaf rust both under *in vitro* and *in vivo*. *In vitro*, all treatments inhibited spore germination by more than 93 per cent. Neem extract recorded 98.99 per cent inhibition of spore germination with no significant difference from the fungicide sumi-8 (100 %). Under greenhouse conditions, seed soaking application in neem extract (at concentration of 2 ml/l) resulted in 36.82 per cent reduction in the number of pustules per leaf compared with the untreated control. Foliar spraying of plant extracts on wheat seedlings decreased the number of pustules/leaf. Spray application of wheat seedlings with neem, clove and garden quinine extracts, four days after inoculation with leaf rust pathogen completely prevented rust development (100 % disease control) and was comparable with the fungicide Sumi-8.

Bioagents

Patidar (2006) evaluated efficacy of *T. harzianum*, *P. fluorescence* and *B. subtilis* against leaf rust of wheat both under *in vitro* and *in vivo* condition. *In vitro* studies revealed that mean maximum uredospore germination inhibition was observed in *T. harzianum* (61.76 %) followed by *B. subtilis* (51.60 %) and *P. fluorescence* (40.86 %). In field evaluation the spraying of *T. harzianum* showed least ACI (8.13) followed by *P. fluorescence* (10.19 ACI) and *B. subtilis* (13.87 ACI).

Hamdy *et al.* (2001) tested effect of three bioagents *viz.*, plant guard (*Trichoderma. harzianum*), yeast (*Saccharomyces cerevisiae*) and Rhizo-N (*Bacillus subtilis*) against leaf rust of wheat and reported significant reduction in leaf rust severity of 96.3, 81.5 and 71.1 per cent, respectively. Application of yeast and plant guard also resulted significant increase in grain yield of wheat by about 53.28 and 45.5 per cent, respectively.

El-Sharkawy *et al.* (2014) observed that inoculation with two bio-agents *viz.*, *T.harzianum* and *Streptomyces viridosporus* on genotypes Morocco and Sids-1 against leaf rust disease of wheat increased both incubation period (IP) and latent period (LP) of the disease and decreased the number of pustule per cm^2, than the uninoculated control.

The results revealed that the amount of photosynthetic pigments, chlorophyll a, b was lower in the infected plants than in healthy ones. It also indicated that spraying the plants of both the genotypes with the tested bioagents decreased significantly leaf rust severity (%), increased spike weight (g), grains weight per spike (g) and 1000 kernel weight (g) as compared with unsprayed control.

Indigenous Technology Knowledge (ITK's)

Borgen and Krishtensen (2001) examined that seed treatment of wheat with milk powder which fully controlled the *Tilletia tritici* (Bjerk.) Wint. and was found to increase the germination vigor of the seeds and produced the healthy seedlings.

Patidar (2006) evaluated efficacy of four ITK’s *viz.*, cow urine, vermiwash, butter milk and panchagavya at 5, 10, 15 % concentrations both under *in vitro* and *in vivo* condition against leaf rust of wheat. The mean maximum uredospore germination inhibition was noticed in panchagavya (4.15 %), followed by vermiwash (28.61 %) and butter milk (28.42 %). In field condition vermiwash at three per cent concentration reduced leaf rust to maximum extent (7.78 ACI) followed by panchagavya (8.07 ACI) and butter milk (8.83 ACI).

Patil (2009) evaluated five ITK's *viz.*, cow urine (10 %), cow milk (2 %), panchagavya (3 %), buttermilk (10 %) and vermiwash (50 %) against soybean rust under field condition along with check fungicide hexaconazole at 0.1 per cent. There was significant difference among the treatments as check fungicide, hexaconazole recorded significantly low rust severity (44.63 %) followed by cow milk (50.42 %) and it was on par with each other. Cow urine at 10 per cent and vermiwash at 50 per cent were found next best in reducing the rust severity and were on par with each other.

Utpal *et al*. (2011) tested ITK’s against *P. sorghi*, jeevamruta at 20 per cent concentration caused significantly less per cent uredospore germination (22.69 %) followed by panchyagavya at 20 per cent (33.67 %).

Nagaraj and Patil (2014) evaluated five ITK's *in vitro* against inhibition of spore germination of *Puccinia substriata* var. *indica*. by following cavity slide method. Irrespective of ITK's concentration, cow urine (82.14 %) was found best in inhibition of uredospore germination followed by cow milk (79.92 %) and were on par with each other. Next best was panchagavya (75.84 %) followed by butter milk (73.37 %) and were statistically on par with each other. Significantly least inhibition was noticed in vermiwash (65.47 %).

Integrated spray schedule for management of the disease

Spraying with neem leaf extract (2 %) in combination with recommended fungicides recorded numerical superiority in reducing leaf spot and rust incidence in groundnut (Shivashankar and Kadam, 1993).

Sajid *et al.* (1995) studied the comparative effects of neem products and baytan against leaf rust of wheat in the laboratory. Neem oil and baytan (Triademinol) completely inhibited germination of *P. recondita* f.sp *tritici* uredospores. In the field neem oil at 4 per cent concentration checked leaf rust on wheat after four applications but baytan at 0.1 per cent showed excellent rust control resulting in higher yield.

Patil (1996) reported that, the addition of neem seed kernel extract and amaranthus leaf extracts in the spraying schedule along with propiconazole was found to be effective in reducing the severity of sunflower rust at all the stages of crop growth. Area under disease progress curve (AUDPC) values was less in the plant extracts applied plots compared to control. When the fungicide applied with the plant extract in sequence, the disease severity and AUDPC values were more or less on par with the fungicide application alone. Maximum B:C ratio obtained in propiconazole (0.1 %) – amaranthus (5.0 %) – propiconazole (0.1 %) (1:3.2) followed by propiconazole (0.1 %) – nimbicidine (0.5 %) - propiconazole (0.1 %) (1:3.80) spray schedule.

Anahosur *et al.* (2000) observed that use of nimbicidine (0.5 %) inter mixed with hexaconazole (0.1 %) sprays reduced the sorghum rust and thereby increased the yield compared to control and this spray schedule was found to be economic in operation.

Sunkad (2004) reported that among the different triazoles (difenconazole, propiconazole, hexaconazole) and NSKE sprayed on groundnut crop to control rust, the alternative spray of hexaconazole and NSKE (H-N-H) showed mean PDI of 30.47 with per cent disease reduction of 51.57 compared to all treatments with the highest B:C ratio of 4.58.

Kalappanavar *et al.* (2008) reported that among the 13 treatments imposed fungicide propiconazole performed best followed by triadimefon and hexaconazole. However, in different categories, neem leaf extract, *T. harzianum* and panchagavya were the succeeding treatments effective against leaf rust of wheat. The yield of propiconazole, triadimefon and hexaconazole sprayed plots were significantly superior over control indicating marked influence of leaf rust on yield.

Khedekar (2012) reported that integrated management of soybean rust with adaptive module consisting of seed treatment with *T. harzianum* (6g/kg) + *Rhizobium* (500 g ha^{-1} seeds) followed by spraying neem oil (0.5 %) at 45 DAS and second spray with hexaconazole (0.1 %) at 60DAS followed by a combined spray of kresoxim methyl (0.1 %) and *P. fluorescens* (0.5 %) at 75DAS is best strategy to control disease with lower PDI of 52.90 and higher grain yield of 30.80 q ha^{-1} which was on par with chemical control (ST with captan 2g/kg and spray hexaconazole 0.1 % at 45 and 60DAS) with PDI 42.80 and grain yield of 32.20 q ha^{-1}.

Nagaraj and Patil (2014) evaluated the spray schedule involving systemic and nonsystemic fungicides, botanicals and ITK's against pearl millet rust. Among the seven spray schedules evaluated using fungicide (hexaconazole), botanical (neem oil) and ITK (cow urine) under field condition, hexaconazole (0.1 %) followed by hexaconazole (0.1 %) spray schedule recorded least rust severity (15.30 %), highest grain yield (30.50 q/ha) and 1,000 grain weight (10.51 g) with highest benefit : cost ratio of 2.40.

3. MATERIAL AND METHODS

The material and methods pertaining to various aspects of the research such as survey, screening, race analysis, slow rusting characters and development of integrated spray schedule has been systematically designed and adopted as per the research standards. All most all the peninsular zone (PZ) released wheat varieties released from AICRP centres across the country collected prior to start of the experiment and various methods are followed as described belowe under following headings.

3.1 Survey for foliar diseases severity in northern parts of Karnataka

3.2 To conduct screening and understanding the prevalence of races of *P. triticina* on wheat varieties released for peninsular zone

3.3 Studies on slow rusting components in selected peninsular zone released wheat varieties

3.4 Development of integrated spray schedule for management of the disease

3.1 Survey for foliar diseases severity in northern parts of Karnataka

Intensive roving survey was conducted in wheat growing areas of Dharwad, Belagavi, Bagalkot and Vijayapura districts of Karnataka during *rabi* 2015-16 and 2016-17 (Plate 3). Wheat fields on the survey route were visited and the detailed information was collected regarding the crop and the disease severity (Plate 4). Loegering scale (Joshi *et al.*, 1988) and Modified Cobb's scale (Peterson *et al.*, 1948) was used for recording leaf rust infection type and severity, respectively. Then response values are assigned to each reaction type from 0.0 to 1.0 as given below.

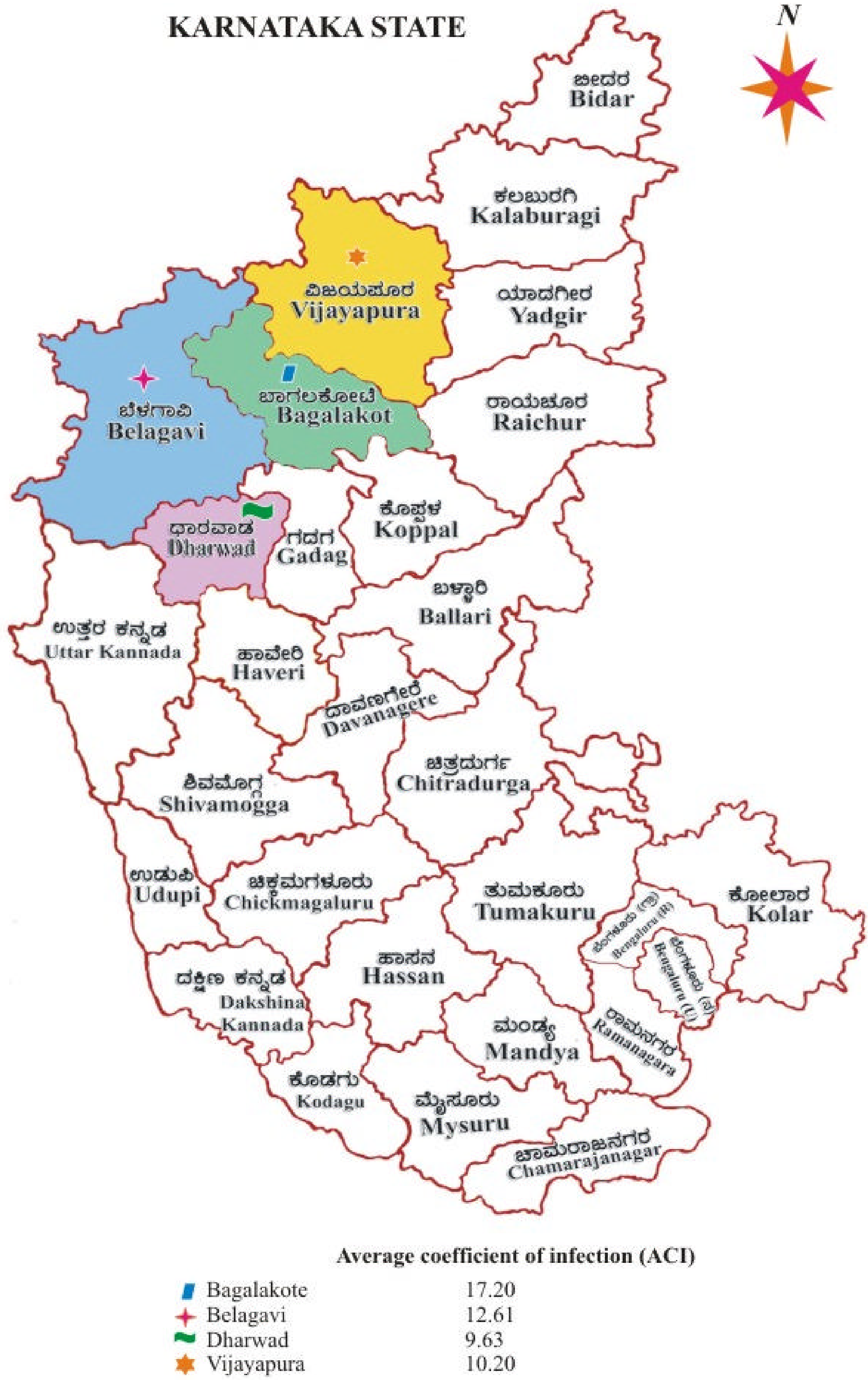


Plate 3. Karnataka map showing different surveyed districts with ACI

a) Leaf rust severity upto 20S at Kabbur village (Chikkodi taluk)

b) Leaf rust severity upto 40S at Yekkundi village (Jamakhandi taluk)

c) Visit to irrigated field of Ankali village (Chikkodi taluk)

Plate 4:Survey for foliar diseases severity during *rabi* 2015-16

Loegering (Joshi *et al.*, 1988) and Modified Cobb's scale (Peterson *et al.*, 1948)

Infection type	Host response	Symptoms	Response value
0	Immune	No visible symptoms on plants.	0.0
0;	Nearly Immune	Yellow flecks on plants	0.0
R	Resistant	Necrotic areas, with or without minute uredia.	0.2
MR	Moderately resistant	Small uredia surrounded by necrotic areas.	0.4
X	Mesothetic/Heterogeneous	Variable sized uredia, some with necrosis or chlorosis.	0.6
MS	Moderately susceptible	Medium uredia with no necrosis but possibly some distinct chlorosis	0.8
S	Susceptible	Large uredia with no necrosis but possibly some distinct chlorosis.	1.0

Then CI (Coefficient of infection) was calculated by multiplying per cent disease infection and response value, assigned to each infection type as per Loegering (Joshi *et al.*, 1988) as mentioned above. Double digit (DD) notation was used for recording leaf blight severity (Saari and Prescott, 1975).

$$\text{CI} = \text{Per cent infection} \times \text{Response value}$$

During survey around 90 leaf rust infected leaf samples were collected from different farmer's wheat fields and were sent to IIWBR Regional Station, Flowerdale, Shimla for race identification.

3.2 To conduct screening and understanding the prevalence of races of *P. triticina* on wheat varieties released for peninsular zone

3.2.1 Screening

Screening was carried out in two *rabi* seasons at two locations *viz*., All India Co-ordinate Research Project on Wheat and Barley, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad and Research and Development Unit, Ugar Sugars Works Ltd., Ugar Khurd (Plate 5). Totally 47 varieties during *rabi* 2015-16 and 57 varieties during *rabi* 2016-17 were screened for leaf rust severity which were released for cultivation in peninsular zone by various wheat improvement centers (Anon., 2011). However, Dharwad dry, Amruth, Bansi white and Bansi red are widely cultivated in these areas and these were included in the present study (Table 1).

The details of field screening experiment are given below

Design : Non replicated augmented design

Rows : 2 rows of 1 m length for each genotype

Row to row spacing : 20 cm

Date of sowing : As given below

Season	Dharwad	Ugar Khurd	No. of varieties
Rabi 2015-16	1-12-2015	17-12-2015	47
Rabi 2016-17	29-11-2016	13-11-2016	57

At Dharwad 12 days prior to sowing of test entries, susceptible checks (Agra local, Lal bahadur, Pusa 4, Amruth and Local red) were sown individually in 1.0 m X 1.6 m sized plots all along the borders of the field. Further, at the time of sowing of plots with test entries, a single line of mixture of all the susceptible checks

a) Field layout of screening plots

b) Inculation to susceptible checks

c) Field screening at Dharwad during *rabi* 2016-17

d) Field screening at Ugar Khurd during *rabi* 2016-17

Plate 5: Screening of PZ released wheat varieties for leaf rust resistance

Table 1: Wheat varieties released for cultivation in peninsular zone

Sl. No.	Cultivar name	Pedigree / Parentage	Genes present	Year of notification	Developed by	Production condition
T. aestivum						
1	AKAW 4627	147/SUNSTAR*/C 80.1	NP	2009	AKOLA	TS, IR
2	AKW 381	-	-	-	-	-
3	DBW 93	WHEAR/TUKURU//WHEAR	NP	2015	IIWBR, KARNAL	TS, RIR
4	Dharwad dry	-	-	-	-	-
5	DWR 162	BB	*Lr* 26+, *Lr*23+, *Sr* 2+, *Sr* 31+, *Yr* 9	1993	DHARWAD	TS/IR
6	DWR 195	BONMARA-105-7	*Lr* 26+, *Lr* 23+, *Lr* 1, *Sr*2+, *Sr* 31+, *Yr* 9	1995	DHARWAD	TS/IR
7	GW 322	GW173/GW196	-	2002	VIJAYAPURA	TS, IR
8	HD 2833	PBW226/HW1042//HD2285	NP	2004	N. DEHLI	LS, IR
9	HD 2380	HD2255/HD8857	*Lr*23+, *Lr*10	1989	N. DEHLI	TS, LS IR/RF
10	HD 2189	1931	*Lr*13+, *Lr*34, *Sr*2	1970	N. DEHLI	TS, IR
11	HD 2932	KAUZ/STAR//HD2643	*Lr*13+	2007	N. DEHLI	LS, IR
12	HD 3090	SFW/VAISHALI//UP2435	*Lr* 26+1+, *Sr* 31+	2014	N. DEHLI	LS, IR
13	HI 977	GLL/AUST61.157/CNO/NO66/3/Y50/3/KAL	*Lr*23+, *Lr*34+, *Sr*2+, *Sr*9b+, *Sr*11, *Yr*2+, *Yr*18	1988	INDORE	LS,IR
14	KRL 19	PBW255/KRL 1-4	*Lr*13, *Sr*8b+, *Sr*9b+, *Sr*11	2000	CSSRI	TS/IR,ALK./ SAL
15	KRL 1-4	KHARCHIA65/ WL711	*Lr*13, *Sr*9b+, *Sr*11, *Yr* 2ks	1990	CSSRI	TS/IR,ALK./ SAL
16	KRL 210	PBW65/2*PASTO	NP	2009	CSSRI	TS,IR
17	KRL 213	/MEXL-2/3/Ae.Squarrosa	NP	2009	CSSRI	TS,IR
18	MACS 2496	SERI"S"	*Lr* 26+, *Lr* 23+, *Lr* 1, *Sr*2+, *Sr* 31+, *Yr* 9+	1991	PUNE	TS, IR

Contd…..

Sl. No.	Cultivar name	Pedigree / Parentage	Genes present	Year of notification	Developed by	Production condition
19	MACS 2846	CPAN 6079 /MACS 2340.	*Lr* 23+, *Sr* 9e	1998	PUNE	TS, IR
20	MACS 6222	2496	*Sr* 31+, *Lr* 26+, *Yr* 9+27	2009	PUNE	TS, IR
21	MACS 6478	CS/Th. sc//3*PVN/3MIRLO/BUC/4/MILAN /5/TILHI	*Lr* 13+, *Sr* 13+, *Yr* 2+	2014	PUNE	TS, IR
22	NIAW 917	GW 244/BOB WHITE	*Sr* 31+, *Sr* 2+, *Lr* 26+, *Yr* 9+	2005	NIPHAD	TS, IR
23	NIAW 34	CNO 79/PRL "S"	*Lr*13+, *Lr*34+, *Sr*11+, *Yr*18	1997	NIPHAD	LS/VLS,IR
24	NIAW1415	GW 9506/PRL//PRL	*Lr* 26+, *Sr*31+, *Yr*9+	2011	NIPHAD	TS, RF/IR
25	NI 5643	NEW THATCH /D221 NI 284-S	NP	1978	NIPHAD	TS, IR
26	PBN 51	BUC'S'/FLK'S'	NP	1996	PARBHANI	TS, IR
27	PBN 142					
28	UAS 304	SERI/CEP80120//KAUZ/PBW343	*Lr* 1+, 10+	2013	DHARWAD	
29	UAS 334	SITE/MO/4/NAC/TH.AC//3*/PVN/3 /MIROL/BVC	*Sr* 31+, *Lr*26+1, *Yr* 9+A	-	DHARWAD	
30	UAS 347	(TOB/ERA/TOB/CNO67/#/PLO/$/V EE#5/5/KAUZ/6/FRET2) /DWR162	*Lr*13+, 10+1+, *Lr* 23+, *Sr*2+, *Yr* 2+	2015	DHARWAD	TS, RF
T. durum						
31	Amruth	-	NP		DHARWAD	RF
32	AKDW 2997-16	CPAN-6140/RAJ-1557 (4191)	Sr7b+	2006	AKOLA	-
33	AKDW 4021	AJAIA-12/F3-LOCAL (SELETHI-138.88)	NP	-	AKOLA	-
34	Bansi white	Local selection	NP	-	AKOLA	-
35	Bansi red	Local selection	NP	-	AKOLA	-

Contd.….

Sl. No.	Cultivar name	Pedigree / Parentage	Genes present	Year of notification	Developed by	Production condition
36	Bijaga red	M.LOCAL/GAZA	NP	1965	VIJAYAPUR	TS, RF
37	Bijaga yellow	M.LOCAL/GAZA	*Lr*23+, *Sr*2+, *Sr*11	1965	VIJAYAPUR	TS, RF
38	DWR 185	RAJ1555	*Sr* 11	1998	DHARWAD	TS, IR
39	DWR 1006	AA2	*Sr* 9e+	2006	DHARWAD	TS, IR
40	DWR 2006	SULA/CREX//AAZ	NP		DHARWAD	TS, IR
41	HD 2781	BOW /C 306 //C591/HW 2004	NP	2002	N. DELHI	TS, RF
42	HI 8663	HI 8177/HI 8185	*Lr*23, *Sr*9e	2008	INDORE	TS, IR
43	MACS 9	(T.DUR) /F183 (T.POL)	NP	1978	PUNE	TS, RF
44	MACS 1967	1471	*Sr* 11	1987	PUNE	TS, RF
45	MACS 2694	1555 // MACS 2130	NP	1997	PUNE	TS, RF
46	MACS 3125	6120	NP	2001	PUNE	TS, IR
47	NI 5749	G-4-48 * N59	NP	1978	NIPHAD	TS, RF
48	NIDW 15	DOM 50	*Sr*2+,*Sr*9e	2004	NIPHAD	TS, RF
49	NIDW 295	BOOMER 33 / PLATA 8	*Sr*9e+, *Sr*2+	2007	NIPHAD	TS, IR
50	UAS 415	GALLI/BOOMER20//WR 185	*Lr* 23+, *Sr* 9e+	2008	DHARWAD	TS, IR
51	UAS 428	GREEN-14/YAV-10/AUK/UAS402	*Lr*23+, *Sr*11+	2012	DHARWAD	TS, IR
52	UAS 446	DWR 185/ DWR 2006//UAS 419	*Lr*23+, *Sr*2+, 11+, *Yr*2+	2014	DHARWAD	TS, RF
T. dicoccum						
53	DDK 1009	NP200*4//NP200/ALTAR-84	NP	1998	DHARWAD	TS, IR
54	DDK 1025	DDK1013/DDK1001//278-13	NP	2005	DHARWAD	TS/IR
55	DDK 1029	DDK1012/HW1093//276-15	NP	2007	DHARWAD	TS/IR
56	HW 1098	NP 201 (Mutant developed through 20 Kr irradiation)	NP	2015	WELLINGTON	TS, IR
57	MACS 2971	KTR 5*2/NP 200	NP	2009	PUNE	TS, IR

NP: Not postulated, TS: Timely sown, LS: Late sown, IR: Irrigated, RIR: Restricted irrigation, RF: Rain fed were sown on all four borders of the plots to create high leaf rust disease pressure. During evening hours border sown susceptible check plots were inoculated at 15 days after sowing with uredospore inoculum having mixture of races of leaf rust received from Indian Institute of Wheat and Barley Research (IIWBR), Regional Research Station, Flowerdale, Shimla. The inoculum sprayed plants in each plot were covered with polythene bags for a night to create high humidity for better infection. Inoculum spray was repeated three times at weekly interval to develop high disease pressure. Observations on leaf rust severity was recorded starting from the onset of disease in any of the test entries. Further observations were recorded at weekly interval (7 days) till the varieties attain physiological maturity. At Ugar Khurd the same augmented design was followed for sowing and varieties were left for natural infection in the field condition in both the *rabi* season without any inoculum spray. These observations were further used for calculating coefficient of infection (CI) using the formula mentioned earlier.

Grain yield

The individual genotype plots were harvested separately and grain yield was recorded and it was further converted into quintals per hectare.

1,000 grain weight

A total of 1,000 grains were counted randomly from each genotype and weighed in grams.

3.2.2 Prevalence of races of *P. triticina* on peninsular zone released wheat varieties

The PZ released wheat varieties which were planted at Research and Development Unit, Ugar Sugars Works Ltd., Ugar Khurd during *rabi* 2015-16 were used for understanding the existence of different races of *P. triticina* on these varieties. The leaf rust severity on each genotype was recorded at physiological maturity and leaf rust samples were collected from the infected varieties and packed neatly with all necessary information. These samples were sent to Indian Institute of Wheat and Barley Research (IIWBR), Regional Station, Flowerdale, Shimla, Himachal Pradesh for race identification.

3.3 Studies on slow rusting components in selected peninsular zone released wheat varieties

Study of components of slow rusting mechanism helps in determining the type and degree of resistance shown by different varieties to pathogen and it can be further utilized by plant breeders for developing new genotypes which are more superior to the existing one. These studies are further more useful in breaking the rust epidemics well in advance.

Glass house study was carried out at the All India Coordinated Research Project on Wheat and Barley, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during *rabi* 2016-17 to study the different components of slow rusting such as latent period, uredial density per unit area and size of the uredial pustule on 13 selected peninsular zone released wheat varieties (Plate 6a).

All the 13 varieties (UAS 415, UAS 428, UAS 446, DWR 2006, Bijaga yellow, DWR 162, DWR 195, UAS 304, UAS 334, UAS 347, MACS 6222, HD 2189, GW 322) were sown on 7-01-2017 in plastic cups containing standard pot mixture. Three replications were maintained in each genotype and seedlings were inoculated 11 days after sowing with uredospore suspension ($5x10^5$ spores per ml) and covered with polythene bag for a night to maintain high humidity. Then constant watch was made to determine the latent period and after 13 days of inoculation when leaves covered with sufficient leaf rust pustules, these were taken to determine pustule density and size of the pustule.

3.3.1 Area under disease progress curve

The AUDPC and apparent rate of infection (r) for these 13 varieties were taken from field screening trail conducted during *rabi* 2016-17 at Dharwad. The coefficient of infection (CI) was calculated as mentioned earlier at seven days intervals for each genotype and these CI values are used for further calculating area under disease progress curve as per the following formula given by Wilcoxson *et al.* (1975).

$$\text{AUDPC} = \sum_{i=1}^{k} \left[\frac{1}{2} (S_i + S_i - 1) \times d \right]$$

Where,

S_i = Disease severity at the end of time I

k = Number of successive evaluations of rust

d = Interval between two evaluations

3.3.2 Apparent rate of infection

The apparent rate of infection ('r') at different intervals was calculated by using the formula given by Van der Plank (1968).

$$r = \frac{2.3}{t_2 - t_1} \log10 \frac{X_2}{X_1}$$

Where,

r = apparent rate of growth of disease (units da y^{-1})

X_1 = per cent disease severity at t_1 date

X_2 = per cent disease severity at date t_2

$t_2 - t_1$ = time interval in days between the two observations

Observations on following slow rusting components were recorded in glass house experiment

a) Latent period

b) Pustule or uredial density

c) Pustule or uredial size

3.3.3 Latent period: Number of days taken for the appearance of uredial pustules on each genotype from the date of inoculation was critically observed and recorded.

3.3.4 Pustule density (number per unit area)

Number of pustules per half centimeter square area was counted. Three squares each at base, middle and tip of the leaf on each 1^{st}, 2^{nd} and 3^{rd} leaf was counted and averaged. The average uredia per half cm^2 on each genotype were thus obtained.

3.3.5 Pustule size (mm)

Twenty randomly selected pustules from each leaflet of each genotype were used for measuring length and breadth of the pustules using digital microscope at 10X magnification and measurements were recorded in millimeter. Area of the pustule was calculated using the formula given by Kochman and Brown (1975).

$$\text{Area of the pustule} = n\ (a \times b)^{1/4}$$

Where, a = length of the pustule

b= breadth of the pustule

n = number of pustule

3.4 Development of integrated spray schedule for management of the disease

3.4.1 *In vitro* evaluation of fungicides, commercially available botanicals, bioagents and Indigenous Technology Knowledge (ITK)

Various systemic, non-systemic and combiproduct fungicides, commercially available botanicals, bioagents and ITK's were evaluated under *in vitro* condition against *P. triticina* following "cavity slide" method. Required concentrations of each product were prepared in distilled water. In each treatment three replications were maintained. These slides were kept in moist chamber for incubation under room temperature (25 ± 1^0C) for 12 hrs. In each experiment one control was maintained with distilled water. Three microscopic fields were observed in each cavity and per cent uredospore germination was calculated by following formula.

$$\text{Per cent germination (PG)} = \frac{A}{B} \times 100$$

Where,

A = No. of uredospores germinated

B = Total no. of uredospores observed

The per cent uredospore germination inhibition was calculated by the following formula given by Vincent (1947).

$$I = \frac{C - T}{C} \times 100$$

Where,

I = Per cent inhibition

C = Germination percentage in control

T = Germination percentage in treatment

The following four non systemic, five systemic and seven combiproduct fungicides were evaluated with following concentrations.

Non systemic fungicides: 0.1, 0.2 and 0.25 per cent

Systemic fungicides: 0.025, 0.05 and 0.1 per cent

Combiproduct fungicides: 0.05, 0.1 and 0.2 per cent

List of various fungicides used for *in vitro* evaluation

Sl. No.	Common name	IUPAC name	Trade name
	a. Non systemic		
1	Mancozeb 75 % WP	Manganese zinc ethylene bis Dithiocarbomate	Indofil M-45
2	Captan 50 % WP	N-Trichloromethyl-1-thio-4-cyclohexane-1,2 dicorboximide	Captaf
3	Chlorothalonil 75 % WP	2,4,5,6-tetrachloroisophthalonitrile	Kavach
4	Propineb 70 % WP	polymeric zinc 1,2- propylenebis (dithiocarbamate)	Antracol

Contd….

Sl. No.	Common name	IUPAC name	Trade name
	b. Systemic fungicides		
1	Propiconazole 25 EC	1- (2,4-dichlorophenyl) 4 propyl-1-3-dioxalan-2-methyl) H-1, 4-triazole)	Tilt
2	Hexaconazole 5 EC	(RS) -2- (2,4-dichlorophenyl) -1H-1, 2,4-triazol-1-yl) hexan-2-0*l*)	Contaf
3	Penconazole 10 EC	1-[2-2 (2-4-dichlorophenyl) -nphenyl]-1H-1, 2,4, triazole	Topas
4	Difenconazole 25 EC	Cis, trans-3-chloro-4 (4-methyl-2 (1H-1,2,4-triazole-1-yl methyl) 1,3 dioxalan-2yl) phenyl, 4-chlorophenylether	Score
5	Tebuconazole 25 EC	(RS) - 1- (4-Chlorophenyl) - 4,4-dimethyl-3- (1*H*, 1,2,4-triazol-1-ylmethyl) pentan- 3-ol	Folicure

Combiproduct fungicides

Sl. No.	Common name	Chemical name	Trade name
1	Captan 70 % + Hexaconazole 5 %	N-trichloromethyl mercapta 4-cyclohexene 1,2-dis carboximide N-trichloromethyl thiotetra hydro othalamide + Rs) -2- (2,4-dichlorophenyl) -1- (14-1,2,4-trizole-1y1) hexane-2-1	Taqat 75 % WP
2	Carbendazim 12 % + Mancozeb 63 %,	Methyl 1-1-2 benzimidozole carbonate + Manganese ethylene bis dithiocarbamate	Saaf 75 % WP
3	Hexaconazole 4 % + Zineb 68 %	2-2,4-dichloro phenyl 1- (1H,1,2,4-trizol-1y1) hexan -2-01 + zinc ethylene bis dithiocarbamate	Avtar 72 % WP
4	Azoxystrobin 14.4 % + Propiconazole 11.4 %	Methyl (E) -2-{2-[6- (2-cyanophenoxy) pyrimidin-4-yloxy]phenyl}-3- methoxyacrylate 1-[[2- (2,4-dichlorophenyl) -4-propyl-1,3- dioxolan-2-yl]methyl]-1H-1,2,4-triazole	Headway

5	Tebuconazole 50 % + Trifloxystrobin 25 %	1-4 (4-chlorophenol) -4,4 dimethyle-3- (1,4-trizole-l-yl-methyle-pemtene-3ol + Methyl (E) -3- {3[6- (6- (3-cyanophenoxy) pyrimidin-4yloxy] phenyl} -3- (Methoxyacrylate) benzeneacetate	Nativo 75 %WG
6	Difenconazole 13.9 % + Propiconazole13.9 %	1- (2- (2,4-D) -4-Propyl-1,3 diozolan-2ylmethyl) IH-l, 2, 4 Trizole + Cis, trans-3-chloro-4 (4-methyl-2- (1H-1, 2, 4-Trizole-l-yl, methyl) -1,3-dioxolan-2-yl) phenyl 4-chlorophenyl ether	Taspa 27.8 % EC
7	Tricyclazole 45 % + Hexaconazole 10 %	-	ICF-110

Following six commercially available plant based products were evaluated under *in vitro* at 0.25, 0.5 and 1.0 per cent concentrations.

Sl. No.	**Product name**	**Contents**
1	Agroneem	Neem oil based herbal pesticide
2	Raw neem oil	Azadirachtin
3	Soldier	*Aegl marbelos* (20 %) *Ricinus communis* (20 %) *Hygrophila spinosa* (20 %) *Laminaria* spp. (20 %) *Lantana* camera (20 %)
4	Discheck	*Ficus bengalensis* (0.0001 %) *Ficus religiosa* (0.0001 %) *Ficus retusa* (0.0001 %) *Aqua solvent* (99.99 %)
5	Neem gold	Azadirachtin (0.15 %)
6	Nimbicidine	Azadirachtin (0.03 %)

The bio-efficacy of three bioagents (*Trichoderma harzianum* Rifai, *Pseudomonas fluorescens* Migula and *Bacillus subtilis* Cohn.) alone and their combinations were evaluated under *in vitro* on uredospore germination inhibition of *P. triticina* by following cavity slide method as given below

Treatment details of bio-agents and their combinations

Treatments	**Bioagents**
T_1	*T. harzianum* @ 10 g/l
T_2	*P. fluorescens* @ 10 g/l
T_3	*B. subtilis* @ 10 g/l
T_4	T_1 @ 5 g/l + T_2 @ 5 g/l
T_5	T_1 @ 5 g/l + T_3 @ 5 g/l
T_6	T_2 @ 5 g/l + T_3 @ 5 g/l
T_7	T_1 @ 3.33 g/l + T_2 3.33 g/l + T_3 3.33 g/l
T_8	Talk powder @ 10 g/l
T_9	Control (water)

Four ITK'S such as cow urine, butter milk (curd diluted in water @ 1:4 and fermented for two days), panchagavya and vermiwash were evaluated under *in vitro* condition against inhibition of uredospore germination of *P. triticina* at 5, 10 and 20 per cent concentrations.

3.4.2 Development of spray schedule using *in vitro* effective fungicide, plant based product, ITK and bio-control agent in an integrated approach

The field experiment was conducted during *rabi* 2016-17 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad with the following details.

Design	: Randomized Block Design (RBD)		
Replications	: 3		
Treatments	: 14		
Plot size	: Gross plot	: $2.8\,m \times 2.0\,m$
	Net plot	: $2.4\,m \times 2.0\,m$
Variety	: DWR 162		
Date of sowing	: 12-12-2016		

Totally, there were 14 treatments with three replications (total no. of plots 42) with net area of each plot $4.8m^2$ (Plate 6b). In each plot, the genotype DWR 162 procured from AICRP on Wheat and Barley, Dharwad was sown in 12 rows of each 2m length with row to row spacing of 20cm. A single row of mixture of susceptible checks (Agra local and Amruth) was sown on either side of each plot and 20 days after sowing (DAS) uredospore suspension was sprayed on these checks to create artificial epiphytotic condition. Recommended package of practice was followed to raise the crop. First IDM spray was taken 65 DAS (15-02-2017) with the knapsack sprayer when initial rust symptoms were observed on lower leaves. Second spray was done 15 days after the first spray (03-03 2017). The integration of effective and economically viable fungicide, plant based product, biocontrol agent and ITK based on *in vitro* evaluation results was done and evaluated in field as per the schedule given below.

Spray schedule for the management of wheat leaf rust

Treatments	Spraying schedule	
	I spray	**II spray**
T_1	Hexaconazole @ 0.1 %	Hexaconazole @ 0.1 %
T_2	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %
T_3	Nimbicidine @ 1.0 %	Nimbicidine @ 1.0 %
T_4	(*T. harzianum* + *B. subtilis*) @ 1.0 %	(*T. harzianum* + *B. subtilis*) @ 1.0 %
T_5	Panchagavya @ 10.0 %	Panchagavya @ 10 %
T_6	Hexaconazole @ 0.1 %	Nimbicidine @ 1.0 %
T_7	Hexaconazole @ 0.1 %	(*T. harzianum* + *B. subtilis*) @ 1.0 %
T_8	Hexaconazole @ 0.1 %	Panchagavya @ 10 %
T_9	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	Nimbicidine @ 1.0 %
T_{10}	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	(*T. harzianum* + *B. subtilis*) @ 1.0 %
T_{11}	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	Panchagavya @ 10.0 %
T_{12}	Hexaconazole @ 0.1 %	No spray
T_{13}	No spray	Hexaconazole @ 0.1 %
T_{14}	Unsprayed control	

Plate 6a: Glasshouse experiment on slow rusting mechanism in PZ varieties at MARS, Dharwad during *rabi* 2016-17

Plate 6b: Overall field view of IDM experiment at MARS, Dharwad, during *rabi* 2016-17

Following observations were recorded in each plot as given below

1. **Disease severity:** Disease severity was recorded one day before both the sprays and 15 days after the second spray (total three observations). Coefficient of infection was calculated as per the formula mentioned earlier.

2. **Grain yield per hectare:** The individual plots were harvested separately and grain yield was recorded and it was further converted into quintals per hectare (q/ha).

3. **1,000 grain weight:** A total of 1,000 grains were counted randomly from each plot and weighed in grams (g).

4. **Biomass:** The straw weight from each plot weighed in kilo grams and then converted into tons per hectare (t/ha).

4. EXPERIMENTAL RESULTS

The results of the investigation on various aspects of leaf rust of wheat caused by *Puccinia triticina* Eriks. with respect to survey, screening, race identification, slow rusting mechanism and integrated management of leaf rust are presented below under following headings.

4.1 Survey

4.2 Evaluation of peninsular zone released wheat varieties for leaf rust resistance

4.3 Race pattern of *P. triticina* Eriks. on peninsular zone released wheat varieties

4.4 Components of slow rusting resistance in peninsular zone released wheat varieties

4.5 Evaluation of integrated spray schedule for the management of leaf rust of wheat

4.1 Survey

The roving survey was carried out in Dharwad, Belagavi, Vijayapura and Bagalkot districts of northern Karnataka during *rabi* 2015-16 and *rabi* 2016-17 to assess the status of wheat rusts severity under field condition. Variable amount of leaf rust severity was observed in these districts during *rabi* 2015-16 (Plate 7). Maximum leaf rust severity was observed in parts of Bagalkot, Belagavi and Vijayapura districts with variable proportion ranging from 0 to 40S in these districts and results pertaining to this survey were presented in Table 2. However, there was no appearance of either leaf rust or stem rust in any parts of these districts during *rabi* 2016-17.

The mean maximum leaf rust severity was observed in Bagalakot (ACI-17.20) followed by Belagavi (ACI-12.61), Vijayapura (ACI-10.20) and the least (ACI-9.63) was in Dharwad. In Bagalakot the highest severity (40S) was noticed in Yekkundi village of Jamkandi taluk and the least (TS) was in Konnur village of Badami taluk.

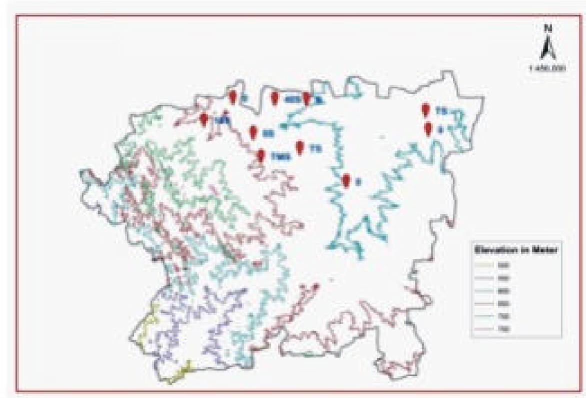
Table 2: Survey of foliar diseases severity of wheat in northern parts of Karnataka during *rabi* 2015-16

District	Taluka	Village	Latitude (N)	Longitude (E)	Elevation (m)	Variety/ species	Crop grown condition	Stage of the crop	Stem rust	Leaf rust	CI (leaf rust)	Leaf blight (DD)	Remarks
Dharwad	Dharwad	Amminabhavi	15.5386	75.0524	681	DWR 162	IR	Maturity	0	40S	40	00	Moderate aphid incidence
		Harobelavadi	15.617331	75.070619	617	UAS 446	IR	Maturity	0	0	0	00	-
		Hebballi Agasi	1527.828	7503.115	674	BW	IR	Milky	0	5S	5	00	Moderate aphid incidence
		Shivalli	1527.681	7509.162	653	BW	RF	Flowering	0	0	0	00	-
		Mangalagatti	1532.700	7457.832	684	BW	IR	Tillering	0	TS	1	0-12	-
		Lokur	1535.295	7458.133	651	BW	RF	Dough	0	10S	10	00	Leaf folder 5-10 %
		Yadawad	1532.717	7457.335	651	DW	RF	Dough	0	0	0	00	-
		Narendra	1531.004	7458.487	675	Amruth	RF	Maturity	0	TMS	0.8	12/24	Stem borer <5 %
	Hubballi	Byahatti	1527.053	7513.214	608	BW	RF	Maturity	0	0	0	00	-
		Hebsuru	1529.474	7518.498	585	BW	IR	Milky	0	TS	1	01	Moderate aphid incidence
	Navalgund	Navalgund	1533.901	7522.277	573	BW	RF	Milky	0	0	0	00	-
District ACI : 9.63													
Belagavi	Bailhongal	Arvalli	1544.262	7452.698	663	BW	RI	Milky	0	TMR	0.4	00	-
		Sampagaon	1544.394	7452.673	686	DW	RF	Milky	0	0	0	00	Severe moisture stress
	Saudatti	Yaragatti cross	15.9667	75.01670	674	BW	IR	Milky	0	5S	5	00	-
		Inamhongal	1542.029	7505.959	657	BW	RF	Dough	0	0	0	00	-
		Jivapur	1555.104	7503.625	646	DIC	IR	Dough	0	5S	5	00	-
	Gokak	Hirenandi	16.059742	74.959280	625	BW	IR	Milky	0	TS	1	00	-
		Gokak	16.168036	74.82235	550	BW	IR	Milky	0	20S	20	00	Moderate aphid incidence
		ARS arabhavi	1613.505	7449.153	570	All	IR	Dough	0	10S	10	00	-
	Chikkodi	Ankali	16.539475	74.669605	538	BW	IR	Dough	0	5S	5	00	-
		Kabbur	1620.798	7444.099	621	DIC	IR	Flowering	0	40S	40	00	-
		Kankanawadi	1621.051	7453.905	592	BW	IR	Flowering	0	0	0	00	-

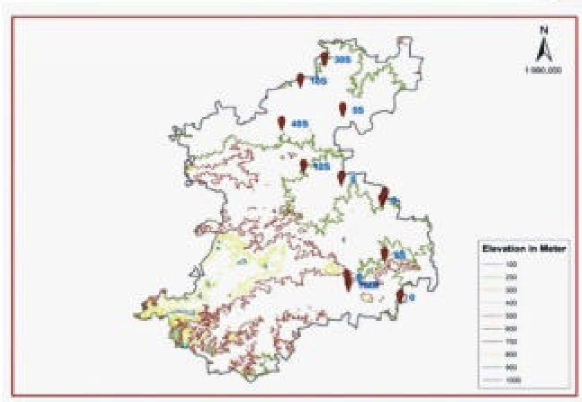
Contd……

District	Taluka	Village	Latitude (N)	Longi tude (E)	Elevation (m)	Variety/ species	Crop grown condition	Stage of the crop	Stem rust	Leaf rust	CI (leaf rust)	Leaf blight (DD)	Remarks
	Athani	Ugar	16.629515	74.847133	543	BW	IR	Dough	0	20S	20	00	-
		Ainapur	16 39 729	74 51 372	539	BW	IR	Grain filling stage	0	30S	30	01	Moderate aphid incidence
		Shiraguppi	1636.692	7442.451	536	BW	RI	Milky	0	10S	10	00	Moderate aphid infestation
	Ramdurg	Sidnal cross	1602.593	7509.223	638	DW	RF	Dough	0	0	0	00	-
		Panchagaon	1605.706	7515.389	673	BW	IR	Milky	0	5S	5	00	-
District ACI : 12.61													
Bagalkot	Badami	Konnur	1552.732	7529.874	556	BW	RF	Milky	0	TS	1	00	-
	Bagalkote	KVK, bagalkote	1610.502	7541.813	541	ALL	IR	Milky	0	5S	5	00	-
		Anagudi	1616.164	7537.453	534	DIC	IR	Maturity	0	30S	30	00	-
	Jamakhandi	Yekkundi	1637.847	7532.478	574	DIC	IR	Maturity	0	40S	40	00	-
		Kavatagi cross	1634.188	7525.161	537	BW	IR	Maturity	0	10S	10	00	-
	Mudhol	Shindogi	1625.153	7516.656	578	BW	IR	Dough	0	0	0	00	-
District ACI : 17.20													
Vijaypura	Vijaypura	Ronihal	1630.610	7541.231	670	BW	RF	Dough	0	TMR	0.4	00	-
		Mulawad	1637.359	7543.905	623	BW	RF	Dough	0	0	0	00	2-3 Loose smut infected plants are noticed
		Khajiapur	1646.182	7540.719	627	DIC	IR	Milky	0	20S	20	00	
		Sarwad	1642.553	7537.528	595	DW	RF	Milky	0	0	0	00	2-3 Loose smut infected plants are noticed
District ACI : 10.20													

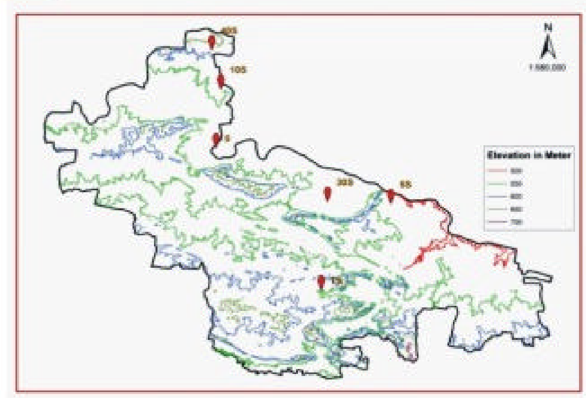
Note: IR: Irrigated, RF: Rainfed, BW: Bread wheat, DW: Durum wheat, DIC: Dicoccum wheat, DD: Double digit, CI: Coefficient of infection



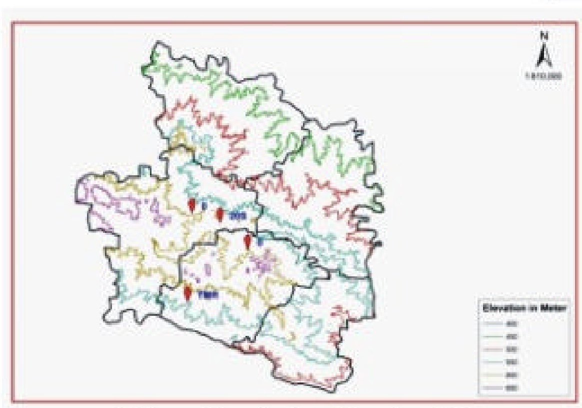
a) Severity of wheat leaf rust in Dharwad district



b) Severity of wheat leaf rust in Belagavi district



c) Severity of wheat leaf rust in Bagalkot district



d) Severity of wheat leaf rust in Vijayapura district

Plate 7: GPS map of surveyed districts of northern parts of Karnataka during *rabi* 2015-16

However, in Belagavi district the maximum severity was noticed in Kabbur village (40S) and it was least in Hirenandi (TS) village of Gokak taluk. The maximum leaf rust severity of 20S was observed in Khajapur village of Vijayapura district and minimum was in Ronihal (TMR). However, in Dharwad district highest leaf rust severity was observed in Amminabavi (40S) and least was at Narendra (TMS) village of Dharwad taluk.

Over all survey in these districts revealed that around 62 per cent of these surveyed wheat fields are in irrigated condition and maximum leaf rust severity was observed in irrigated fields than the rain fed grown wheat fields. Results also revealed that maximum area was under cultivation of bread wheat (around 67 %), followed by durum wheat (18.91 %) and dicoccum wheat (13.51 %). There was moderate incidence of aphids in some irrigated fields (Amminabavi, Ainapur, Shiraguppi villages) and two to three loose smut infected plants were observed in rainfed grown wheat fields of villages Mulawad and Sarwad of Vijayapura taluk. Leaf blight was observed in very less form and there was no incidence of stem rust in both the *rabi* seasons in any part of the surveyed areas.

During the cropping year 2015-16, 90 leaf rust infected samples from two districts, Dharwad and Belagavi were analyzed for existence of races and data pertaining to this is given in Table 3. The frequency of pathotype group 77 was maximum (88.24 %) followed by pathotype group 104 (8.24 %) and pathotype group 12 (2.35 %) and least was group 162 (1.18 %). In these districts pathotype 77-9 was most frequent (68.24 %) followed by pathotype 77-5 (11.76 %) and 104-2 (7.06 %), whereas other pathotypes were identified in few samples only.

4.2 Evaluation of peninsular zone released wheat varieties for leaf rust resistance

Screening of peninsular zone released wheat varieties for leaf rust resistance was taken under both natural infection and artificial inoculation during *rabi* 2015-16 and *rabi* 2016-17 at MARS, Dharwad and Ugar Sugars Works Ltd. Ugar Khurd as explained in Material and Methods and results pertaining to this study are presented in Table 4.

Table 3: Distribution of leaf rust pathotype groups and pathotypes in northern parts of Karnataka during *rabi* 2015-16

Sl. No.	Pathotype group	Per cent distribution	Pathotype	Per cent distribution	District wise per cent distribution	
					Dharwad	Belagavi
1	12	2.35	12-1 (5R37)	1.18	0	100
			12-5 (109R37)	1.17	100	0
2	77	88.24	77-1 (109R63)	3.53	0	100
			77-5 (121R63-1)	11.76	100	0
			77-7 (121R127)	1.18	0	100
			77-9 (121R60-1)	68.24	60	40
			77-10 (377R60-1)	1.18	100	0
			77-5+77-9	2.35	50	50
3	104	8.24	104-2 (21R55)	7.06	0	100
			104-3 (21R63)	1.18	0	100
4	162	1.18	162-2	1.18	100	0
		100.00		100.00		

Table 4: Adult plant resistance of peninsular zone released wheat varieties to leaf rust under field conditions during *rabi* 2015-16 and *rabi* 2016-17

Sl. No.	Varieties	Ugar Khurd (Natural condition)					Dharwad (Artificial inoculations)			
		rabi 2015-16			*rabi* 2016-17		*rabi* 2015-16		*rabi* 2016-17	
		Leaf rust severity	CI	Races prevailed	Leaf rust severity	CI	Leaf rust severity	CI	Leaf rust severity	CI
T. aestivum										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	AKAW 4627	NE	-	-	0	0.00	NE	-	0	0
2	AKW 381	NE	-	-	0	0.00	NE	-	40S	40
3	DBW 93	60S	60	-	TMR	0.40	80S	80	30S	30
4	Dharwad dry	5MS	4	-	0	0.00	20MS	16	10MS	8
5	DWR 162	20S	20	-	TR	0.20	80S	80	40S	40
6	DWR 195	30MS	24	162-2	0	0.00	80S	80	20S	20
7	GW 322	20S	20	-	0	0.00	30MS	24	5MS	4
8	HD 2833	NE	-	-	0	0.00	NE	-	0	0
9	HD 2380	NE	-	-	0	0.00	NE	-	5MR	2
10	HD 2189	NE	-	-	0	0.00	NE	-	20S	20
11	HD 2932	NE	-	-	0	0.00	NE	-	40S	40
12	HD 3090	0	0	-	0	0.00	0	0	0	0
13	HI 977	5MS	4	-	0	0.00	40S	40	10MS	8
14	KRL 19	0	0	-	0	0.00	10MS	8	30S	30
15	KRL 1-4	0	0	-	0	0.00	20S	20	5S	5
16	KRL 210	10MS	8	-	0	0.00	30MS	24	20S	20
17	KRL 213	1OMS	8	-	0	0.00	20MS	16	0	0
18	MACS 2496	20MS	16	77-1	0	0.00	60S	60	10S	10

Contd……

	1	2	3	4	5	6	7	8	9	10
19	MACS 2846	5MS	4	-	0	0.00	10MS	8	5S	5
20	MACS 6222	0	0	-	TR	0.20	TMS	0.8	0	0
21	MACS 6478	40S	40	-	TR	0.20	40S	40	10S	10
22	NIAW 917	5MS	4	-	0	0.00	80S	80	20S	20
23	NIAW 34	20S	20	77-5+77-9	0	0.00	60S	60	40S	40
24	NIAW1415	10X	8	-	0	0.00	20MS	16	20MS	16
25	NI 5643	80S	80	77-9	TMR	0.40	80S	80	80S	80
26	PBN 51	20S	20	77-9	40S	40.00	80S	80	80S	80
27	PBN 142	0	0	-	10MS	8.00	60S	60	5S	5
28	UAS 304	10MS	8	-	0	0.00	10MS	0.8	5MS	4
29	UAS 334	20MS	16	-	0	0.00	20MS	16	10S	10
30	UAS 347	60S	60	104-2	TMR	0.40	80S	80	20S	20
T. durum										
31	Amruth	60S	60	77-9	20S	20.00	80S	80	30S	30
32	AKDW 2997-16	NE	-	-	0	0.00	NE	-	20MS	16
33	AKDW 4021	NE	-	-	0	0.00	NE	-	10MS	8
34	Bansi white	80S	80	-	0	0.00	80S	80	80S	80
35	Bansi red	80S	80	-	0	0.00	80S	80	80S	80
36	Bijaga red	NE	-	-	0	0.00	NE	-	TMR	0.4
37	Bijaga yellow	5MS	4	-	TMS	0.80	30MS	24	30MS	0.80
38	DWR 185	5MR	2	-	0	0.00	30MS	24	10MS	8
39	DWR 1006	TMR	0.4	-	0	0.00	0	0	10MS	8
40	DWR 2006	TMR	0.4	-	0	0.00	30MS	24	30S	30
41	HD 2781	NE	-	-	0	0.00	NE	-	15S	15

Contd……

	1	2	3	4	5	6	7	8	9	10
42	HI 8663	0	0	-	0	0.00	TMR	0.4	10MS	8
43	MACS 9	0	0	-	0	0.00	80S	80	15S	15
44	MACS 1967	0	0	-	TR	0.20	30MS	24	15S	15
45	MACS 2694	TMR	0.4	-	TR	0.20	TMR	0.4	15MS	12
46	MACS 3125	TMR	0.4	-	0	0.00	5MS	4	5MS	4
47	NI 5749	40S	40	77-5	TMR	0.40	40S	40	40S	40
48	NIDW 15	5R	1	-	0	0.00	10MS	8	TMS	0.8
49	NIDW 295	0	0	-	0	0.00	TR	0.2	10MS	8
50	UAS 415	TR	0.2	-	0	0.00	30S	30	20MS	16
51	UAS 428	TR	0.2	-	0	0.00	15S	15	30S	30
52	UAS 446	0	0	-	0	0.00	10MS	8	15S	15
	T. dicoccum									
53	DDK 1009	5MR	2	-	0	0.00	5MS	4	20MS	16
54	DDK 1025	5MR	2	-	0	0.00	TMS	0.8	20MS	16
55	DDK 1029	TMR	0.4	-	0	0.00	5MS	4	10MR	4
56	HW 1098	0	0	-	0	0.00	0;	0	0	0
57	MACS 2971	0	0	-	0	0.00	0;	0	0	0

Note: CI: Coefficient of Infection, NE: Not Evaluated

Totally 47 varieties during *rabi* 2015-16 and 57 varieties during *rabi* 2016-17 were screened at both the locations. Six weekly observations on leaf rust severity at Dharwad and three observations at Ugar khurd were recorded and the final rust severity was recorded. The observations on leaf rust severity under natural infection at Ugar Khurd during both the years revealed that, the total 41 varieties recorded CI up to 10.00 and remaining 16 had CI of more than 10.00. Under artificial inoculation at Dharwad during both the years 17 varieties were found to have CI up to 10.00 and remaining found to have CI of more than 10.00. In artificial inoculation the numbers of varieties with less than 10 CI were reduced as compared to natural infection and those 17 varieties which remain less than 10 CI are found real resistant to leaf rust disease.

Rust resistant wheat varieties (CI up to 10.00) both at Ugar Khurd (natural infection) and Dharwad (artificial inoculation) during *rabi* 2015-16 and 2016-17 are given below

Ugar Khurd (Natural infection)

T. aestivum

AKAW 4627, AKW 381, Dharwad dry, HD 3090, HD 2833, HD 2380, HD 2189, HD 2932, HI 977, KRL 19, KRL 1-4, KRL 210, KRL 213, MACS 2846, MACS 6222, NIAW 917, NIAW 1415, PBN 142, UAS 304.

T. durum

AKDW 2997-16, AKDW 4021, Bijaga red, Bijaga yellow, DWR 2006, DWR 185, DWR 1006, DWR 2006, HD 2781, HI 8663, MACS 1967, MACS 2694, MACS 3125, MACS 9, NIDW 295, NIDW 15, UAS 415, UAS 428, UAS 446.

T. dicoccum

DDK 1029, DDK 1025, DDK 1009, HW 1098, MACS 2971.

Dharwad (Artificial inoculation)

T. aestivum

AKAW 4627, HD 3090, HD 2833, HD 2380, MACS 2846, MACS 6222, UAS 304.

T. durum

AKDW 4021, Bijaga red, DWR 1006, HI 8663, NIDW 15, NIDW 295, MACS 3125.

T. dicoccum

DDK 1029, HW 1098, MACS 2971.

4.3 Race pattern of *P. triticina* Eriks. on peninsular zone released wheat varieties

Totally 36 leaf rust infected samples from the 48 peninsular zone released wheat varieties sown at Ugar Khurd during *rabi* 2015-16 were sent for race identification and results pertaining to this is given in Table 4. Five different pathotypes of *P. triticina* were observed on nine samples. Pathotype 77-9 was most frequent and appeared four times (on varieties Amruth, PBN 51, NIAW 34 and NI 5643) followed by 77-5 appeared two times (on varieties NIAW 34 and NI 5749). Pathotypes 77-1, 162-2 and 104-2 were observed only in one sample each on genotype MACS 2496, DWR 195 and UAS 347, respectively.

4.4 Components of slow rusting resistance in peninsular zone released wheat varieties

The different components of slow leaf rusting resistance such as latent period, uredial density and uredium size were studied in 13 selected peninsular zone released wheat varieties under glass house condition as explained in Material and Methods and the results pertaining to this study are presented in Table 5.

4.4.1 Latent period

Latent period of these varieties varied from 6-8 days. Interestingly the genotype MACS 6222 has not taken any infection and showed no symptoms. The latent period for this genotype was zero. However, eight varieties (UAS 415, UAS 428, UAS 446, DWR 2006, DWR 162, DWR 195, UAS 334 and UAS 347) recorded lowest latent period of 6 days and two varieties (Bijaga yellow and UAS 304) recorded 7 days and remaining two (HD 2189 and GW 322) recorded highest latent period of 8 days.

Table 5: Components of slow rusting in peninsular zone released wheat varieties

Sl. No.	Varieties	Latent period (days)	Uredial density (Per 0.5 cm^2)	Uredium size (mm^2)	Mean apparent rate of infection	AUDPC
1	UAS 415 (D)	6	2.11	0.71	0.16	129.50
2	UAS 428 (D)	6	4.56	0.71	0.16	312.90
3	UAS 446 (D)	6	3.22	0.60	0.13	182.00
4	DWR 2006 (D)	6	3.11	0.35	0.13	306.60
5	Bijaga yellow (D)	7	3.11	0.31	0.18	364.00
6	DWR 162	6	4.56	0.67	0.16	659.40
7	DWR 195	6	4.22	0.35	0.08	399.00
8	UAS 304	7	3.00	0.62	0.11	23.10
9	UAS 334	6	3.00	0.40	0.14	165.20
10	UAS 347	6	4.67	0.58	0.17	170.10
11	HD 2189	8	4.00	0.35	0.17	196.70
12	GW 322	8	1.67	0.30	0.08	25.20
13	MACS 6222	0	0.00	0.00	0.00	0.00

Note: < 100 AUDPC - Resistant
101 – 200 AUDPC - Slow rusters
>200 - Susceptible (Fast rusters)

4.4.2 Uredial density

Number of uredia per 0.5cm^2 area was calculated for each genotype. The results revealed that, the uredial density ranged from 0.00 to 4.67 among 13 varieties. All the varieties showed significant difference for uredial density. The genotype MACS 6222 recorded zero uredial density. The least uredial density was observed with GW 322 (1.67 uredia per 0.5 cm^2) followed by UAS 415 (2.11 uredia per 0.5 cm^2). The maximum uredial density was observed in genotype UAS 347 (4.67 uredia per 0.5 cm^2) which was followed by UAS 428 and DWR 162 (each 4.56 uredia per 0.5 cm^2).

4.4.3 Uredium size

Length and breadth of each uredium was measured and area was calculated for each genotype as per methodology described in the Material and Methods. Significant difference was observed among the 13 varieties tested for uredium size. The size ranged from 0.00 mm^2 to 0.71 mm^2 as presented in Table 5 and Plate 8. The minimum uredium size was recorded in genotype GW 322 (0.30 mm^2) and it was on par with the varieties DWR 2006, DWR 195 and HD 2189 (each 0.35 mm^2). The maximum uredium size was recorded in two varieties *viz.*, UAS 415 and UAS 428 (0.71mm^2) followed by DWR 162 (0.67 mm^2), UAS 304 (0.62 mm^2) and UAS 446 (0.60 mm^2) which were on par with each other.

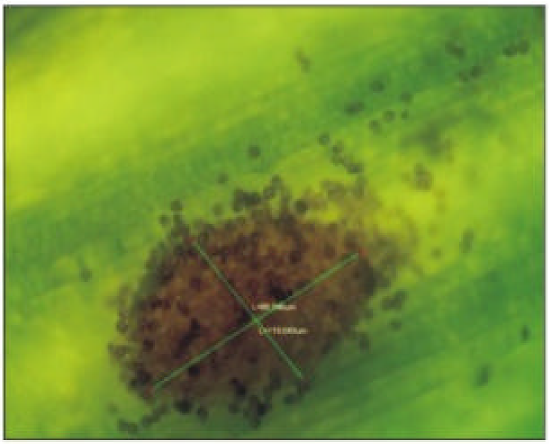
4.4.4 Apparent rate of infection (r)

The mean r value of these 13 varieties was taken from the field screening trial of Dharwad conducted during *rabi* 2016-17 and it ranged from 0.00 to 0.18. The lowest mean r value was recorded in two varieties *viz.*, DWR 195 and GW 322 (each 0.08), while highest was in Bijaga yellow (0.18) followed by UAS 347, HD 2189 (each 0.17), UAS 415, UAS 428 and DWR 162 (each 0.16).

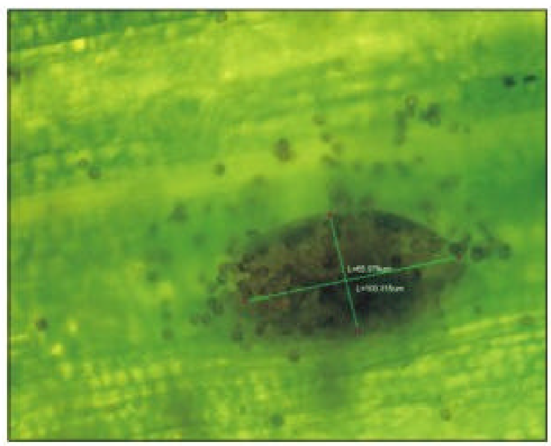
4.4.5 Area under disease progress curve (AUDPC)

Area under disease progress curve is a measure of slow rusting under field condition. The area under disease progress curve of these varieties was taken from the field screening trial of Dharwad conducted during *rabi* 2016-17 and the data is presented in Table 5. The AUDPC values for these varieties ranged from 23.10 to 659.40.

a) Pustule size of UAS 415 (100X)



b) Pustule size of UAS 446 (100X)



c) Pustule size of UAS 334 (100X)

d) Pustule density of HD 2189 (100X)

Plate 8: Pustule size in different wheat varieties

Among the 13 varieties lowest AUDPC was recorded in variety UAS 304 (23.10) followed by GW 322 (25.20) and these two were on par with each other. The highest AUDPC value was recorded with DWR 162 (659.40). The next higher AUDPC value was observed with DWR 195 (399.00), Bijaga yellow (364.00) and DWR 2006 (306.00). MACS 6222 recorded zero AUDPC.

Based on the AUDPC value, five varieties (UAS 415, UAS 446, UAS 334, UAS 347 and HD 2189) were categorized as slow rusters and other five (DWR 162, UAS 428, DWR 2006, Bijaga yellow and DWR 195) as susceptible (fast rusters) and remaining two (UAS 304, GW 322) were categorized as resistant.

4.5 Evaluation of integrated spray schedule for the management of leaf rust of wheat

The investigation was undertaken to develop effective and economically feasible spray schedule for management of leaf rust involving commercially available botanicals, bioagents, ITKs and fungicides based on *in vitro* results during *rabi* 2016-17 at Main Agricultural Research Station, Dharwad using susceptible genotype DWR 162. The results pertaining to this investigation are presented here under.

4.5.1 *In vitro* evaluation of fungicides, commercially available botanicals, bio-agents and ITK's against *P. triticina*

4.5.1.1 Fungicides

In vitro evaluation of fungicides was conducted with respect to inhibition of uredospore germination of *P. triticina* at different concentrations of fungicides using cavity slide method and the data is presented in Table 6 and Plate 9. The efficacy of four non-systemic fungicides and five systemic fungicides on inhibition of uredospore germination of *P. triticina* was carried out. Among the non systemic fungicides (Table 6a) the maximum inhibition was noticed in chlorothalonil (87.62 %) at 0.1 per cent concentration, which was on par with captan (86.88 %) and propineb (85.79 %) and

Table 6: *In vitro* evaluation of systemic and non systemic fungicides on uredospore germination inhibition of *P. triticina*

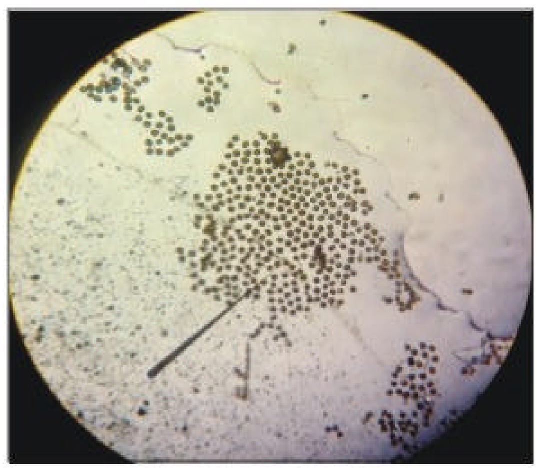
Sl. No.	a. Non systemic fungicides	Per cent uredospore germination inhibition at			
		0.10 %	**0.20 %**	**0.25 %**	**Mean**
1	Mancozeb 75 % WP	84.43 (68.66) *	90.93 (74.15)	93.54 (80.63)	**89.70 (71.56)**
2	Captan 50 % WP	86.88 (69.23)	90.60 (74.22)	94.80 (78.27)	**90.76 (73.36)**
3	Chlorothalonil 75 % EP	87.62 (70.63)	92.15 (77.01)	94.63 (78.25)	**91.46 (74.10)**
4	Propineb 70 % WP	85.79 (68.86)	92.70 (75.58)	95.37 (79.63)	**91.28 (73.91)**
Mean		**86.45 (69.29)**	**91.59 (74.24)**	**95.11 (78.66)**	
			Fungicides (F)	**Concentrations (C)**	**FXC**
		S.Em. ±	1.28	0.99	2.21
		C.D. @ 1 %	4.86	3.77	8.42

Sl. No.	b. Systemic fungicides	Per cent uredospore germination inhibition at			
		0.025 %	**0.05 %**	**0.10 %**	**Mean**
1	Propiconazole 25 EC	93.59 (76.62)	97.72 (83.59)	98.02 (84.37)	**96.44 (80.83)**
2	Hexaconazole 5 EC	93.76 (76.83)	98.85 (88.23)	99.95 (89.31)	**98.15 (82.29)**
3	Penconazole 10 EC	87.89 (70.66)	94.39 (77.97)	95.19 (79.28)	**92.49 (75.26)**
4	Difenconazole 25 EC	86.71 (69.82)	88.67 (71.47)	95.92 (80.48)	**90.43 (73.00)**
5	Tebuconazole 25 EC	92.17 (74.91)	94.71 (77.14)	98.37 (85.50)	**95.08 (77.62)**
Mean		**90.89 (73.49)**	**95.31 (78.97)**	**97.49 (82.98)**	
			Fungicides (F)	**Concentrations (C)**	**FXC**
		S.Em. ±	0.75	0.49	1.29
		C.D. @ 1 %	2.85	1.87	4.93

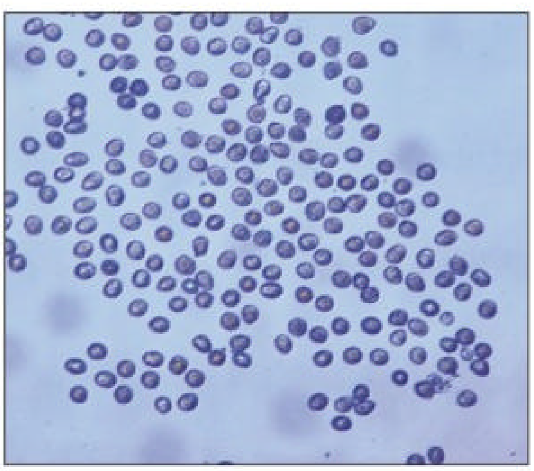
* Angular transformed values.

a) Uredospore germination in control (100X)

b) Germination inhibition in panchgavya @ 5 % (100X)



c) Germination inhibition in (Hexaconazole 4% + Zineb 68 % WP) @ 0.2 % (100X)



d) Germination inhibition in Hexaconazol alone @ 0.1 % (400X)

Plate 9: *In vitro* evaluation studies

least inhibition of uredospore germination was noticed in mancozeb (84.43 %) at same concentration. At 0.2 per cent concentration, maximum inhibition was noticed in propineb (92.70 %) which was on par with all other tested fungicides except captan (90.60 %). At 0.25 per cent concentration, maximum inhibition was noticed in chlorothalonil (94.63 %) which was on par with all other tested fungicides. Irrespective of fungicide concentration, chlorothalonil (91.41 %) was found to have highest inhibition of spore germination and remain on par with propineb (91.28 %), captan (90.76 %) and mancozeb (90.70 %).

Among systemic fungicides (Table 6b) maximum inhibition was noticed in hexaconazole (93.76 %) at 0.025 per cent concentration which was on par with propiconazole (93.59 %) and tebuconazole (92.17 %) at the same concentration. Least inhibition of uredospore germination was noticed in difenconazole (86.71 %). At 0.05 per cent concentration, maximum inhibition was noticed in hexaconazole (98.85 %) which was on par with all other tested fungicides except difenconazole (88.67 %). At 0.1 per cent concentration, maximum inhibition was observed in hexaconazole (99.95 %) and it was on par with all other tested fungicides except penconazole (95.19 %). Irrespective of fungicide concentration, hexaconazole (98.15 %) was found to have highest inhibition of spore germination and remain on par with propiconazole (96.44 %) and tebuconazole (95.08 %).

Among the seven different combiproduct fungicides evaluated (Table 7) under *in vitro* condition against *P. triticina*, captan 70 % + hexaconazole 5 % inhibited maximum uredospore germination (74.89 %) at 0.05 per cent concentration followed by tebuconazole 50 % + trifloxystrobin 25 % (65.79 %) and carbendazim 12 % + mancozeb 63 % (65.30 %) at the same concentration. At 0.1per cent, among all the fungicides captan 70 % + hexaconazole 5 % significantly (77.16 %) inhibited uredospore germination which was on par with tebuconazole 50 % + trifloxystrobin 25 % (75.25 %). The next higher level of inhibition was observed in azoxystrobin 11.4 % + propiconazole 11.4 % (73.21 %) followed by carbendazim 12 % + mancozeb 63 % (71.19 %) and least inhibition was observed in difenconazole + propiconazole (52.82 %) at the same concentration. Highest uredospore germination inhibition was observed in hexaconazole 4 % + zineb 68 % (91.41 %) followed by captan 70 % +

Table 7: *In vitro* evaluation of combiproduct fungicides on uredospore germination inhibition of *P. triticina*

Sl. No.	Fungicides	Per cent uredospore germination inhibition at			
		0.05 %	0.10 %	0.20 %	Mean
1	Captan 70 % + Hexaconazole 5 %	74.89 (60.03) *	77.16 (61.50)	90.40 (72.07)	**80.82 (64.53)**
2	Carbendazim 12 % + Mancozeb 63 %	65.30 (53.92)	71.19 (57.58)	86.19 (68.20)	**74.23 (59.90)**
3	Hexaconazole 4 % + Zineb 68 % WP	53.33 (46.93)	68.50 (55.90)	91.41 (73.03)	**71.08 (58.62)**
4	Azoxystrobin 11.4 % + Propiconazole 11.4 %	62.13 (52.02)	73.21 (58.83)	85.16 (67.52)	**73.50 (59.46)**
5	Tebuconazole 50 % + Trifloxystrobin 25 %	65.79 (54.21)	75.25 (60.19)	76.58 (61.13)	**72.54 (58.51)**
6	Difenconazole 13.9 %+ Propiconazole 13.9 %	41.03 (39.81)	52.82 (46.62)	67.15 (55.09)	**53.67 (47.17)**
7	Tricyclazole 45 %+ Hexaconazole1 %	63.43 (52.80)	74.23 (59.52)	75.95 (60.78)	**71.20 (57.70)**
	Mean	**64.57 (53.57)**	**68.65 (56.19)**	**79.79 (64.19)**	
			Fungicides (F)	**Concentrations (C)**	**FXC**
		S.Em. ±	0.96	0.63	1.67
		C.D. @ 1 %	3.67	2.40	6.36

* Angular transformed values.

hexaconazole 5 % (90.40 %) at 0.20 per cent concentration. The least inhibition was observed in difenconazole 13.9 % + propiconazole 13.9 % (67.15 %). The combi product hexaconazole 4 % + zineb 68 % recorded highest (91.41 %) uredospore germination inhibition at 0.20 per cent concentration compared to other combi product fungicides.

4.5.1.2 Commercially available botanicals

In vitro evaluation of six different commercially available botanicals (Table 8) was done against *P. triticina* on uredospore germination inhibition and the results revealed that nimbicidine was highly effective in inhibition of uredospore germination (68.60 %) followed by raw neem oil (58.30 %) which was on par with neemgold (58.12 %), whereas least inhibition was observed in agroneem (49.87 %) at all the concentrations (0.25, 0.5 and 1.0 %). Among the interaction effect nimbicidine at 1.0 per cent showed highest uredospore germination inhibition (86.34 %) followed by neemgold at 1.0 per cent (68.04 %), which was on par with discheck (68.03 %) at the same concentration. The lowest (39.25 %) inhibition was noticed in agroneem at 0.25 and 0.5 per cent concentrations.

4.5.1.3 Bioagents

Evaluation of bioagents against inhibition of uredospore germination of *P. triticina* was done by cavity slide method (Table 9). The results revealed that maximum inhibition of uredospore germination (30.06 %) was noticed in *T. harzianum* + *B. subtilis* at 10 g/l (5 g each) concentration followed by *B. subtilis* alone (27.76 %) at 10 g/l concentration. The minimum inhibition of uredospore germination was noticed in *P. fluorescence* + *B. subtilis* (13.96 %) at 10 g/l (5 g each) concentration.

4.5.1.4 ITK's

Among the four different ITK's evaluated against inhibition of spore germination of *P. triticina* (Table 10), panchagavya showed the highest inhibition of uredospore germination (52.55 %) followed by cow urine (47.86 %) and butter milk (45.97 %) which were on par with each other at all the concentrations (5 %, 10 % and 25 %). Whereas the least inhibition of uredospore germination was observed in vermiwash (36.83 %) at all the concentrations.

Table 8: *In vitro* evaluation of commercially available botanicals on uredospore germination inhibition of *P. triticina*

Sl. No.	Botanicals	Per cent uredospore germination inhibition at			
		0.25 %	**0.5 %**	**1.0 %**	**Mean**
1	Agroneem (Neem oil based herbal pesticide)	39.95 (39.12) *****	43.83 (41.38)	65.82 (54.44)	**49.87 (44.98)**
2	Rawneem oil (Azadirachtin)	45.86 (42.61)	62.86 (52.50)	66.19 (54.69)	**58.30 (49.93)**
3	Soldier [*Aegl marbelos* (20 %) *Ricinuscommunis* (20 %) *Hygrophila spinosa* (20 %) *Laminaria spp*. (20 %) *Lantana camera* (20 %)]	53.62 (47.21)	55.29 (48.17)	64.44 (53.42)	**57.78 (49.60)**
4	Discheck [*Ficus bengalensis* (0.0001 %) *Ficus religiosa* (0.0001 %) *Ficus retus* (0.0001 %) Aqua solvent (99.99 %)]	40.14 (39.30)	49.37 (44.55)	68.03 (55.58)	**52.51 (46.48)**
5	Neemgold (Azadirachtin 0.15 %)	51.78 (46.02)	54.55 (47.62)	68.04 (55.69)	**58.12 (49.78)**
6	Nimbicidine (Azadirachtin 0.03 %)	52.34 (46.38)	67.12 (55.01)	86.34 (68.70)	**68.60 (56.70)**
	Mean	**47.28 (43.44)**	**55.50 (48.21)**	**69.81 (57.09)**	
			Botanicals (B)	**Concentrations (C)**	**B x C**
		S.Em.±	1.89	1.34	3.27
		C.D. @ 1 %	7.21	5.10	12.49

* Angular transformed values.

Table 9: ***In vitro*** **evaluation of bioagents on uredospore germination inhibition** ***P. triticina***

Sl. No.	Bioagents	Per cent uredospore germination inhibition
1	*Trichoderma harzianum* @ 10 g/l	23.64 (29.00) *
2	*Pseudomonas fluorescens* @ 10 g/l	18.23 (25.30)
3	*Bacillus subtilis* @ 10 g/l	27.76 (31.70)
4	*T. harzianum* +*P. fluorescens* @ 10 g/l (5 g each)	23.34 (28.50)
5	*T. harzianum* +*B. subtilis* @ 10 g/l (5 g each)	30.06 (33.20)
6	*P. fluorescens* + *B. subtilis* @ 10 g/l (5 g each)	13.96 (21.90)
7	*T. harzianum* +*P. fluorescens* + *B. subtilis* @ 10 g/l (3.3 g each)	20.95 (27.20)
8	Talk powder @ 10 g/l	14.08 (21.90)
	S.Em. ±	2.17
	C.D. @ 1 %	6.58

* Angular transformed values.

Table 10: ***In vitro*** **evaluation of ITK's on uredospore germination inhibition of** ***P. triticina***

Sl. No.	ITK's	Per cent uredospore germination inhibition at			
		5 %	**10 %**	**25 %**	**Mean**
1	Cow urine	36.81 (37.33) *	42.96 (40.92)	63.81 (53.05)	**47.86 (43.77)**
2	Butter milk	36.55 (37.12)	43.98 (41.53)	57.39 (49.29)	**45.97 (42.65)**
3	Panchagavya	40.99 (39.76)	48.56 (44.16)	68.09 (55.61)	**52.55 (46.51)**
4	Vermiwash	14.05 (21.98)	38.67 (38.38)	57.75 (49.48)	**36.83 (36.61)**
	Mean	**32.10 (34.05)**	**43.54 (41.25)**	**61.76 (51.86)**	**45.80 (42.38)**
			ITK's (I)	**Concentration (C)**	**IXC**
		S.Em. ±	4.18	3.62	2.41
		C.D. @ 1 %	12.26	10.62	7.07

* Angular transformed values.

4.5.2 Evaluation of developed integrated spray schedule for the management of leaf rust of wheat

An integrated spray schedule was developed using *in vitro* effective fungicides (hexaconazole 5 EC and hexaconazole 4 % + zineb 68 % WP), commercially available botanical (nimbicidine), bioagents (*T. harzianum* + *B. subtilis*) and ITK (panchagavya) and evaluated under field condition during *rabi* 2016-17 at MARS, Dharwad and the data is presented in Table 11 and Plate 10.

4.5.2.1 Effect of spray schedule on leaf rust severity

The results indicated the significant differences among the spray schedule which was evident with respect to two leaf rust quantification parameters *viz.*, coefficient of infection (CI) and area under disease progress curve (AUDPC). Among the 13 different spray schedules involving fungicide, botanicals, bioagents and ITK's, the spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded the least AUDPC value of 6.60 and CI of 0.27 followed by single spray of hexaconazole @ 0.1 % at 60 DAS (T_{12}) (9.05 AUDPC and 0.61 CI) and (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % (T_2) (11.95 AUDPC and 0.14 CI). The spray schedule combinations (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - panchagavya @ 10 % (T_{11}) (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_{10}), hexaconazole @ 0.1 % - panchagavya @ 10 % (T_8), hexaconazole @ 0.1 % - nimbicidine @ 1 % (T_6) were recorded 14.75, 26.65, 29.35 and 23.10 AUDPC, respectively. The control treatment T_{14} recorded significantly highest AUDPC and CI of 433.75 and 30.33, respectively. The spray schedule nimbicidine @ 1 % - nimbicidine @ 1 % (T_3) (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_4) and panchagavya @ 10 % - panchagavya @ 10 % (T_5) recorded significantly higher AUDPC values of 402.20, 344.30 and 300.39, respectively.

4.5.2.2 Effect of spray schedule on grain yield, 1,000 grain weight and biomass

The grain yield, 1,000 grain weight and biomass were recorded after harvest of the crop (Table 11). And the spray schedule (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % (T_2) recorded highest grain

Table 11: Evaluation of integrated spray schedule for the management of leaf rust of wheat

Treat ment No.	Spray schedule		CI	AUDPC	Grain yield (q/ha)	1000 grain weight (g)	Biomass (t/ha)	B:C ratio
	I spray	II spray						
T_1	Hexaconazole @ 0.1 %	Hexaconazole @ 0.1 %	0.27 (1.13) *	6.60	35. 38	33.95	27.70	2.30
T_2	Hexaconazole 4 % + Zineb 68 % WP @ 0.2 %	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	0.14 (1.07)	11.95	35.13	33.55	25.11	2.12
T_3	Nimbicidine @ 1.0 %	Nimbicidine @ 1.0 %	12.62 (3.69)	402.20	31.38	30.95	21.62	2.08
T_4	(*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each)	(*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each)	13.31 (3.71)	344.30	29.60	31.58	21.49	1.85
T_5	Panchagavya @ 10.0 %	Panchagavya @ 10.0 %	10.15 (3.29)	300.39	29.25	31.43	20.14	1.92
T_6	Hexaconazole @ 0.1 %	Nimbicidine @ 1.0 %	2.00 (1.73)	40.80	33.10	32.55	22.62	1.90
T_7	Hexaconazole @ 0.1 %	(*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each)	3.44 (2.07)	61.35	32.97	33.23	20.31	1.97
T_8	Hexaconazole @ 0.1 %	Panchagavya @ 10.0 %	1.89 (1.68)	29.35	33.47	32.90	21.53	2.02
T_9	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	Nimbicidine @ 1.0 %	1.81 (1.66)	40.95	33.42	33.13	21.92	1.85
T_{10}	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	(*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each)	0.42 (1.18)	26.65	33.90	35.02	24.68	2.07
T_{11}	(Hexaconazole 4 % + Zineb 68 % WP) @ 0.2 %	Panchagavya @ 10.0 %	0.79 (1.34)	14.75	33.45	31.23	23.11	2.20
T_{12}	Hexaconazole @ 0.1 %	No spray	0.61 (1.26)	9.05	32.70	34.88	21.08	2.23
T_{13}	No spray	Hexaconazole @ 0.1 %	0.51 (1.23)	214.70	32.64	33.03	20.78	2.05
T_{14}	Unsprayed control		30.33 (5.60)	433.75	28.30	30.37	19.79	1.54
		S.Em. ±	0.21		0.75	0.68	0.22	0.06
		C.D. @ 5 %	0.62		2.17	1.98	0.64	0.17

*Square root transformed values, CI: Coefficient of Infection.
Cost of grain @ Rs. 2400/q, Cost of fungicides/botanicals/bioagents/ITK's in Rs: hexaconazole – Rs. 590 /l, (hexaconazole 4 % + zineb 68 % WP) - Rs. 240/250 g, nimbicidine - Rs. 430/l, *T. harzianum* - Rs.130/kg, *B. subtilis* - Rs.130/kg, panchagavya - Rs.10 /l. Labour charges for two sprayes per hectare: Rs. 1000

a) Field view of IDM at 60 DAS

b) Severity upto 40S in control plot

c) T_1 - Hexaconazole @ 0.1 % - Hexaconazole @ 0.1 %

d) T_{14} - Unsprayed control

Plate 10: Integrated disease management of leaf rust

yield of 35.38 q ha^{-1} and it was statistically on par with T_1 (35.13 q ha^{-1}), T_{10} (33.90 q ha^{-1}), T_8 (33.47 q ha^{-1}) and T_9 (33.42 q ha^{-1}) except unsprayed control which recorded 28.25 q ha^{-1}. In case of 1,000 grain weight, the spray schedule (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_{10}) recorded highest grain weight of 35.02 g followed by T_{12} (34.88g), T_1 (33.95 g), T_2 (33.55 g) and these were on par with each other. Unsprayed control (T_{14}) recorded lowest grain weight of 30.37 g.

Similar trends were observed in case of biomass yield (t/ha). The spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest biomass of 27.70 t ha^{-1} and it was statistically on par with (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % (T_2) (25.11 t ha^{-1}) and (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_{10}) (24.68 t ha^{-1}). The unsprayed control T_{14} recorded lower biomass yield of 19.79 t ha^{-1}.

4.5.2.3 Benefit : Cost ratio

The benefit cost ratio has been worked out for different spray schedule and presented in Table 11. The highest B:C ratio was obtained with spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) (1:2.30) followed by single spray of hexaconazole @ 0.1 % (T_{13}) (1:2.23), (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - panchagavya @ 10 % (T_{11}) (1:2.20) and (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % (T_2) (1:2.12). The lowest B:C ratio was observed with (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_4) (1:1.85) and panchagavya @ 10 % - panchagavya @ 10 % (T_5) (1:1.92).

5. DISCUSSION

Wheat [*Triticum* spp.] is the most important winter cereal crop of the world known from the ancient times to mankind as staple food and as a energy driven for large number of hungry stomachs. Human population is largely dependent and believed on this crop for the survival then and now and area and production of wheat is continuously increasing throughout the world with the ever increasing human population. It occupies first place both in production and cultivated area in the world food grain scenario. In India, it occupies an area of 31.46 m ha with the production of 96.64 mt. (Anon., 2016a). Among the important wheat growing zones in the country, peninsular zone (PZ) is unique in cultivation of wheat where in all the three species of wheat are cultivated and is known for production of quality wheat grain. In recent days several factors are attributed to limit the yield of wheat and the diseases play a major role. Rust caused by the fungus *Puccinia triticina* Eriks. is one of the major disease affecting both forage and grain production in wheat. It has been observed throughout India. In southern India, the disease usually starts from the month of December and it reaches alarming status in the mid winter to late winter as the crop approaches for harvesting. Its survival and nationwide perpetuation is well explained by the historical aerobiological discovery popularly known as puccinia path which is dependent on upper air currents blowing from southern parts of India to the central wheat growing areas. The disease is of major concern in peninsular India both for the farmers and researchers where the wheat is sown early in post rainy season (*rabi*) and acts as secondary foci of infection which favored by then prevailing cold weather in winter season in these areas. All growth stages of the plant are susceptible to rust attack and under favorable environment, crop is severely affected in foliage growth and produces shriveled seeds. The rust infection on wheat has been reported to cause up to 40 per cent reduction in grain yield (Saari and Prescott, 1985).

Leaf rust (*P. triticina*) being an obligate and host specific fungal species, has reached all its potential to achieve this great widespread destructive nature. Its strategies to survive, disseminate and infect host in obligate parasitic manner all together needs a holistic movement towards its control. So the various management practices such as gene deployment, gene cycling, host resistance and integrated management practices are adopted nationwide and each wheat cultivating zones of India have their own strategies in combating the disease as directed and coordinated by central rust monitoring authorities. The regular monitoring through surveys, race identification and effective use of slow leaf rusting wheat cultivars play major role in control of leaf rust in peninsular zone along with adopting integrated disease management strategy involving commercially available botanicals, bioagents, ITK's and the fungicides.

Hence, the present study was undertaken considering different aspects like survey of the disease to know the disease severity and prevailing rust races in different districts of northern Karnataka, evaluation of peninsular zone released wheat varieties for leaf rust resistance, studies on slow rusting characters of these peninsular zone released wheat varieties and finally developing effective and economic spray schedule involving commercially available botanicals, bio-agents and ITK's along with fungicides. Results of these studies are discussed here under following headings.

5.1 Survey

5.2 Evaluation of peninsular zone released wheat varieties for leaf rust resistance

5.3 Race pattern of *P. triticina* Eriks. on peninsular zone released wheat varieties

5.4 Components of slow rusting resistance in peninsular zone released wheat varieties

5.5 Evaluation of integrated spray schedule for the management of leaf rust of wheat

5.1 Survey

Survey on severity and occurrence of rust revealed that the magnitude of dependency of pathogen on prevailing environmental conditions in a cropping season. Park *et al.* (2011) stated that survey and surveillance form the basis for any successful plant protection strategy that depends on early detection of the disease followed by timely adoption of control measures. Hence in the present investigation, roving survey was undertaken in major wheat growing areas of northern Karnataka.

The roving survey on rust severity was carried out in Dharwad, Belagavi, Vijayapura and Bagalkot districts of northern Karnataka during *rabi* 2015-16 and *rabi* 2016-17. There was no appearance of leaf rust in any parts of these districts during *rabi* 2016-17. However, variable amount of rust severity was observed in these districts during *rabi* 2015-16. The overall severity of the disease generally varied from taluk to taluk and year to year. Such variations in the disease severity have also been observed by earlier workers (Arunkumar, 2013; Singh *et al.,* 2016). Mean maximum leaf rust severity was observed in Bagalkot (ACI 17.20) and Belagavi (ACI 12.61) where, wheat was grown more or less under irrigated or restricted irrigated conditions.

During *rabi* 2015-16, the growing season in northern Karnataka was relatively cool, which showed the development of wheat leaf rust. The first observance of wheat leaf rust was in the month of February. This is much later than the normal date of appearance *i.e.,* usually December first week. During *rabi* 2016-17, there was no appearance of leaf rust in any of the farmers field visited, however its appearance was observed at the end of the season in few highly susceptible cultivars sown at Ugar Khurd to the magnitude of TS to 40S. This may be due to less inoculum coming in to northern Karnataka from south central India, due to non-conducive weather, less *rabi* rains (total rain fall during *rabi* 2016-17, 121 mm, Appendix III) and wind pattern for spread. The net result was a very low level of wheat leaf rust infection in northern Karnataka during *rabi* 2016-17, compared with other years. Wind dissemination over long distances is typical of cereal rusts and affects many cereal hosts grown over large areas. Even though leaf rust uredospores are mainly wind disseminated, rain can also spread uredospores, with many spores occurring in clusters, although distances are limited (Rapilly, 1979). Infection efficiency can be high because spore clusters have a high germination and infection potential compared to single spores.

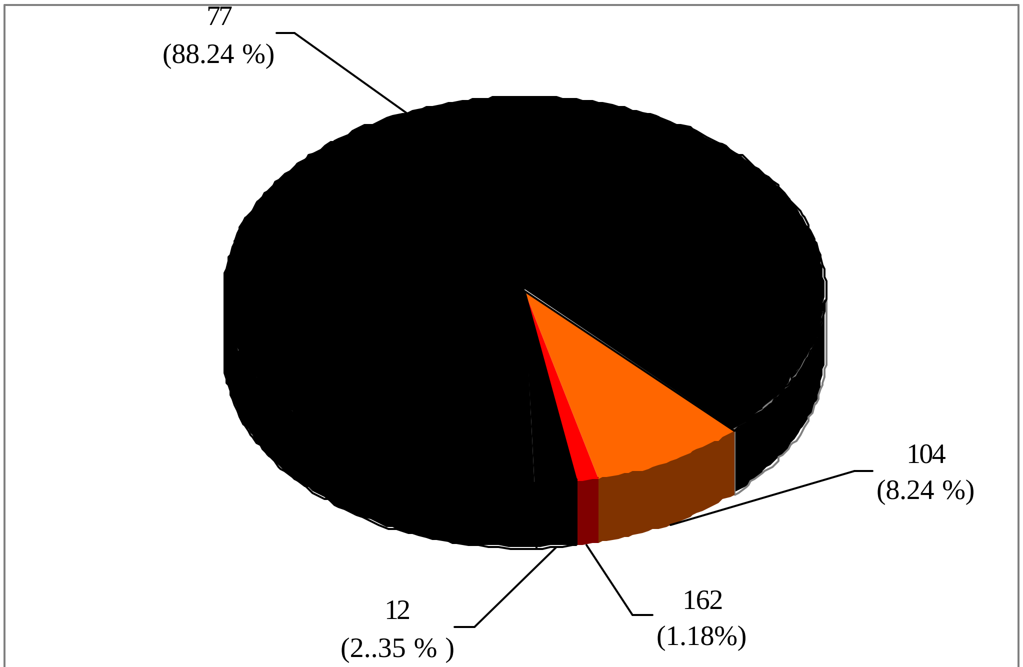
Survey also revealed that there was less or non appearance of rust in rainfed wheat cultivation. This happens because physiological conditions of the plant such as water relations may influence whether a specific infection part may be accessible by pathogens. Water status is known to affect stomatal opening, lenticels diaphragm rupture which represents an important areas of pathogen entry at least for obligates like rust fungi (Orcut and Erik, 2014).

Analysis of leaf rust infected samples collected from the farmer's fields during *rabi* 2015-16 for understanding the prevalence of races in northern Karnataka revealed the existence of diverse population of the pathogen with respect to virulence and varietal specificity conferring resistance against leaf rust (Fig. 1). In Karnataka pathotypes 77-9, 77-5 and 104-2 were most predominant in *rabi* 2015-16 and these races were known to occur regularly since previous two decades in peninsular India and this has been confirmed by earlier workers from time to time (Kalappanavar *et al.,* 2006; Indu Sharma and Saharan, 2011; Singh *et al.,* 2016).

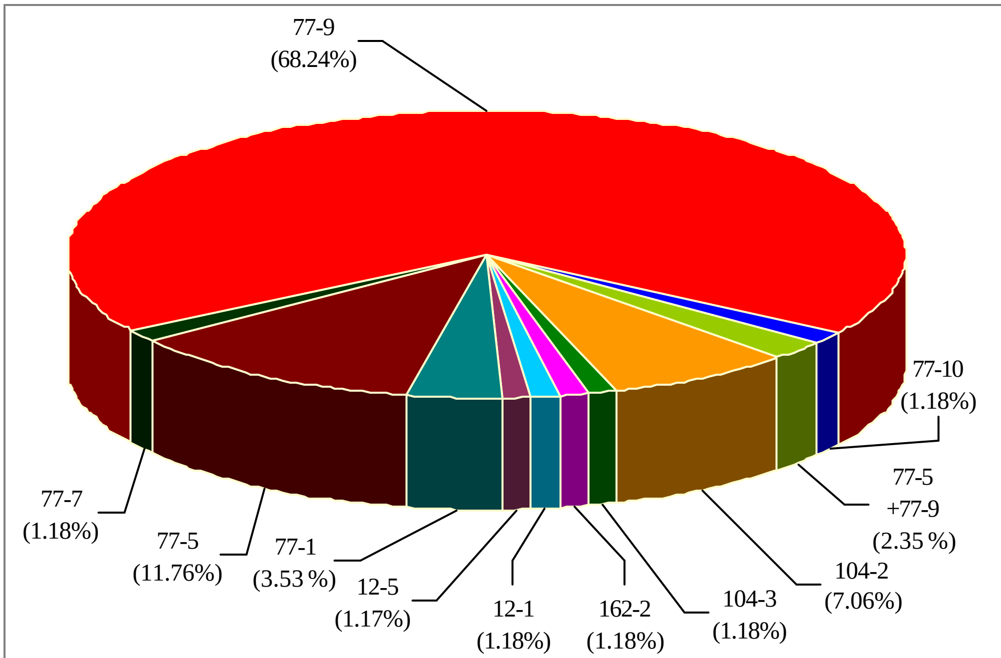
5.2 Evaluation of peninsular zone released wheat varieties for leaf rust resistance

The management of disease through host plant resistance has been an apt choice in the crop improvement programme. Evaluation and utilization of resistant varieties in farming is the most simple, effective and economical method in the management of disease. Screening of peninsular zone released wheat varieties for their variable amount of resistance to leaf rust provides an opportunity to assess their usefulness in the present approach of rust management such as use of durable resistance, gene cycling and gene deployment. Most of the grand old peninsular zone released wheat varieties are still under cultivation in some parts of the wheat growing areas of Karnataka and Maharashtra. Evaluating their performance in confirming resistance against leaf rust both in natural and artificial inoculated condition gives an idea to advance these cultivars and reuse them in nationwide rust management strategy.

This investigation was under taken both in natural infection and artificial inoculation during *rabi* 2015-16 and *rabi* 2016-17 at MARS, Dharwad and Ugar Sugars Works Ltd. Ugar Khurd. In natural infection the maximum disease severity of 60S to 80S was observed in some of the susceptible varieties (DBW 93, NI 5643) indicating the presence of sufficient disease pressure in the year *rabi* 2015-16 to screen these varieties. However, the overall disease pressure was low in next year *rabi* 2016-17, ranging from 10MS to 40S in some of the varieties (PBN 142, PBN 51). The observations on leaf rust severity under natural condition at Ugar Khurd during both the years revealed that 19 varieties each from aestivum and durum group and four varieties



a) Pathotype groups



b) Pathotypes

Fig. 1: Pie chart showing the distribution of leaf rust pathotype groups and pathotypes in northern Karnataka during *rabi* 2015-16

from dicoccum group have recorded CI up to 10.00. Among the five aestivum varieties (DWR 162, DWR 195, UAS 304, UAS 334, UAS 347) released by Dharwad centre, UAS 304 (year of release 2013) has recorded CI up to 10.00. The variety UAS 304 is known to carry rust resistant gene combination *Lr*1 $^{+,}$ *Lr*10 $^{+.}$ Also the old varieties of aestivum released for peninsular zone like HD 2189 (1970, *Lr* 13 $^{+,}$ *Lr* 34), HI 977 (1988, *Lr* 23 $^{+,}$ *Lr* 34 $^{+}$) have shown resistant to leaf rust under natural condition during both the years. The maximum disease severity among durum varieties ranged from 40S to 80S (NI 5749, Bansi white, Amruth). Ninteen varieties out of 23 have recorded CI up to 10.00 and remaining four have recorded CI more than 10.00 (Amruth, Bansi white, NI 5749). The old durum varieties like Bijaga red (1965), Bijaga yellow (1965), DWR 185 (1998), MACS 9 (1978) and MACS 1967 (1987) have shown resistant reaction to leaf rust under natural condition and all the five dicoccum varieties have recorded CI up to 10.00.

Under artificial inoculation at Dharwad during both the years 17 varieties from all the three species were found to have CI up to 10.00 and remaining was found to have CI of more than 10.00. The old varieties HD 2380 (1989) and MACS 2846 (1998, *Lr* 23 $^{+}$) remained resistant both in natural and artificial inoculation. Also UAS 304 (2013) showed resistance under both the conditions. The seven varieties from durum group showed resistant reaction both in natural and artificial inoculation that includes Bijaga red and DWR 2006. In artificial inoculated condition the number of varieties with less than 10.00 CI were reduced as compared to natural condition and those 17 varieties which remain less than 10 CI are found real resistant to leaf rust disease and similar results were reported by various workers on the performance of different class of varieties used in the breeding strategy (Kalappanavar *et al.,* 2003; Singh *et al.,* 2004).

5.3 Prevalence of leaf rust races on peninsular zone released wheat varieties

Race determination in rusts is based on differential cultivars of the uredospore-host tested under controlled conditions. Races are then differentiated by different infection types on differential varieties (Fuchs, 1972). Race identification provides data for mapping the distribution and frequency of races. This provides the information necessary for selection of new sources of host resistance and most race identifications were designed to detect new virulent pathogen phenotypes before they increased to economically important levels within the pathogen population (Roelfs *et al.,* 1992).

Leaf rust virulence survey since many decades reveals that, the population is highly variable leading to the evolution of new pathotypes through mutation and rarely through somatic hybridization (Bhardwaj *et al.,* 2005). In the present investigation, the pathotype group 77 was dominant on peninsular zone released wheat varieties (Ugar Khurd, *rabi* 2015-16). Five different pathotypes of *P. triticina* were observed on nine samples. Pathotype 77-9 was most frequent and appeared on four varieties (Amruth, PBN 51, NIAW 34 and NI 5643) followed by 77-5 which appeared on two varieties (NIAW 34 and NI 5749). The predominance and wide distribution of above mentioned pathotype groups in wheat cultivating areas of northern Karnataka and on some of these cultivated peninsular zone wheat varieties is confirmed with earlier reports of many workers (Hasabnis, 1998; Kalappanavar *et al.,* 2006; Arunkumar, 2013).

Understanding the variability in pathogenic population (race analysis) will certainly play an important role in disease management. The ability to manage disease depends on understanding the composition of pathogen populations. Lebeda (1982) found that genetic diversity, varied in virulence in pathogenic fungal populations and is usually expressed as virulence factors or virulence phenotypes. He also noted that intraspecific genetic variability is most frequently characterized by the proportions of physiological races in the population. Stubbs (1967) found that physiological specialization of yellow rust on wheat and barley could vary from year to year. These changes in the occurrence of infection type could be attributed to seasonal environmental differences, favoring one type over another. Knott (1989) states that variation in populations of any rust depends on climate and resistance of the host cultivars. Within an area annual variation is usually dependent on the weather. Knott also found that the virulence types tend to be similar throughout an area. However, changes can occur within an area if the predominant cultivars use different resistance genes and if inoculum can be disseminated between areas.

5.4 Components of slow rusting resistance in peninsular zone released wheat varieties

Leaf rust caused by *P. triticina* is known for its surviving nature in mega range of climatic conditions appears to be the most important pathogen in the country as well as in the world. The wheat scientists, apprehensive with the management of this pathogen were attentive of the fact that due to its wide spreading nature, it is cumbersome to manage the disease and avoid epiphytotic conditions in the country by the use of expensive chemicals which are the most important deterrent measure in the management strategy. The trend to look for resistance sources against leaf rust running up to the current epoch and will be continued as the increase in the world population and diversity of the pathogen to overcome the resistance genes. The current strategy to combat this ever evolving pathogen is by breeding for durable leaf rust resistance and needs constant efforts to identify new sources of durable rust resistance genes as well as varieties.

The search and use of varieties with less terminal leaf rust severity is an important practice to manage the obligate parasites. The slow rusters which are characterized by longer latent period, slow development of leaf rust, lesser number of uredia per unit area of leaf, lesser size of uredia and lower values of AUDPC which, ultimately results in low terminal disease severity. The low terminal disease severity append in the yield of slow rusters because more leaf area is available for photosynthesis during the peak growth period.

In the light of this the present investigation was carried out during *rabi* 2016-17, to identify new slow rusters among the 13 selected peninsular zone released wheat varieties under glass house condition at MARS, Dharwad. Observations from the present investigations revealed that, there was significant difference among these 13 varieties comprising of all the three species for various slow rusting characters such as lower latent period, less uredial density per unit leaf area, small uredium size and AUDPC.

5.4.1 Latent period (LP)

Latent period is one of the most important components for slow rusting and assessment of partial resistance. Kulkarni *et al*. (1982) concluded that latent period, infectibility and sporulation were the most important components of slow rusting of wheat with *Puccinia recondita* f.sp. *tritici* Rob.ex Desm. These factors collectively determine the rate of disease development in an additive manner.

Latent period among 13 varieties varied from 6-8 days. Within five durum varieties Bijaga yellow recorded maximum latent period of 7 days and remaining four varieties *viz*., UAS 415, UAS 428, UAS 446 and DWR 2006 recorded 6 days of latent period. Among the aestivum group varieties, HD 2189 (1970, *Lr* 13 +, *Lr* 34) and GW 322 (2002) had recorded maximum of 8 days latent period. The genotype UAS 304 has recorded latent period of 7 days. Interestingly the genotype MACS 6222 has not taken any infection and showed no symptoms. The latent period for this genotype was zero. Sokhi and singh (1984) reported that the cultivars with longer latent period will produce the less uredospores per unit area coupled with smaller pustule size.

Kapoor and Joshi (1981) reported that sonalika produces comparatively fewer flecks and pustule number per centimeter of leaf area than agra local, which were attributed to longer latent period of Sonalika. Shaner and Finney (1980) and Sareen *et al.* (2012) also showed that slow rust development in the cultivars was associated with longer latent period coupled with smaller and fewer uredia.

5.4.2 Uredial density

Uredial density is the number of uredia per unit area of leaf. Uredial density is another important component for identifying slow rusting varieties and less number of uredia per unit area is positively correlated with the slow rusting mechanism in most of the wheat varieties (Kulkarni *et al.*, 1982).

In the present investigation, uredial density ranged from 0.00 to 4.67 among 13 varieties (Fig. 2). All the varieties showed significant difference for uredial density. The genotype MACS 6222 recorded zero uredial density. The least uredial density was observed with GW 322 (1.67 uredia per 0.5 cm^2) followed by UAS 415 (2.11 uredia per 0.5 cm^2). The maximum uredial density was observed in genotype UAS 347 (4.67 uredia

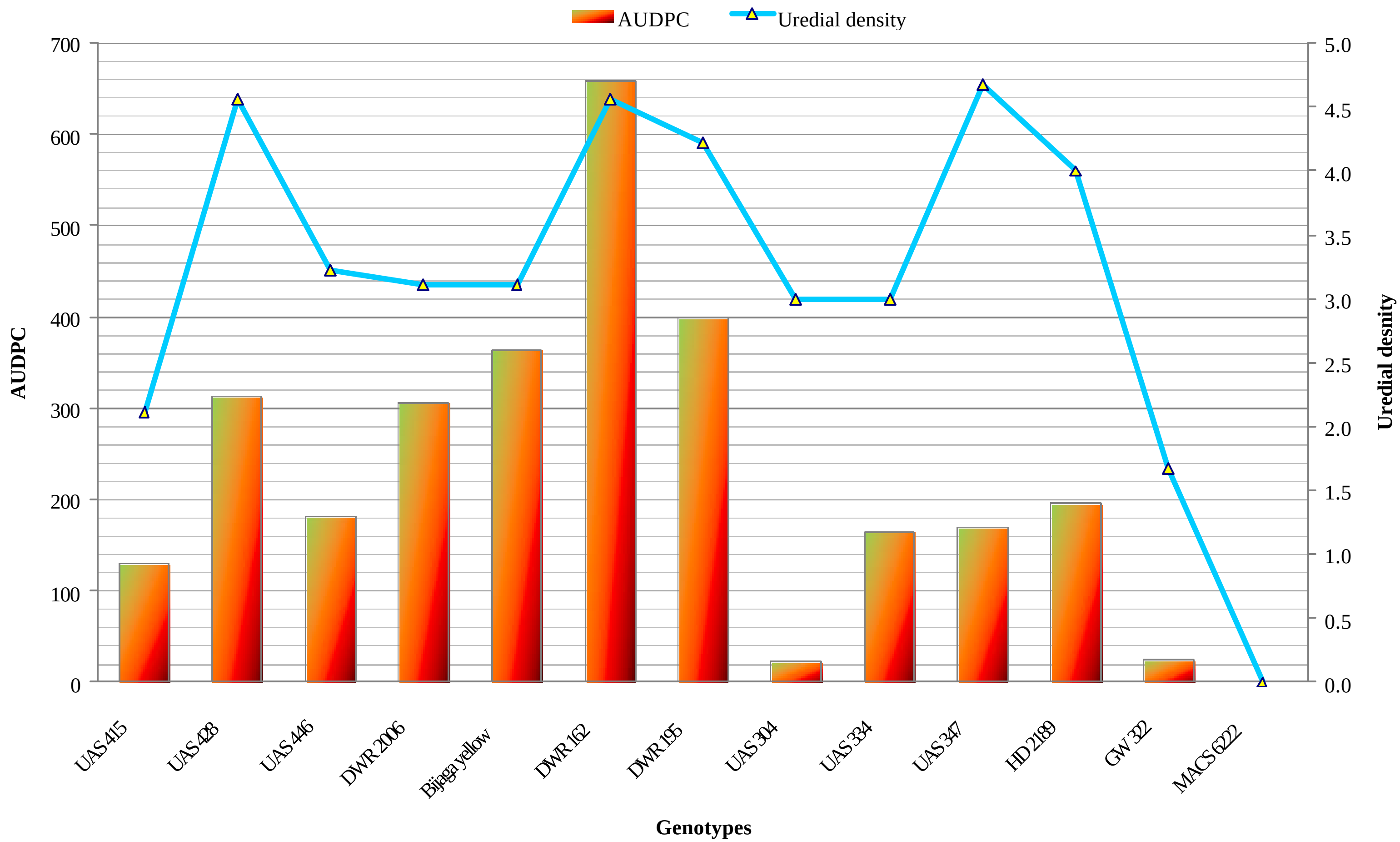


Fig. 2: Variation in uredial density and AUDPC of selected PZ varieties

per 0.5 cm^2) which was followed by UAS 428 and DWR 162 (each 4.56 uredia per 0.5 cm^2). It is very much clear that susceptible varieties recorded the highest number of pustules per cm^2 (4.67) on the contrary, slow rusters recorded slightly less number of pustules per cm^2 (1.67) and the same observations were reported by the earlier workers (Patidar *et al.*, 2007; Sneha, 2015).

5.4.3 Uredium size

Area of the individual pustule is known as uredium or pustule size. Several researchers have reported the importance of small pustule size to recognise partial resistance in rust disease of many crops (Kuhn, *et al.*, 1978; Shaner, 1983). Similarly in the present investigation significant differences were observed for uredium size among the 13 varieties tested. The size ranged from 0.00 mm^2 to 0.71 mm^2. The minimum uredium size was recorded in genotype GW 322 (0.30 mm^2) followed by varieties DWR 2006, DWR 195 and HD 2189 (each 0.35 mm^2). The maximum uredium size was recorded in two varieties *viz.*, UAS 415 and UAS 428 (0.71mm^2). Goolappa (2015) reported the elite bread wheat varieties HD 2183 and GW 322 as slow rusters based on the studies on slow rusting components such as lower pustule density and smaller size of uredinium.

In the present investigation, even though Bijaga yellow and DWR 2006 have higher terminal disease severity (364.0 and 306.0 AUDPC, respectively) they have recorded smaller uredium size (0.31 and 0.35, respectively) suggesting that the size of the uredium is variable factor among the varieties and it is genotype specific in its expression. Similar results were found with Patil and Kachapur (2002) working on the components of slow rusting in different sunflower varieties, opined that the ureduim size was not a suitable parameter to study the slow rusting resistance as uredium size was higher in slow rusting varieties and vice-versa. In the present investigation, no much difference in uredium size was observed in both slow and fast rusting wheat varieties.

5.4.4 Area under disease progress curve (AUDPC)

Area under disease progress curve is a measure of slow rusting in field conditions and plotted against time. It was calculated as per the formula of Wilcoxson *et al.* (1975).

AUDPC values and r values were used for comparing slow rusting ability. Shaner and Finney (1980) opined that the area under disease progress curve was a better criterion to measure partial resistance than apparent rate of infection.

Among durum varieties, UAS 415 and UAS 446 have recorded AUDPC value of 129.50 and 182.00, respectively and the remaining three varieties, UAS 428, DWR 2006 and Bijaga yellow have recorded AUDPC values of more than 300. Among eight aestivum varieties, UAS 304 and GW 322 have recorded lowest AUDPC values of 23.10 and 25.20, respectively. UAS 334, UAS 347, HD 2189 have recorded AUDPC value of less than 200 and two varieties, DWR 162 and DWR 195 have recorded AUDPC value of more than 300 Fig. 2.

Similar results were reported by Sneha (2015) where, WH 1080, UP 262, JWS 530, HPW 251, Parula, NIAW 1689, PBW 175 and MACS 3817 were identified as slow rusters, with low terminal disease severity, less rate of disease development, minimum AUDPC value, lower pustule density and smaller size of uridinium. Hasabnis *et al.* (2002) and Thombare (1981) reported similar results regarding ACI and AUDPC values. Based on AUDPC values, Nargund (1989) identified DWR-39, HD 2189, HI 977, Keerti, Sonalika, WH 147 and WH 416 varieties as slow leaf rusters.

5.4.5 Mean apparent rate of infection (r)

Mean apparent rate of infection (r) determines effect of horizontal resistance on development of epidemics by its effect on the infection rate and subsequent development of the disease. It is calculated using the formula given by Vander Plank (1963) to quantify the rate of disease development.

In the present study, mean "r" values varied among the varieties from 0.08 to 0.18. In general, both increase and decrease in the development of rust at different intervals was observed among the varieties. There was no consistency throughout the course of disease development and even the lowest mean 'r' value of a genotype was not correlated with lower terminal disease severity. The genotype which showed positive for all the slow rusting characters such as HD 2189 has recorded maximum mean 'r' value of 0.17 suggesting its inconsistency for slow rusting character of a genotype as earlier workers (Nagesha *et al.,* 2005, Patidar, 2006) also reported the same results which are in conformity with Nargund (1989) who reported differences in the rate of spread of leaf rust per unit per day in *T. durum* and *T. aestivum* varieties. The variety, Raj 1555 (0.24) of *T. durum* and Kalyansona (0.42) and sonalika (0.3798) of *T. aestivum* showed maximum rate of spread. Further, he reported no relationship between "r" value and slow rusting nature of varieties and concluded that "r" values are not useful as AUDPC values in studying the slow rusting nature of cultivars.

5.5 *In vitro* evaluation of fungicides, commercially available botanicals, bio-agents and ITK's against *P. triticina*

5.5.1 *In vitro* evaluation of fungicides

Fungicides can supplement the use of resistant cultivars to control pathogens when (a) a new race of the rust fungus occurs and the disease threatens to become epidemic (b) the expression of rust resistance depends on environmental factors and weather changes to favor rust development, or (c) the rust epidemic is occasional in areas where the disease is too rare to justify breeding programs (Cook and Veseth, 1991).

In vitro evaluation of fungicides was conducted with respect to inhibition of uredospore germination of *P. triticina* at different concentrations. The results on efficacy of four non-systemic fungicides on inhibition of uredospore germination of *P. triticina* revealed that irrespective of fungicide concentration, chlorothalonil (91.41 %) was found to have highest inhibition of spore germination and remained on par with propineb (91.28 %), captan (90.76 %) and mancozeb (90.70 %) and the least inhibition of uredospore germination was noticed in mancozeb (84.43 %) at 0.1 per cent concentration (Fig. 3a). Similar results were observed by Chaudhary and Chaudhary (2013) on inhibition of uredospore germination of *P. triticina* by mancozeb (54.85 %) and chlorothalonil (40.89 %) at 1000 ppm concentration.

Among the systemic fungicides irrespective of concentration, maximum inhibition was noticed in hexaconazole (98.15 %) which was on par with propiconazole (96.44 %) and tebuconazole (95.08 %). Least inhibition of uredospore germination was noticed in difenconazole (90. 43 %) followed by penconazole (92.49 %) (Fig. 3b). Earlier evaluations on efficacy of triazole fungicides against wheat leaf rust were done

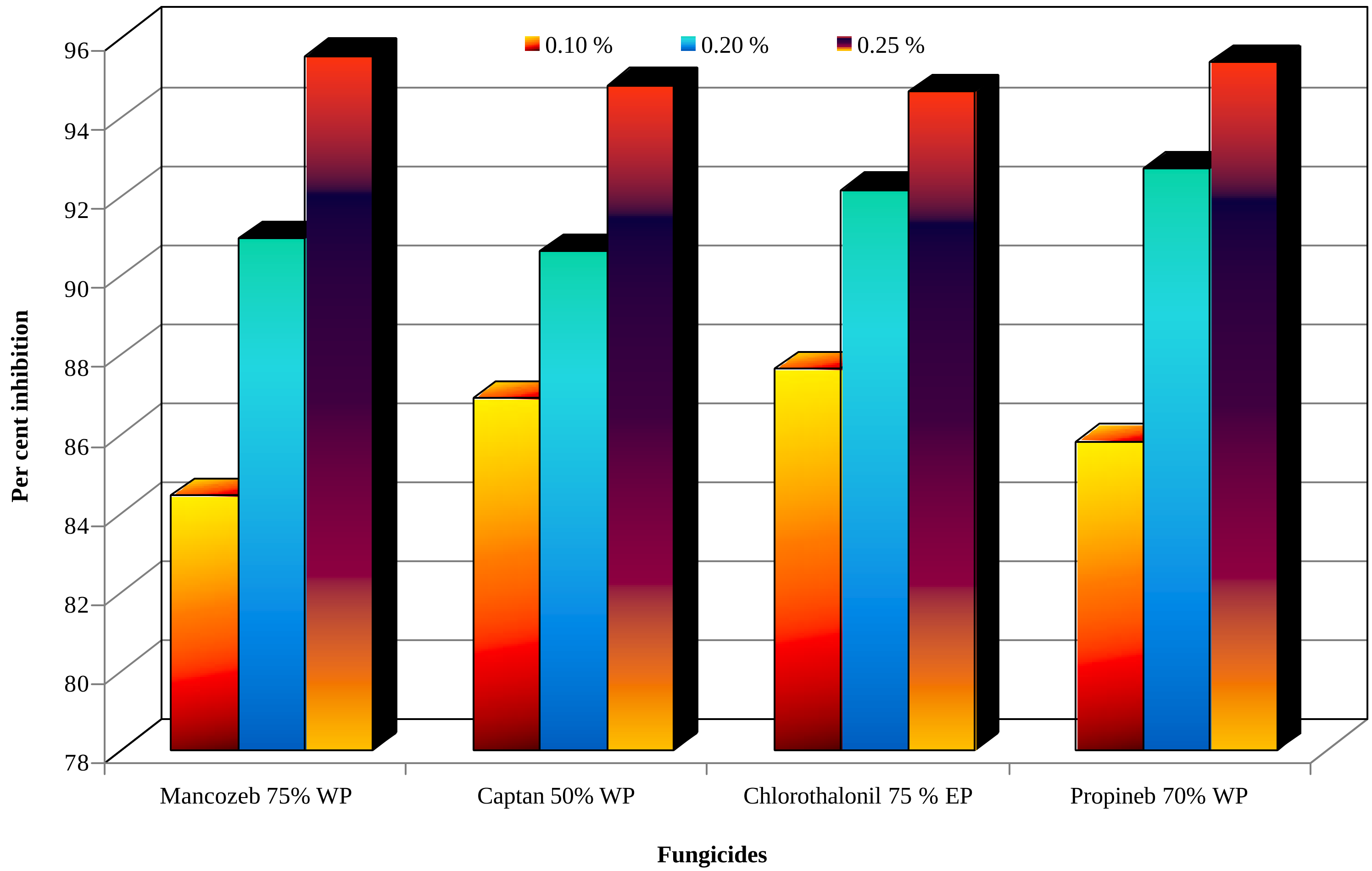


Fig. 3a: Effect of different non systemic fungicides on inhibition of uredospore germination of *P. triticina*

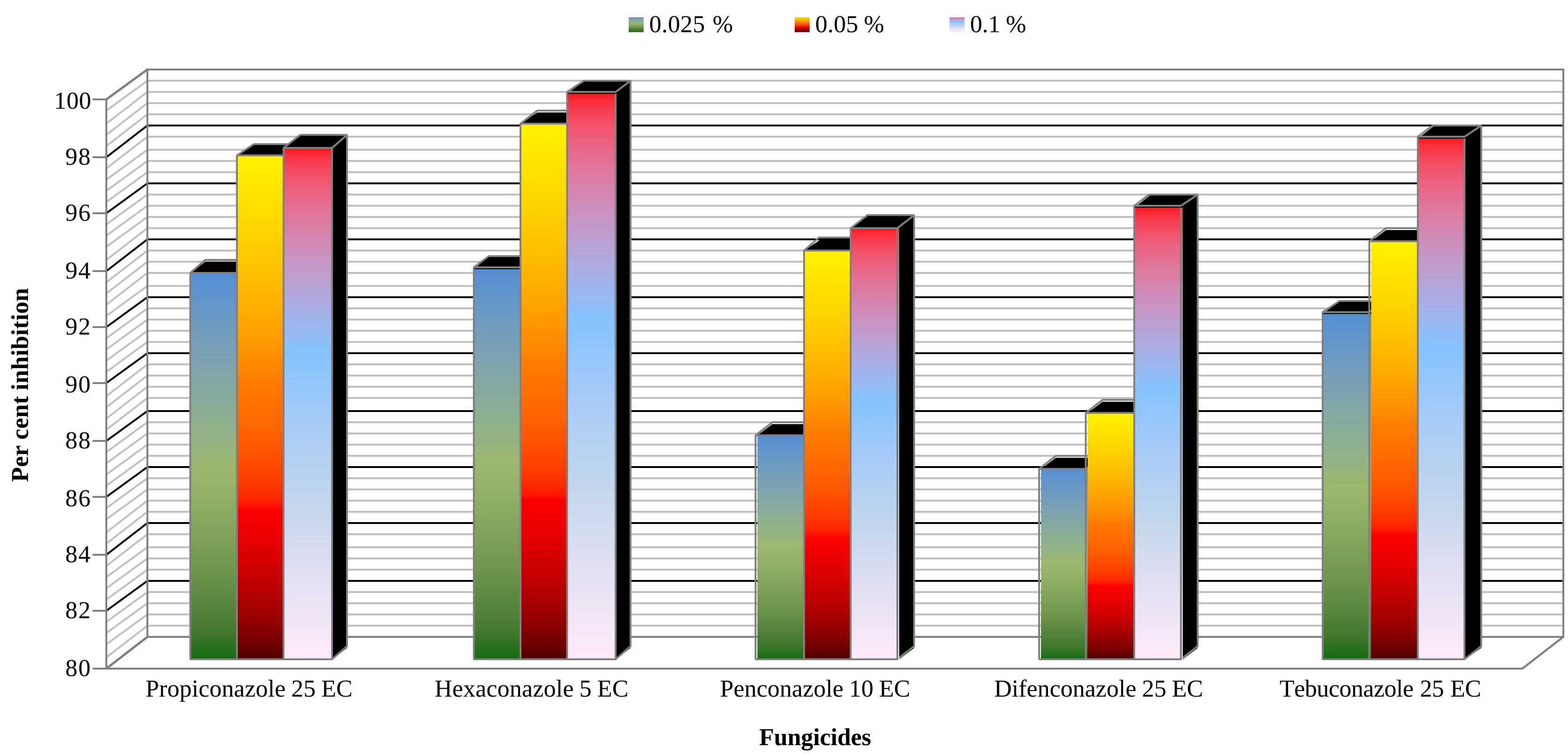


Fig. 3b: Effect of different systemic fungicides on inhibition of uredospore germination of *P. triticina*

by many workers and they found similar results with respect to *in vitro* evaluation (Basandarai *et al.,* 2013; Utpal *et al.,* 2013).

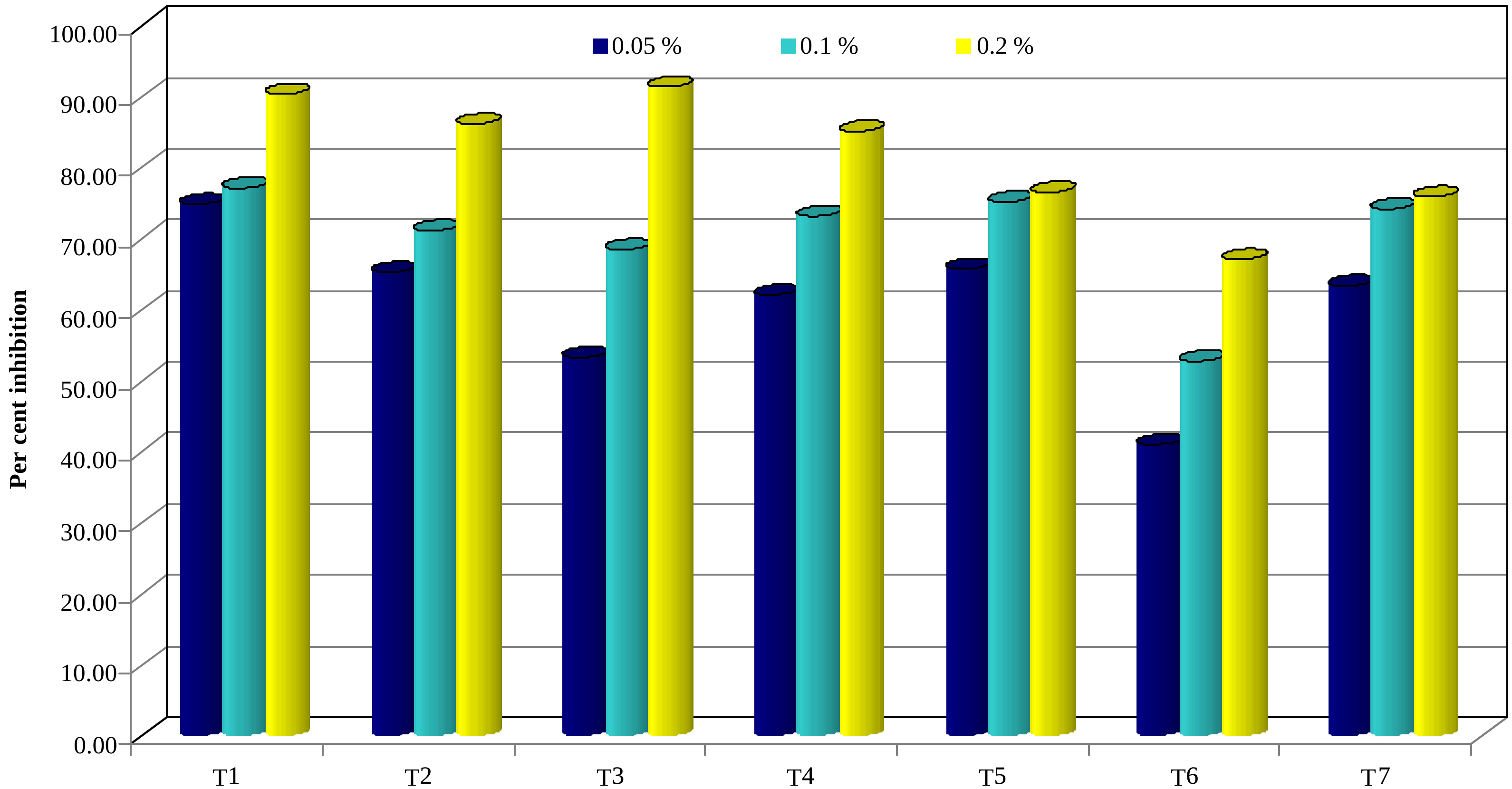
Among the seven different combiproduct fungicides evaluated under *in vitro* condition against *P. triticina,* the combiproduct fungicide hexaconazole 4 % + zineb 68 % recorded highest (91.41 %) uredospore germination inhibition at 0.20 per cent concentration compared to other combiproduct fungicides and the least inhibition was observed in difenconazole + propiconazole (41.03 %) at 0.05 per cent concentration (Fig. 4). Arunkumar (2013) who reported that among different chemicals the combiproduct fungicide pyraclostrobin 13.3 % + epoxiconazole 5 % (Opera 18.3 % SE) at 0.1 per cent concentration was found to be effective in inhibition of uredospore germination of *P. triticina*.

5.5.2 *In vitro* evaluation of commercially available botanicals

In vitro evaluation of six different commercially available botanicals was done against *P. triticina* on uredospore germination inhibition and the results revealed that at three different concentrations nimbicidine at 1.0 per cent showed highest uredospore germination inhibition (86.34 %) followed by neemgold at 1.0 per cent (68.04 %), which was on par with discheck (68.03 %) at the same concentration. The lowest (39.25 %) inhibition was noticed in agroneem at 0.25 and 0.5 per cent concentrations (Fig. 5). The similar results were found with other workers (Dey *et al.,* 2013; Cawood *et al.,* 2013) testing the efficacy of botanicals in inhibiting uredospore germination inhibition as Dey *et al.* (2013) reported the superiority of neemazole F5 % in inhibition of uredospore germination of *Puccinia sorghi*.

5.5.3 *In vitro* evaluation of bioagents

Bio agents such as *T. harzianum* and *B. subtilis* are biological weapons against most of the plant pathogenic fungi and their environmental safety makes them a reliable tool in plant disease management. In this investigation, the results revealed that maximum inhibition of uredospore germination (30.06 %) was noticed in *T. harzianum* + *B. subtilis* at 10 g/l (5 g each) concentration followed by *B. subtilis* alone (27.76 %) at 10 g/l concentration (Fig. 6). The minimum inhibition of uredospore germination was noticed in *P. fluorescence* + *B. subtilis* (13.96 %) at 10 g/l (5 g each) concentration and



T_1: Captan 70 % + Hexaconazole 5 %
T_2:Carbendazim 12 % + Mancozeb 63 %
T_3:Hexaconazole 4 % + Zineb 68 % WP
T_4: Azoxystrobin 11.4 % + Propiconazole 11.4 %
T_5: Tebuconazole 50 % + Trifloxystrobin 25 %
T_6: Difenconazole 13.9 %+ Propiconazole 13.9 %
T_7: Tricyclazole 45 %+ Hexaconazole1 %

Fig. 4: Effect of different combiproduct fungicides on inhibition of uredospore germination of *P. triticina*

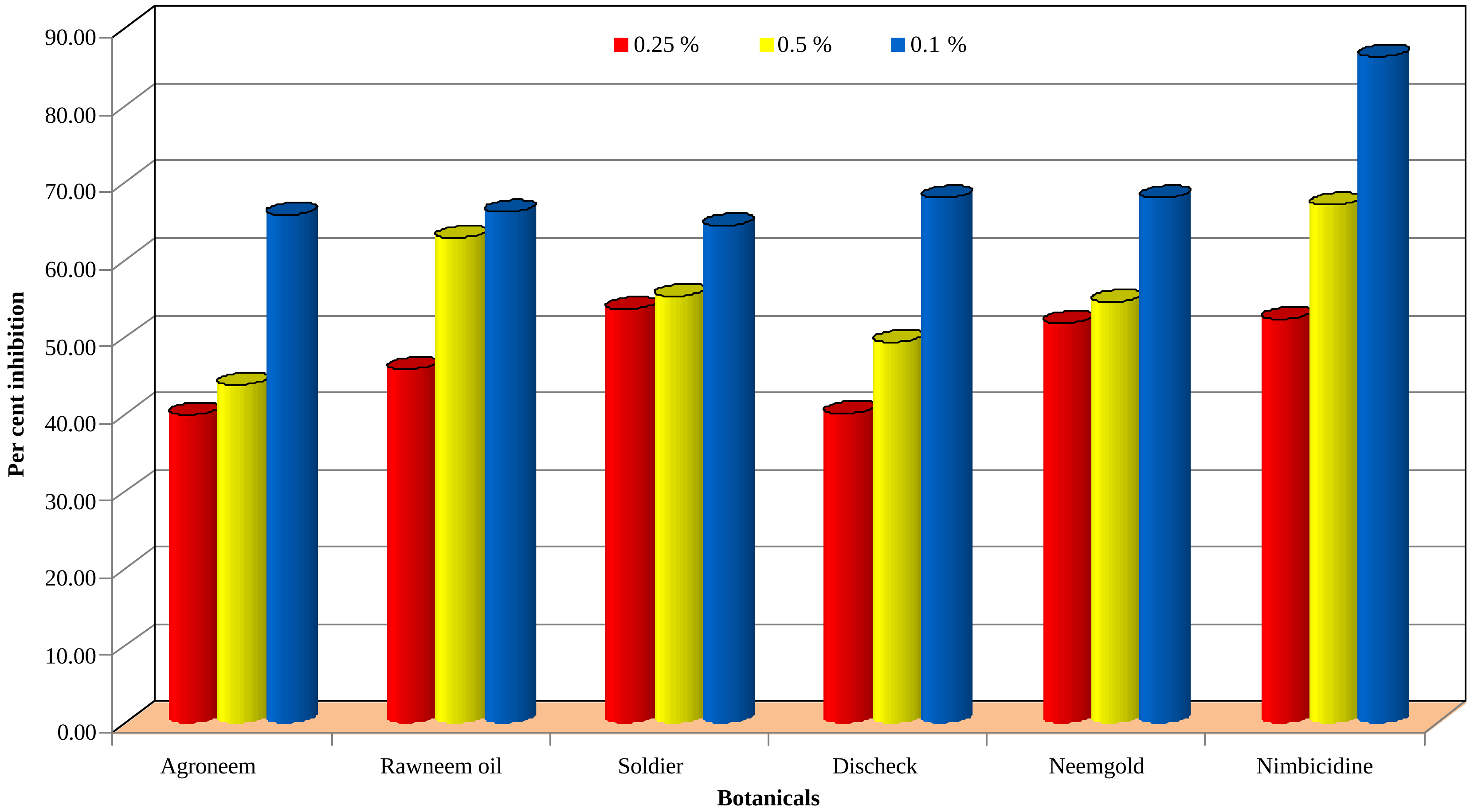
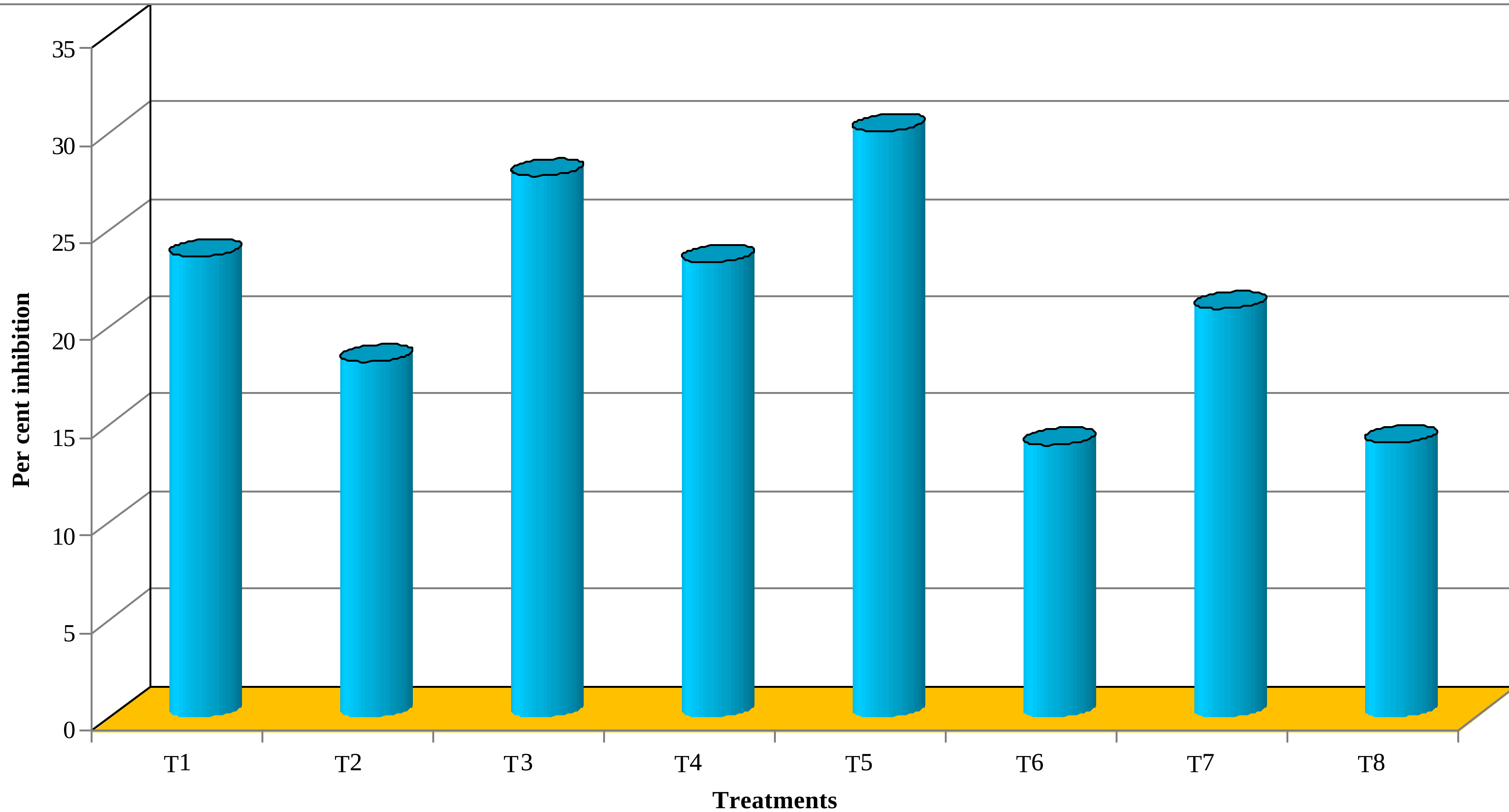


Fig. 5: Effect of different commercially available botanicals on inhibition of uredospore germination of *P. triticina*



T_1 -*Trichoderma harzianum* @ 10 g/l

T_2 -*Pseudomonas fluorescens* @ 10 g/l

T_3 -*Bacillus subtilis* @ 10 g/l

T_4 -*T. harzianum* +*P. fluorescens* @ 10 g/l (5g each)

T_5 -*T. harzianum* +*B. subtilis* @ 10 g/l (5g each)

T_6 -*P. fluorescens* + *B. subtilis* @ 10 g/l (5g each)

T_7 -*T. harzianum* +*P. fluorescens* + *B. subtilis* @ 10 g/l (3.3g each)

T_8 -Talk powder @ 10 g/l

Fig. 6: Effect of different bio-agents on inhibition of uredospore germination of *P. triticina*

the similar results were found with Hamdy *et al.* (2001). The efficacy of bioagents against wheat leaf rust pathogen was also worked out by El-Sharkawy *et al.* (2014).

Overall germination inhibition of all the bio-agents was very less (maximum inhibition achieved 30.60 %), when compared with all other agents used in *in vitro* evaluation. The activity of these bioagents is certainly influenced by the environment in which they are released and the type of carrier material used for their commercial preparation. Some bioagents need activation and their establishment in host or soil system prior to combat against invading pathogen.

5.5.4 *In vitro* evaluation of ITK's

Through the long path from primitive agriculture to the modern farming people have developed a number of farming techniques through their own age old experiments by trial and error in their attempt to overcome numerous problems faced during the farming operations. This knowledge is based on many generations of insight gained through close interaction within the natural and physical micro-environments. This form of knowledge in today's parlance is popularly known as Indigenous Technical knowledge (ITK) or Indigenous Knowledge System (IKS). These ITK's certainly play major role in plant disease management strategy of sustainable agriculture.

In the present investigation among the four different ITK's evaluated against inhibition of spore germination of *P. triticina*, irrespective of the concentration, panchagavya showed the highest inhibition of uredospore germination (52.55 %) followed by cow urine (47.86 %) and butter milk (45.97 %) which were on par with each other. Whereas, the least inhibition of uredospore germination was observed in vermiwash (36.83 %) (Fig. 7). The similar results were found with other workers on effectiveness of various ITK's in uredospore germination inhibition of various obligate fungal pathogens (Patil, 2009; Utpal Dey *et al.*, 2011; Nagaraj and Patil, 2014).

5.6 Evaluation of developed integrated spray schedule for the management of leaf rust of wheat

Integrated management of disease requires keeping disease levels below economic threshold levels and includes consideration of crop, pathogen and environment

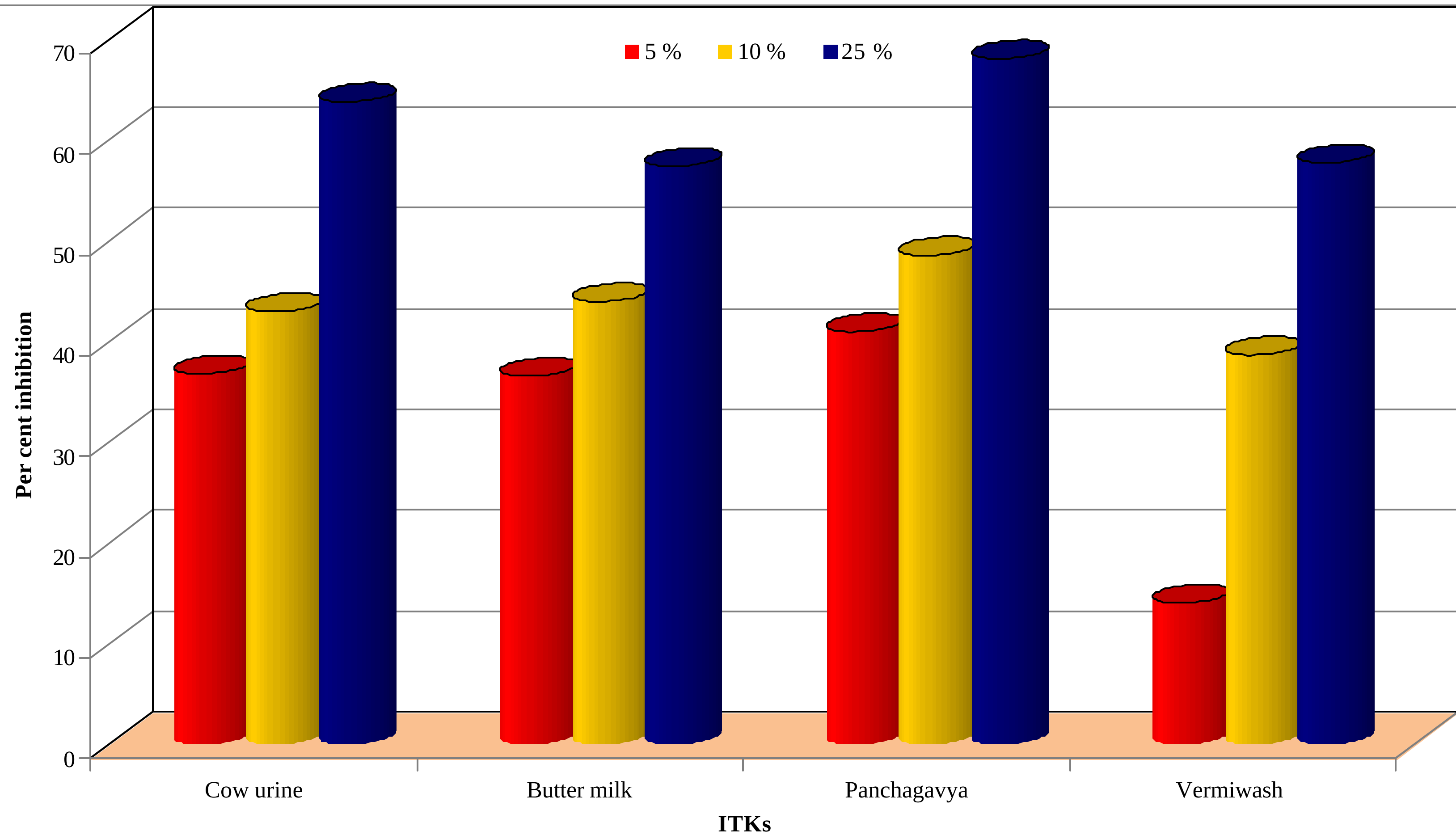


Fig. 7: Effect of different ITKs on inhibition of uredospore germination of *P. triticina*

in devising economic control programs. These programs may utilize biological, physical and chemical methods. The most plant pathogens can be managed by combinations of host plant resistance, chemical and cultural methods. Any single method of disease control has its limitations. Therefore, an integrated approach utilizing different tactics of control for rust and will likely is the most stable over the longest period of time (Brown *et al.,* 2001).

In this experiment spray schedule was developed by making combination of chemical, commercially available botanical and ITK and also spray was taken chemical followed by chemical and chemical followed by commercially available botanical and chemical followed by ITK and bio-agents to know the individual and their combinations spray effect. In the present investigation, lowest disease severity compared to unsprayed control was recorded in the spraying schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) with AUDPC value of 6.60 and CI of 0.27 followed by single spray of hexaconazole @ 0.1 % at 60 DAS (T_{12}) (9.05 AUDPC and 0.61 CI) and (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % (T_2) (11.95 AUDPC and 0.14 CI). The spray schedule nimbicidine @ 1 % - nimbicidine @ 1 % (T_3) recorded significantly higher AUDPC values of 402.20 compared to all other spray schedules (Fig. 8).

The spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest grain yield of 35.38 q ha^{-1} and it was statistically on par with T_2 (35.13 q ha^{-1}), T_{10} (33.90 q ha^{-1}), T_8 (33.47 q ha^{-1}) and T_9 (33.42 q ha^{-1}) except unsprayed control which recorded 28.25 q ha^{-1}. In case of 1,000 grain weight, the spray schedule (hexaconazole 4 % + zineb 68 % WP) @ 0.2 % - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_{10}) recorded highest grain weight of 35.02 g followed by T_{12} (34.88g), T_1 (33.95 g), T_2 (33.55 g) and these were on par with each other. Unsprayed control (T_{14}) recorded lowest grain weight of 30.37 g. The highest B:C ratio was obtained with spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) (1:2.30) followed by single initial spray of hexaconazole @ 0.1 % (T_{13}) (1:2.23). The lower B:C ratio was obtained with respect to spray schedules involving (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) - (*T. harzianum* + *B. subtilis*) @ 10 g/l (5 g each) (T_4) (1:1.85) and Panchagavya @ 10.0 % - Panchagavya @ 10.0 % (T_5) (1:1.92).

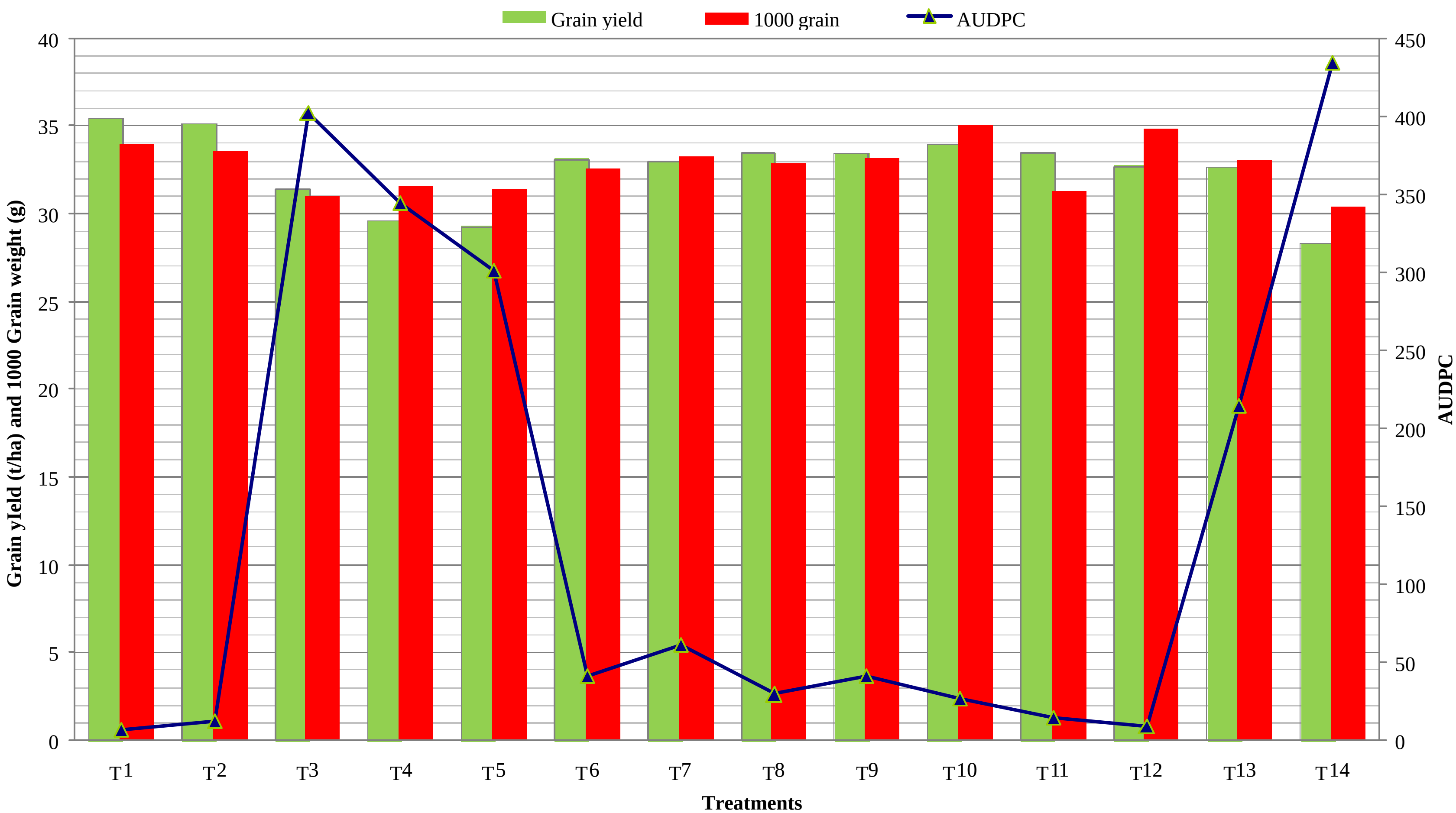


Fig. 8: Evaluation of spray schedule involving fungicides, commercially available botanical, bioagent and ITK on leaf rust during *rabi* - 2016-17

These results were in agreement with most of the earlier workers, where they highlighted the efficacy of triazole fungicides in leaf rust management (Brahma *et al.*, 1991; Khan and Ilyas, 1996; Patidar, 2007). Kalappanavar and Patil (1998) reported that hexaconazole, propiconazole and triadimefon were the most effective fungicides for the management of leaf rust of wheat.

Kalappanavar *et al.* (2008) reported that among the 13 treatments imposed, fungicide propiconazole performed best followed by tradimefon and hexaconazole. However, in different catogaries, neem leaf extract, *T. harzianum* and panchagavya were the succeeding treatments effective against leaf rust of wheat. The yield of propiconazole, triadimefon and hexaconazole sprayed plots were significantly superior over control indicating marked influence of the leaf rust on yield. The 1,000 grain weight was also significant in the above said treated plots compared to other treatments.

Patil *et al.* (2016) who confirmed least pearl millet rust severity of 15.30 per cent in hexaconazole @ 0.1 % - hexaconazole @ 0.1 % spray schedule with highest grain yield (30.50 q ha^{-1}). Whereas spray schedule neem oil @ 1.0 % - neem oil @ 1.0 % recorded grain yield 27.50 q ha^{-1} and disease severity 23.56 per cent which was found to be on par with hexaconazole @ 0.1 % - hexaconazole @ 0.1 %, indicating the importance of addition of botanicals and ITK's in spray schedule along with fungicide in the management of disease.

The present investigation and also reports from earlier workers from time to time indicated the reduction in wheat grain yield in rust infected plots compared to rust controlled plots. This reduction in grain yield attributed to reduction in number of kernels per unit area in field condition. According to Sayre *et al.* (1998), grain yield losses due to leaf rust in bread wheat were associated with reductions in kernel weight, kernels per square meter, spikes per square meter and grain-filling rate. Singh and Huerta-Espino (1994) reported yield losses due to leaf rust was associated with biomass, kernel weight, kernels per spike, harvest index and test weight. This relationship between reduction in kernel weight and yield losses caused by leaf rust has been found by many authors (Chester 1946; Keed and White, 1972; Salazar Huerta *et al.*, 1993; Singh and Huerta-Espino, 1994; Singh *et al.*, 1991; Subba Rao *et al.*, 1989).

Future line of work

1. Regular survey is needed for estimating leaf rust severity and to understand the prevailing races.
2. Screening of peninsular zone varieties should be continued every year to understand nature of resistance and prevailing races on these varieties.
3. There is a need to develop more number of slow rusting varieties for peninsular zone as it acts as secondary foci of infection.
4. There is a need to identify non chemical agents with still higher efficacy in controlling disease both under *in vitro* and *in vivo*.

6. SUMMARY AND CONCLUSIONS

Peninsular zone plays an important role in production of quality wheat in Indian subcontinent. Over the years area and production of wheat is expanding in the peninsular zone and irrigated fields contribute more to the area under all the three species of wheat. Being on the Deccan plateau of peninsular India this zone is known to take initial leaf rust along the succeeding *puccinia* path and acts as secondary foci of infection. In recent days along with biotic stress terminal heat stress is posing new problem in wheat cultivation especially in peninsular zone coupled with erratic *rabi* rain fall making it almost difficult to take normal sowing of the wheat. Maharashtra is the only state in peninsular zone having substantial area under wheat followed by Karnata ka having area limited only to $1/4^{th}$ or $1/5^{th}$ of Maharashtra. Lower production of wheat in Karnataka may be attributed to the fact that considerable area of wheat cultivation is under rain fed condition. Slow rusting resistance is a type of durable resistance against wheat leaf rust and its confirmation with the peninsular zone released wheat varieties is necessary to assess their response to this new concept of rust management.

In the present investigation, survey in two seasons *rabi* 2015-16 and *rabi* 2016-17 revealed the annual occurrence of wheat leaf rust in northern parts of Karnataka. There was least or no incidence of rust in cropping season 2016-17. Most of the wheat in these districts is under irrigated condition and most of the wheat cultivars were susceptible to wheat rust. Belagavi, Vijayapura and adjoining Maharashtra areas are known to take rust regularly due to their different dates of sowing making all the stages of crop growth available for infection. Studies on prevailing races of *P. triticina* in northern parts of Karnataka revealed the existence of variation in pathogenic population from different previously existing groups such as group 77, group 104 and group 12.

Evaluation of 58 peninsular zone wheat varieties for leaf rust resistance in both the years *rabi* 2015-16 and *rabi* 2016-17 under both natural and artificial inoculated condition gives us promising PZ wheat varieties having varied amount of leaf rust resistance. 17 varieties have found resistant as these are free from infection or taken less infection (CI up to 10) both in natural and artificial inoculated condition. Also the PZ varieties has not encountered any new pathogenic races of *P. triticina* during the cropping season *rabi* 2015-16. The seven pathotypes belong to group 77, 162 and 104 were observed on these varieties.

Studies on components of slow rusting in selected 13 PZ wheat varieties revealed that there is wide variation among different components of slow rusting resistance from genotype to genotype. The genotype MACS 6222 has not taken any infection and remain rust free throughout the course of study. Two varieties HD 2189 and GW 322 were typically recorded all positive characters of slow rusting such as more latent period, less uredial density per unit leaf area and smaller uredial size. Also these two varieties recorded lower AUDPC and r value taken from the field screening trial conducted during *rabi* 2016-17.

Based on the slow rusting components five varieties (UAS 415, UAS 446, UAS 334, UAS 347 and HD 2189) were considered as slow rusters and remaining three (UAS 304, MACS 6222 and GW 322) as resistant, two (DWR 2006 and Bijaga yellow) as moderately resistant and three varieties (UAS 428, DWR 162 and DWR 195) as fast rusters.

In vitro evaluation of fungicides, commercially available botanicals, bio-agents and botanicals given us an opportunity to use them in integrated disease management strategy. Among different non systemic fungicides, chlorothalonil at 0.1 per cent found effective and among systemic fungicides, hexaconazole was superior in inhibiting uredospore germination at 0.1 per cent concentration. The combiproduct fungicide hexaconazole 4 % + zineb 68 % found effective in inhibiting uredospore germination at 0.2 per cent concentration.

Among commercially available botanicals nimbicidine at 1.0 per cent concentration found effective in uredospore germination inhiobition. The combination of *T. harzianum* + *B. subtillus* at 1.0 per cent was found effective among the three different agents tested for their efficacy against uredospore germination inhibition. Among different ITK's panchagavya found effective in uredospore germination inhibition at 10 per cent concentration.

The evaluation of developed integrated spray schedule for the management of leaf rust of wheat gives an opportunity to use different combinations of spray chemicals to the existing ones. The spray schedule hexaconazole @ 1 % - hexaconazole @ 1 % (T_1) has recorded highest B:C ratio followed by initial single spray of hexaconazole @ 1 % (T_{12}). In case of spray schedule involving fungicide and non fungicide hexaconazole 4 % + zineb 68 % WP at 0.2 per cent – panchagavya at 10 per cent (T_{11}) recorded higher B: C ratio.

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Appendix I: Weekly distribution of meteorological data of MARS, Dharawd during *rabi* 2015-16

Week days	Max. temp (^{0}C)	Min. temp (^{0}C)	RH max (%)	RH min (%)	Total RH (%)	Mean RH (%)	Rainfall (mm)	NRD
Sep 10-Sep 16	28.4	20.6	95	75	170.0	85.0	4.2	0
Sep 17-Sep 23	28.8	20.6	94	65	159.0	79.5	0.2	0
Sep 24-Sep 30	32.4	20.9	89	51	140.0	70.0	0.2	0
Oct 1-Oct 7	29.7	20.5	95	68	163.0	81.5	165.8	4
Oct-8-Oct 14	30.2	20.5	89	56	145.0	72.5	11.6	1
Oct 15-Oct 21	32.4	19.3	71	35	106.0	53.0	0	0
Oct 22-Oct 28	32.2	17.9	61	32	93.0	46.5	0	0
Oct 29-Nov 4	30.9	19.6	90	65	155.0	77.5	7.6	1
Nov 5-Nov 11	30.8	18.3	81	48	129.0	64.5	0	0
Nov 12-Nov 18	30.3	16.7	83	50	133.0	66.5	0	0
Nov 19-Nov 25	28.6	19.6	84	68	152.0	76.0	23.4	1
Nov 26-Dec 2	30.6	16.8	85	45	130.0	65.0	0	0
Dec 3-Dec 9	29.5	14.6	79	39	118.0	59.0	0	0
Dec 10-Dec 16	31.7	18.1	82	40	122.0	61.0	0	0
Dec 17-Dec 23	31.2	17	82	40	122.0	61.0	0	0
Dec 24-31 Dec	31.1	12.9	61	24	85.0	42.5	0	0
1 - 7 Jan	30.3	13.6	51.6	23.0	74.6	37.3	0.0	0
8 - 14 Jan	29.7	12.0	49.3	20.6	69.9	34.9	0.0	0
15 - 21 Jan	28.2	14.5	71.6	41.4	113.0	56.5	0.4	0
22 - 28 Jan	30.7	16.0	63.3	36.0	99.3	49.6	0.0	0
29 Jan - 4 Feb	33.7	14.8	43.6	19.7	63.3	31.6	0.0	0
5 - 11 Feb	32.6	17.0	74.6	34.3	108.9	54.4	0.0	0
12 - 18 Feb	32.0	17.0	59.9	35.3	95.1	47.6	0.0	0
19 - 25 Feb	35.0	20.3	57.4	32.3	73.7	53.9	0.0	0
26 Feb - 4 Mar	34.5	20.2	57.6	27.4	85.0	42.5	0.2	0
5 - 11 Mar	35.7	20.4	51.4	24.1	75.6	37.8	0.0	0
12 - 18 Mar	34.9	19.3	53.0	23.8	70.0	44.7	0.0	0
19 - 25 Mar	38.0	21.4	42.4	20.3	62.7	31.4	0.0	0
26 Mar - 1 Apr	36.7	21.1	75.9	44.1	120.0	60.0	2.4	0

Total rainfall = 216.0 mm

NRD – No. of rainy days

Total number of rainy days = 7

Highest rainfall recived on 01-07 October = 165.8 mm

Appendix II: Weekly distribution of meteorological data of Ugar Khurd during *rabi* 2015-16

Month	Week	Maximum temperature (⁰C)	Minimum temperature (⁰C)	Relative humidity (%)	Rainfall (mm)
October 2015	1	32.00	24.20	80.33	45
	2	33.12	24.50	75.25	-
	3	33.80	25.70	69.40	-
	4	32.50	23.75	70.25	-
	5	33.00	24.00	71.00	-
November 2015	1	32.83	24.41	72.33	-
	2	31.41	23.06	65.83	-
	3	30.28	21.78	66.14	-
	4	29.91	21.63	65.33	-
	5	30.50	22.25	67.50	-
December 2015	1	29.75	20.62	66.00	-
	2	31.21	21.85	71.14	-
	3	31.50	22.50	23.80	-
	4	29.25	17.66	63.66	-
	5	30.83	17.00	64.00	-
January 2016	1	29.20	17.30	70.40	-
	2	29.14	17.64	71.00	-
	3	28.92	19.14	72.57	-
	4	30.58	19.83	74.50	-
	5	32.00	20.66	70.66	-
February 2016	1	33.35	20.92	68.28	-
	2	32.50	21.25	68.33	-
	3	33.08	23.16	70.50	-
	4	35.80	24.40	67.20	-
	5	-	-	-	-
March 2016	1	36.00	24.00	-	-
	2	36.91	24.75	62.50	-
	3	37.00	23.33	64.66	-
	4	38.06	25.50	62.60	-
	5	37.00	26.00	68.00	-

Total rainfall = 45 mm

Appendix III: Weekly distribution of meteorological data of MARS, Dharawd during *rabi* 2016-17

Week days	Max. temp (^{0}C)	Min. temp (^{0}C)	RH max (%)	RH min (%)	Total RH (%)	Mean RH (%)	Rainfall (mm)	NRD
3 - 9 Sep	27.4	19.7	84.7	73.4	158.1	79.1	0.4	0
10 - 16 Sep	27.2	19.9	88.1	81.7	169.9	84.9	14.8	2
17 - 23 Sep	25.6	20.0	90.4	85.1	175.6	87.8	11.8	3
24 - 30 Sep	27.7	20.5	88.9	81.0	157.0	84.9	44.0	1
1 - 7 Oct	27.2	19.5	88.6	70.6	159.1	79.6	6.2	1
8 - 14 Oct	28.9	20.2	88.9	75.3	164.1	82.1	38.6	1
15 - 21 Oct	30.8	16.3	59.3	39.0	98.3	49.1	0.0	0
22 - 28 Oct	31.1	18.5	63.3	39.1	102.4	51.2	0.0	0
29 Oct - 4 Nov	31.5	18.4	65.3	43.0	108.3	54.1	0.4	0
5 - 11 Nov	30.3	12.6	43.0	27.7	70.7	35.4	0.0	0
12 - 18 Nov	31.0	17.2	68.9	45.0	113.9	56.9	5.4	1
19 - 25 Nov	30.1	13.2	55.6	35.1	90.7	45.4	0.0	0
26 Nov - 2 Dec	31.4	13.1	45.7	29.9	75.6	37.8	0.0	0
3 Dec - 9 Dec	29.4	16.2	64.7	44.0	108.7	54.4	0.0	0
10 - 16 Dec	29.0	15.1	61.6	43.6	105.1	52.6	0.0	0
17 - 23 Dec	30.6	13.4	54.3	35.0	89.3	44.6	0.0	0
24 - 31 Dec	30.5	11.8	52.6	25.9	78.4	39.2	0.0	0
1 - 7 Jan	30.0	12.1	48.6	33.1	81.7	40.9	0.0	0
8 - 14 Jan	29.6	13.6	63.9	43.1	107.0	53.5	0.0	0
15 - 21 Jan	29.2	13.4	56.7	35.0	86.7	47.9	0.0	0
22 - 28 Jan	31.3	15.4	63.4	39.0	102.4	51.2	0.0	0
29 Jan - 4 Feb	32.3	15.6	50.6	30.7	81.3	40.6	0.0	0
5 - 11 Feb	32.8	16.1	66.4	24.6	91.0	45.5	0.0	0
12 - 18 Feb	32.3	15.5	45.7	21.6	67.3	33.6	0.0	0
19 - 25 Feb	35.1	17.6	42.4	13.3	48.7	37.6	0.0	0
26 Feb - 4 Mar	35.0	16.9	39.6	15.0	54.6	27.3	0.0	0
5 - 11 Mar	33.9	16.9	39.7	22.4	62.1	31.1	0.0	0
12 - 18 Mar	34.0	17.8	53.4	24.7	78.1	39.1	0.0	0
19 - 25 Mar	36.3	18.4	50.7	22.1	72.9	36.4	0.0	0
26 Mar - 1 Apr	37.0	21.8	77.6	32.0	109.6	54.8	0.0	0

Total rainfall = 121.6 mm

Total number of rainy days = 9

Highest rainfall recived on 24-30 September = 44.0 mm

Appendix IV: Weekly distribution of meteorological data of Ugar Khurd during *rabi* 2016-17

Months	Weeks	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Rainfall (mm)
Oct-16	I	32.25	19.75	0.00
	II	33.12	20.50	7.00
	III	34.25	18.37	0.00
	IV	34.42	18.57	0.00
Nov-16	I	34.12	16.87	0.00
	II	33.00	13.62	0.00
	III	33.25	14.62	0.00
	IV	33.16	14.33	0.00
Dec-16	I	33.12	13.87	0.00
	II	31.75	13.12	0.00
	III	32.62	15.12	0.00
	IV	33.85	12.42	0.00
Jan-17	I	32.25	11.75	0.00
	II	31.12	11.37	0.00
	III	31.62	13.12	0.00
	IV	33.57	16.42	0.00
Feb-17	I	34.62	16.00	0.00
	II	34.25	16.75	0.00
	III	35.87	17.00	0.00
	IV	37.75	16.75	0.00
Mar-17	I	37.12	16.37	0.00
	II	36.75	15.00	0.00
	III	37.37	14.50	0.00
	IV	38.00	15.00	0.00
Apr-17	I	38.62	20.00	0.00
	II	40.25	21.25	0.00
	III	41.00	21.66	0.00

Total rainfall = 7 mm

SLOW RUSTING MECHANISM IN WHEAT VARIETIES OF PENINSULAR ZONE AND INTEGRATED MANAGEMENT OF LEAF RUST (*Puccinia triticina* Eriks.)

NANDEESH R. **2017** **Dr. P. V. PATIL**
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ABSTRACT

An experiment on slow rusting mechanism and integrated management of leaf rust (*Puccinia triticina* Eriks.) was conducted at the AICRP on wheat, MARS, Dharwad during *rabi* 2016-17. Screening and race studies on peninsular zone (PZ) varieties were carried out both under natural infection (Ugar Khurd) and artificial inoculation (Dharwad) during *rabi* 2015-16 and 2016-17.

In *rabi* 2015-16 maximum leaf rust severity was observed in Bagalkot (ACI 17.20) and Belagavi (ACI 12.61) and there was no leaf rust appearance during *rabi* 2016-17. Leaf rust pathotypes 77-9, 77-5 and 104-2 were predominant in northern Karnataka and 77-9 and 77-5 were on PZ wheat varieties. Out of 57 varieties 17 have found resistant (CI up to 10) to leaf rust. Based on the slow rusting components, UAS 415, UAS 446, UAS 334, UAS 347 and HD 2189 were identified as slow rusters.

Under *in vitro* evaluation studies, chlorothalonil and hexaconazole at 0.1 per cent, hexaconazole 4 % + zineb 68 % at 0.2 per cent, Nimbicidine at 1.0 per cent, combination of *Trichoderma harzianum* + *Bacillus subtilis* at 1.0 per cent, panchagavya at 10 per cent concentration effectively inhibited uredospore germination. Two sprays of hexaconazole at 0.1 per cent with 15 days interval has recorded lowest leaf rust severity (CI 0.27) and higher grain yield (35.38 q/ha) with highest B:C ratio (2.30) followed by single spray of hexaconazole at 0.1 per cent soon after the appearance of disease which has recorded rust severity of CI 0.61, grain yield of 32.70 q/ha with B:C ratio of 2.23. In integrated spray schedule, hexaconazole 4 % + zineb 68 % WP at 0.2 per cent – panchagavya at 10 per cent found best.

Thus promising slow rusting genotypes and integrated spray schedule helps in reducing leaf rust epidemics.