PEARL MILLET RUST (*Puccinia substriata* Ell. and Barth. var. *indica* Ramachar and Cummins) AND ITS INTEGRATED MANAGEMENT IN NORTHERN DRY ZONE OF KARNATAKA

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INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most drought and heat tolerant crop. Among the cereals, it has the highest water use efficiency under drought stress. Its seedlings survive at soil surface temperature as high as 62^{o}C, and plants can flower and set seed at air temperatures as high as 46^{o}C with large variability detected for both traits. It is the only major crop that has high level of tolerance to both acidic and saline soils. It can be cultivated even in the sandy, infertile soils and droughty environments of Rajasthan where no other cereal crop can survive. Even under these conditions, pearl millet can produce 300-400 kg ha^{-1} of grains. However genetically improved cultivars maturing in 80-85 days when cultivated as an irrigated summer season crop in parts of Rajasthan, Gujarat and Maharashtra have been reported to give as high as 4000-5000 kg ha^{-1} grain yield. Pearl millet grain have higher protein content, more balanced amino acid profile, higher levels of iron and zinc and insoluble dietary fibre with maltose and d' ribose as the most predominant sugar forms with high amylase activity. Indigenous knowledge in northern India is that when consumed as chapati, it has a worming effect (the reason why pearl millet chapati is consumed mostly in the winter season). On other hand, when consumed as cumbu kool (a drink), cumbu choru (a breakfast item) in Tamil Nadu, it has a cooling effect (the reason why these products are most popular in the summer season in this state). These adoptive and nutritional features combined with yield potential make pearl millet an important cereal crop to address the emerging challenges of global warming, Water shortages, land degradation and food related health issue.

India is the largest pearl millet growing country contributing 42% of world production. Pearl millet covers around 7.40% of total food grain area of the country and contributes nearly 3.4% to the total food grain production. Pearl millet is predominantly cultivated as rain fed crop in diverse soils, climates and is an indispensable crop of semi arid and arid regions in the country.

Pearl millet occupies fourth place in cereals and second place among coarse cereals and accounts for 44% area and 16% production of coarse grain cereals in the country. The features associated with cultivation of this crops are low value status, adaption to poor resource base, production and consumption by poorer of society, stagnant demand and price structure.

Production of pearl millet in India is increasing in spite of the reduction in area. The pearl millet area of 12.31 m ha in late sixties, after gradual marginal decline has stabilized presently around 9.61 m ha with little variation depending on monsoon fluctuation (2010-11). On the contrary the production has gradually increased from 4.5 to 9.52 milllion tonnes during the period (Anon, 2011).

In India major pearl millet growing states in order of pearl millet area are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, Haryana and Karnataka.

In Karnataka pearl millet is grown over an area of 3.11 lakh ha with an annual production of 2.40 lakh tones at the productivity level of 772 kg ha^{-1} (2010-11). Of the total pearl millet area, 2.75 lakh ha is under rainfed (88.5 %) and 0.36 lakh ha is under irrigation (11.5 %). It is the major and indispensable *kharif* cereal crop grown under shallow to medium black soils of the state and is largely cultivated in northern districts comprising Bijapur, Bagalkot, Gulbarga, Raichur, Koppal and Belgaum accounting for 87 per cent of the area and production in the state.

Several factors are attributed to limit the yield of pearl millet and the incidence of diseases is major yield reducing constraint. Rust caused by the fungus *Puccinia substriata* var. *indica* is one of the major diseases affecting both forage and grain production in pearl millet. Rust has been observed throughout India. In northern India, the disease does not frequently occur until flowering time in September when temperatures are somewhat moderate. In other regions of the country, rust may attack even the seedling stage, causing substantial reduction in yield.

The disease is of major concern in peninsular India where pearl millet is planted during the post rainy season (*Rabi*) and rust infection and disease development is favoured by lower temperatures during this season. However, pearl millet rust has also been reported in central and peninsular India in the summer season (March–May) crop where seed production is carried out.

All growth stages of the plant are susceptible to rust attack, and under favourable environment, plants can wither before flowering due to severe rust infection (Ramakrishnan and Sundaram, 1956, Rachie and Majmudar, 1980). Rust infection of pearl millet forage has been reported to cause up to 51% reduction in digestible dry matter yield (Monson *et al*., 1986).

Pearl millet rust caused by *Puccinia substriata* Ell. and Barth var. *indica* Ramachar and cummins is characterized by appearance of small reddish brown to reddish orange, round to elliptical uredinia on the foliage with increased rust infection; leaf tissue gets dried and becomes necrotic from the leaf apex to base. In the later stages, uredinia are replaced by telia which are black elliptical and sub-epidermal.

In recent years pearl millet rust has assumed epiphytotic proportions in northern Karnataka where the crop is grown during rainy season. Rust not only reduces grain yield but also reduces the digestable dry matter yield (Monson *et al*., 1986).

Presently little information is available on pearl millet rust in Karnataka state. Keeping these points in view, the present investigation was under taken with the following objectives.

1. To conduct roving survey for pearl millet rust in Bijapur and Bagalkot districts of northern Karnataka.
2. To study the loss assessment in pearl millet genotypes to rust.
3. Integrated management of pearl millet rust.

REVIEW OF LITERATURE

Rust caused by *Puccinia substriata* var. *indica* has become a major constraint in the cultivation of pearl millet in Karnataka state of India. Little information is available on its distribution, loss assessment aspects of the disease, *in vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against pathogen, integrated management of the disease and identification of sources of resistance to pearl millet rust. Information is lacking on evaluation of ITK's against the disease and hence from related fungal/diseases on these aspects is also reviewed under the following headings in the present study.

2.1 Disease distribution

Rust is one of the important disease of pearl millet and known to occur in many countries of Asia (India, Sri Lanka and Pakistan) and Africa (Chad, Congo, Ethiopia, Ghana, Guinea, Ivory Coast, Kenya, Malawi, Mozambique, Nigeria, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Uganda, Zambia and Zimbabwe (Commonwealth Mycological Institute,1967) and Niger (Jouan and Delassus,1971). It has also been reported in Georgia, USA (Luttrell, 1954 and Wells *et al.,* 1973).

Rust of pearl millet is distributed throughout India wherever the crop is cultivated irrespective of the growing season. The disease is of major concern in central and peninsular India where the crop is grown during summer season (March-May) for seed production.

The knowledge about the distribution of disease, the yield loss and associated environmental and cultural factors in different localities is essential so as to employ the available disease management practices properly. This knowledge can be generated by proper techniques such as field monitoring programmes, disease control trials, crop reporting service and survey (Sturgeon Jr., 1986).

Trivedia and Pandya (2007) reported that a total of 24 villages of Morena, Bhind and Gwalior were surveyed in *Kharif* season 2004-05 and 2005-06 to assess the severity of rust in pearl millet. On the basis of two years data, the range of 0.0 to 15.84 per cent of rust was recorded in three districts. The mean severity of rust in Bhind, Morena and Gwalior was 6.93, 2.36 and 1.56 per cent, respectively.

Benagi (1991) reported that, Raichur is the 'hot spot' for outbreak of groundnut rust caused by *Puccinia arachidis* Speg.

Pande and Narayan Rao (2000) reported highest severity of 81-90% and 11-80% of groundnut rust in Koppal and Raichur district, respectively

2.2 Loss assessment of the disease

In India there is little information available on yield losses caused by rust in pearl millet.

Sokhi *et al.* (1978) reported that foliar spray with mancozeb prevented rust development increased the yield and components (including number of tillers bearing panicles) over the untreated check.

Singh and Sokhi (1983) reported that rust reduced the average number of panicles per plant, grain yield per plant and 1000 grain weight in both slow rusting and fast rusting pearl millet cultivars. The reductions were more in fast rusting cultivars than in slow rusting ones.

Wilson *et al*. (1991) studied the effects of infection by *P.substriata var.indica* on yield and digestibility of the pearl millet forage. Dwarf hybrids 'Tiftleaf 1 (susceptible) and Tiftleaf 2 (resistant), and tall hybrids Gahi 3 (susceptible) and Tift 85DA×186 (experimental cultivar Gahi 4, resistant) were inoculated or treated with fungicide after the first harvest to establish different levels of disease. For both dwarf and tall hybrids, there were no consistent differences in yield or digestibility between the disease-free plots of susceptible and resistant cultivars. Grain yield, dry-matter yield, and forage quality as measured by *in vitro* digestibility were negatively correlated with final rust severity and area under the disease progress curve of dwarf and tall hybrids.

Dry matter concentration was unaffected by disease. Loss of digestible dry matter yield could be expressed by either curvilinear or linear functions of final disease severity. In three of four experiments, the rate of loss of digestible dry matter yield was greater at low rust severities than at higher severities, which indicated that highly effective resistance is necessary to reduce losses attributable to rust.

Wilson *et al*. (1994) reported that the effects of rust, caused by *P.substriata* var. *indica*, on grain yield of the pearl millet hybrid 'Tift $23DA_1E$ x Tift 8677' were evaluated at Tifton, GA from 1992 to 1994. Treatments imposed to vary disease severities in 1992 consisted of inoculation, control, and three fungicide applications (chlorothalonil [2, 4, 5, 6-tetrachloro-1,3-benzenedicarbonitrile], Bravo 720 @ 0.46 oz/gal [3.6 ml/L]). Treatments in 1993 consisted of a control and one or three fungicide applications. Treatments in 1994 were control, two, four, or seven fungicide applications. Early planting in 1992 resulted in crop maturation during early development of the rust epidemic. Mean final disease severities ranged from 0 to 33%. No differences among treatments for yield or 500 grain weight were detected. Late planting in 1993 was more conducive to rust development, and mean final severities ranged from 36 to 96%. Grain yield and 500 grain weight of the control were reduced by 76% and 41%, respectively, of those yield components measured from plots with three fungicide applications. Protein concentration of grain averaged 10.8% (108 g/kg) and did not differ among treatments in 1993. Rust was severe in 1994 as a result of late planting coupled with frequent rain, and averaged 92% severity in plots receiving seven fungicide applications. Grain protein averaged 23.3% (233 g/kg) in 1994, and increased with rust severity. Indirect yield losses from lodging occurred in 1993 and 1994 when final rust severity exceeded 90%. Regression equations suggest that yield losses occur when disease severity exceeds 50%.

Sackston (1953) conducted an yield loss experiments with sunrise and ‘S 37-388’ varieties of sunflower and the results revealed that severity of rust was increased with early inoculation and yield loss was to the extent of 17 per cent and 68 per cent, respectively.

Fick and Zimmer (1975) studied the influence of rust on performance of near isogenic sunflower hybrids. They found that under moderately severe rust infection conditions seed yield of the susceptible hybrids are 11 to 33 per cent less than the yields of their respective resistant near isogenic counter parts.

Kim and Brewbaker (1976) tried eight agronomic trials on maize in Hawaii for estimation of crop loss. They reported that the average reductions caused by rust were 35 per cent for grain yield, 27 per cent for fresh plant weight, 11 per cent for ear length, 10 per cent for kernel weight and ear diameter and less than 5 per cent for plant and ear height and days to silk.

Roduel *et al*. (1980) reported that due to common rust yield loss in maize was up to 45 per cent.

Groth *et al.* (1983) studied yield and quality of fresh ears in field plots on selected hybrids of sweet corn (*Zea mays* L.) that were affected by rust (*Puccinia sorghi* Schw.) or were nearly rust-free (mancozeb-sprayed). In 1978, 28 hybrids were tested. Losses in total yield ranged from zero in the more resistant entries to nearly 50% in more susceptible entries. In 1979, three cultivars were planted. Yield losses of these cultivars were similar in ranking order to those in 1978, although the loss was greater in late-planted plots because of the greater final severity of the disease. Losses in total yield in late-planted sweet corn were 18%, 26% and 49% for cv. Sugarloaf (most resistant), cv. Jubilee (intermediate) and cv. Style Pak (most susceptible), respectively.

In India, Narasimhan *et al.* (1983) estimated the losses in sunflower seed yield, oil content and quality of oil due to rust disease. They observed that there was no significant difference in the plant height among the plants with different grades of infection, but there was significant difference in the seed yield (52.0 to 22.5 g/plant) and head diameter (18.3 to 12.7 cm) of healthy and severely infected plants. The oil content was reduced in infected plants (20.97 per cent) than in healthy (34.7 percent).

Shtienberg and Zohar (1992) studied the effects of rust on the yield components and harvested achene yield of a non-oilseed sunflower cultivar.

They observed reduction in head area and the number of achens per head during severe rust epidemics but were not affected by moderate or mild epidemics. The differences in yield (0.86 to 1.15 t/ha) and in net profit (Ud $ 696 to 1153 per ha) between sprayed and unsprayed was significant.

Patil (1996) reported that per cent disease index consequent to different fungicidal sprays of mancozeb (0.2%) was least in plots which received six sprays and maximum in controlled plots of sunflower due to rust. He also mentioned that, compared to six sprays received plot, the loss of seed yield due to rust was maximum (27.02%) in control. Whereas it was 22.57, 18.57, 12.03, 12.35 and 2.36 per cent in one, two, three, four and five sprays received plots, respectively.

Grant *et al.* (2005) reported from Australia that in Victoria, stripe rust of wheat can reduce yield by up to 50 percent and leaf rust by greater than 20 percent in susceptible varieties.

Sunkad and Kulkarni (2006) conducted the field experiments to assess the pod and haulm yield losses due to rust of groundnut using hexaconazole 5% EC in susceptible (KRG-1) and resistant (K-134) varieties during *kharif* 2002 and 2003. Comparatively lower disease index with increase in pod and haulm yield and also maximum benefit cost ratio (BCR) were recorded in plots receiving three sprays of hexaconazole in a susceptible cultivar KRG-1 and two sprays of the same fungicide in moderately resistant variety K-134. Average pod yield loss of 40.20 and 34.00 per cent, respectively were recorded. Similarly, the loss in haulm yield (47.04%) was more in KRG-1 than K-134 (32.11). Yield loss models using simple linear regression functions in the form Y=a+bx were developed.

Syed Nadeem Afzal *et al* (2007) carried out the field experiments to assess wheat yield losses inflicted by *Puccinia striiformis* f.sp. *tritici* West. Investigations revealed that there exists a direct linkage between the disease level and the yield loss in most common commercially adopted wheat varieties in Pakistan. The yield was significantly negatively correlated with the proportion of leaf area affected by stripe rust. The correlation coefficient (-0.67805) depicted highly significant effect of stripe rust in lowering wheat yield. There was varying resistance level among different wheat varieties. The extensively cultivated wheat variety, Inquilab-91 was found to be most resistant with minimum yield loss of 5.77% followed by Wafaq-2001 and Bakhtawar with yield loss of 6.63% and 14.90%, respectively. Whereas Morocco, proved to be the most susceptible wheat variety with maximum yield deficit to the tune of 39.79%. Evaluation of disease resistance revealed that Inquilab-91, Bakhtawar and Wafaq-2001 exhibited 2.24, 1.57 and 1.36 fold resistance in respect of wheat yield as compared to the most susceptible variety Morocco. Sowing of Inquilab-91 and Bakhtawar is recommended to escape heavy yield losses wreaked by the stripe rust.

Utpal Dey e*t al* (2011) reported the yield losses due to maize common rust were found directly related to disease severity. The avoidable yield losses due to disease were in the range of 11.75 to 60.53% in different spray schedule. Crop loss assessment at different fungicide spray schedule revealed that there was significant reduction in yield when disease severity was more than 50%. Six sprays of the hexaconazole at 0.1% completely controlled the disease and contributed to increased yield.

2.3 *In vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against *P. substriata* var. *indica*

2.3.1 Fungicides

Attempts have been made to control pearl millet rust by chemicals. Though a wide range of chemicals including antibiotics, have been tried, only one systemic fungicide namely plantvax, has been tested. Both *in vivo* and *in vitro* tests have been used to test the effectiveness of chemicals. *In vitro* tests have investigated largely the effect of chemicals on urediniospore germination.

Kapooria (1972) evaluated 21 chemicals representing fungicides, antibiotics, plant growth regulators, and chelating agents. Dithane M-22, Ziram, 0-phenanthroline, and Ceresan effectively reduced urediniospore germination of pearl millet rust at 10, 100, and 1000 ppm, whereas Dithane S31 was effective at 100 and 1000 ppm, and Cupramar and IBA at 1000 ppm only.

Bhowmik and Singh (1979) tested eight fungicides on urediospores germination of *Puccinia helianthi* Schw. at different concentrations (1-25ppm) and observed oxycarboxin and benodanil among the systemic and mancozeb among non-systemic fungicides found effective.

Jalinder *et al*. (1986) described that bayleton was able to inhibit uredospore germination of wheat stem rust at 500 ppm and above concentration.

Benagi (1991) evaluated eight fungicides *in vitro* on uredospore germination of *Puccinia arachidis* Speg. and found cent per cent inhibition with propiconazole, tebuconazole, chlorothalonil, oxadaxil and diclobutrazole at 0.1 per cent concentration.

Chopade (1998) tested five fungicides against *Puccinia graminis f.sp. tritici* West. *in vitro*, bayleton 25 WP (0.2%), daconil 75 WP (0.2%), dithane M-45 (0.3%) and topsin M (0.2%) showed 100% inhibition of spore germination.

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.

Kalappanavar *et al.* (2008) showed that among the three chemicals, propicanazole was most effective against uredospore germination of *P. recondita f.sp. tritici* followed by triadimefon and hexaconazole. Fungicide propiconazole found superior at 0.1 per cent concentration.

Utpal Dey e*t al* (2011) evaluated fourteen fungicides *in vitro* on uredospore germination of *Puccinia sorghi* Schw and found tebuconazole (0.1%) most effective. Hexaconazole (0.1%), difenconazole (0.1%) and mancozeb (0.025%) were found equally effective and recorded lower percentage germination of uredospores.

2.3.2 Commercially available botanicals

Plant derivatives possessing pesticidal properties are evoking worldwide interest as an alternative or as supplements for the existing pesticides for several reasons (Toriyama, 1972). Integration of chemicals, plant extracts and biotic agents along with resistance for managing plant diseases has been considered as a novel approach (Papavizas, 1973). The literature on use of plant extracts to manage pearl millet rust are lacking, so reviews pertinent to rust and other disease of different crops has been given below.

Mishra and Dixit (1978) found antifungal activity in 21 angiosperms against *Puccinia recondita* Rob. ex Desm. on wheat. Shekhawat and Prasad (1971) reported that out of nine plant extracts tested *viz*., *Allium cepa* L.*, Allium sativum* L., *Ocimum sanctum* L., *Mentha piperita* L. and *Beta vulgaris* L. showed strong inhibitory action against *Alternaria tenuis* Nees. from bean, *Helminthosporium* sp. from watermelon and *Curvularia penniseti* (Mitra) Boed. from bajra.

Rahber-Bhatti (1986) observed that diffusates of turnip, cluster beans (*Cyamopsis psoraliodes* DC.), clove (*Syzygium aromaticum* (L.) Merr. et Perry) and turmeric (*Curcuma longa* L.) greatly inhibited the spore germination of *Phakopsora grewiae* (Pat. & Har.) Cummins. Application of turnip seed diffusate significantly reduced rust appearance while diffusate of cloves gave complete protection and eradicated the rust on detached leaf discs of *Grewia asiatica* L.

Wadhwani *et al*. (1986) observed many plants free from rust infection in the fields of sunflower severely infected by *Puccinia helianthi* Schw. Further they reported that the crude leaf extracts of *Amaranthus spinosus* L., *Lagenaria siceraria* Standl, *Nerium indicum* (Mill.) and *Solanum nigrum* Linn.completely inhibited uredospore germination of *P. helianthi*. And also observed differences in length of germtube in different plant extracts.

Navi (1986) evaluated six fungicides *in vitro* and *in vivo* against *Puccina recondita* and found bayleton and calixin were effective.

Benagi (1995) evaluated 22 plant extracts against the conidial germination of *Cercospora personata* (Berk & Curt) V. Arx). Out of 22 leaf extracts of *Datura stromonium* L., *Tridax procumbense, Azadirachta indica* Juss and neem seed kernel extract (NSKE) inhibited maximum conidial germination at 2.5 per cent concentration.

Khadar (1999) noticed the maximum inhibition of uredospore germination of *P. arachidis* Speg. in *Nerium oleander* L. flower extract followed by *Amaranthus viridis* L., neem leaf and seed kernel extract at five per cent concentration.

Hundekar (1999) reported maximum per cent inhibition of uredospore germination of *Phakopsora pachyrhizi* Syd. with tobacco (88.10%) followed by neem (87.21%) and clerodendron (66.74%). All the plant extracts, showed antifungal activity against urediospore germination at all the concentrations tested.

Ramesh *et al*. (2003) reported that maximum inhibition of spore germination of *Colletotrichum gloeosporioides* Penz. was observed in garlic bulb extract at 10 per cent concentration (72.81%) followed by tulasi leaf extract at the same concentration (55.57%).

Hurali (2008) tested 25 plant extracts on urediospore germination of *P.pachryrhizi* and found that *Allium sativum, Azadirachta indica* and *Amaranthus viridis* at 5 and 10 per cent concentration showed maximum per cent inhibition.

Hemachandra haller *et al.* (2011) evaluated efficacy of 10 per cent water extracts of seven plants for their antifungal activity *in vitro* against *Cercospora beticola* Sacc. and observed cent per cent inhibition of mycelial growth by extract of *Allium* sp., followed by *Prosopis julifera* and *Datura metel* recording 50.34 per cent and 31.66 per cent reduction over control, respectively. The least inhibition was observed in the leaf extracts of *Catharanthus roseus* and *Ocimum sanctum*

Utpal Dey e*t al.* (2011) studied the effect of botanicals on uredospore germination of *P. sorghi* revealed that neemazol F5% @ 20 per cent showed less per cent uredospore germination followed by nimbicidine, neemazol F1% and cristol 56 SL.

2.3.3 Evaluation of indigenous technology knowledge (ITK's)

Due to inherent hazardous effects involved in conventional chemical management, the alternative plant protection measures like organic farming, use of FYM, green manuring, neem oil, botanicals and animal by-products such as cow urine, buttermilk as described in Vedas, Arthashastra, Agnipuran, Surapala's (Nene, 2003; Sadhale, 1966, Wojtilla, 1985) etc. are gaining importance.

2.3.3.1 Cow urine

Sridhar *et al*. (2002) reported that application of 50 ml of cow urine in 500 ml of water spraying on plants in early morning reduces the virus, fungus and bacterial incidence in vegetable crops.

Manikandan (2005) observed that spraying of 200 ml of cow urine mixed with two liters of water was found effective in controlling the brinjal damping off in nursery.

Kannan *et al*. (2005) reported that combined application of soil drenching and foliar spray of sheep urine at 10 per cent found most effective in reducing the incidence of groundnut stem rot. With regard to yield the same treatment registered the maximum yield of 1655 kg per ha whereas controlled plot recorded 1053 kg per ha.

Selvi and Kurucheve (2005) evaluated the effect of natural products like sheep urine at 5 per cent, buffalo urine at 20 per cent, hen litter and goat dung at 100 per cent. Results indicated that hen litter was reduced the production of poly galacturonase up to 88.61 per cent, polygalacturonase trans-eliminase with 90.83 and pectin trans-eliminase with 83.63 per cent than the other products tested.

Priya and Kurucheve (2005) studied the effect of animal excrements on the conidial germination of *C. personata.* Among the animal excrements tested, cow urine at 10 per cent, cow dung at 20 per cent and cow urine plus cow dung (1:1) at 2.5 per cent concentration recorded complete inhibition of conidial germination. In control, maximum conidial germination of 96.0 per cent was recorded.

Raja *et al*. (2005) noticed that animal urine containing high nitrogen significantly reduced the *Macrophomina phaseolina* (Tassi) Goid., *Fusarium oxysporum f.sp. lycopersici* (Sacc.) and *Rhizoctonia solani* Kuhn.

Kannan *et al*. (2007) reported that, foliar spray of combined application of buffalo urine and sheep urine (1:1 v/v) at 5 per cent concentration on peanut have completely inhibited the mycelial growth, production and germination of sclerotia of *Sclerotium rolfsii* Sacc. when compared to control and chemical fungicide, mancozeb (0.05%). Subsequently it has increased the pod yield.

Patil (2008) observed that among the seven commercially available neem based products tested viz., neem oil, margotricure, nimbicidine and neem gold at 0.5 per cent and wanis at 1 per cent, sprayed thrice at an interval of 10 days starting from the onset of disease were found promising in reducing the soybean rust severity wth significant increase in seed yield and 100 seed weight.

Utpal Dey e*t al.* (2011) tested ITK's against *P. sorghi*, jeevamruta @ 20 per cent concentration caused significantly less per cent uredospore germination of 22.69% followed by panchyagavya @ 20 per cent (33.67%).

2.3.3.2 Butter milk

Jayashree *et al*. (1999) observed that plant derivatives, neem oil and Thuja 30 inhibited the pumpkin yellow vein mosaic virus effectively. The only product tested was butter milk which was found to reduce the virus transmission effectively.

Sapre and Verma (2006) reported that cow urine and butter milk reduced the mycelial growth, number and size of sclerotia of *Rhizoctonia bataticola* (Taub.) Butler. The mycelial growth was completely inhibited by butter milk at 500 and 1000 ppm whereas at 100 ppm it was least (3.31 mm). Cow urine and butter milk not only reduced the mycelial growth of *S. rolfsii* but also affected the viability of sclerotia formed and reduced number of sclerotia per plate.

Smallest sclerotia were recorded in butter milk followed by cow urine, slight reduction in mycelial growth of *Fusarium solani f.sp. glycine* by cow urine and butter milk. Conidial production decreased with increasing concentration of cow urine.

2.3.3.3 Cow milk

Sollinger *et al*. (1997) reported that seed treatment with skimmed milk powder, quick lime and through seed washing gave a level of control of common bunt of wheat (*Tilletia caries* (DC) Tul) which was similar to that obtained with copper oxychloride control.

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

Ribeiro *et al*. (2001) reported that spraying the mixture of 30 per cent raw milk and 10 per cent bougainvillea leaf extract from plant emergence until the initiation of flowering on zucchini (*Cucurbita pepo*) has reduced the incidence of zucchini yellow mosaic virus (ZYMV) and simultaneously increased the yield of zucchini.

Arunkumar *et al*. (2002) claimed that milk sprays induced systemically acquired resistance in chilli against leaf curl. Milk also used for controlling powdery mildews. The amino acid proline found systemically induces resistance in plants (Niranjan and Shetty, 2002) High amounts of endogenous proline increases the contents of cytokinin and auxins. Therefore, milk treatment requires early attention and gives an opportunity to rediscover its beneficial effects.

Zatarim *et al*. (2005) tested the efficacy of several types of cow milk for the control of powdery mildew of pumpkin (*Cucurbita moschata* L.) cv. Piramoita, caused by *Sphaerotheca fuliginea* (Schltdl.) under field conditions. Among those, raw cow milk, pasteurized type C milk and type C+ Yakult were the most efficient in the control of disease.

2.3.3.4 Vermiwash

Szczech (1999) reported that vermicompost added to various container media significantly inhibited the infection of tomato plant by *F. oxysporum* f.sp. *lycopersici*.

Banu and Rohini (2006) tested different dilutions of vermiwash against nematodes under *in vitro* conditions and found to be deleterious to varying extent. It greatly inhibited juvenile hatching of *Meloidogyne incognita*. Undiluted vermiwash caused maximum nematode mortality and inhibition in hatching.

2.3.3.5 Panchagavya

Padmodaya (1994) reported the inhibitory effect of mahapanchagavya on tomato wilt pathogen under *in vitro* condition and showed superior to carbendazim in reducing *Fusarium* wilt of tomato and increasing the vigor of plant and yield.

Jahagirdar *et al*. (2000) conducted field experiment and investigated ecofriendly integrated management of pepper foot rot caused by *Phytophthora capsici* Leonian and observed that combined application of *Trichoderma viride* and modified panchagavya was reduced the disease incidence and increased the yield above 50 per cent when compared to control.

Jahagirdar *et al*. (2003) opined that traditional methods form the basis of management of plant diseases in low input situations. Modified panchagavya mixture (mixture of cow milk, curd, ghee, dung and urine supplemented with yeast and common salts) found most effective for the management of panama disease of banana.

Sugha (2005) evaluated antifungal potential of panchagavya against *R. solani* causing damping off of cauliflower seedlings. It inhibited 40-100 per cent mycelial growth and suppressed the disease by 78-82 per cent in nursery beds.

Yadav and Lourduraja (2006) studied the effect of organic manures and panchagavya spray on rice (*Oryza sativa* L.) quality. Foliar spray of panchagavya recorded significantly higher physical characteristics like grain size, 1000 grain weight and milling quality as well as cooking quality.

Sumangala and Patil (2007) found the antifungal activity of panchagavya against *Curvularia lunata* in rice. It resulted in 86.30 per cent inhibition of mycelial growth and 95.9 per cent of spore germination of *C. lunata*. Seed treatment with panchagavya further enhanced the seed germination with 90.7 per cent and vigour index of 1036.

2.4 Integrated management of pearl millet rust

The possibilities of controlling plant diseases by the integration of several methods have been the subject of extensive research. Integration of chemicals, botanicals and ITK's, for managing plant disease has been considered as a novel approach. The literature on integrated management of pearl millet rust is lacking. Therefore, the review pertinent to rust and other diseases of different crops has been given below.

Spraying of 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).

Benagi (1995) observed that fungicide (chlorothalonil 0.2%) application on 30th and 50th day after sowing (DAS) and either tridax leaf extract or neem seed kernel extract (5%) spray on 45 DAS gave better pod yield with minimum disease severity. Cost: Benefit ratio of 1:7.48 and 1:6.48 were obtained in chemical tridax leaf extract and chemical (CNC) spray schedule.

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 and/or amaranthus leaf extracts in the spraying schedule along with propiconazole 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 were 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 C: B ratio obtained in propiconazole-amaranthus-propiconazole (1:3.02) followed by propiconazole-nimbicidine-propiconazole (1:80) spray schedule.

Anahosur *et al*. (2000) observed that use of nimbicidine (0.5%) inter mixed with hexaconazole (0.1%) sprays reduced the disease of sorghum rust index and there by inarease the yield.

Fugro (2000) reported that application of FYM, vermicompost and neem cake followed by organic pesticidal sprays (garlic and chilli extracts) 15 days after transplanting followed by nimin solution 4ml/liter spray, showed reduction of leaf curl index (2.12%) and die back (4.03%) in chilli.

Basak and Lee (2002) reported that cow urine found inhibitory to the mycelial growth of *Fusarium oxysporum* f. sp. *cucumerinum*, *F. solani* f. sp. *cucurbitae* and *Sclerotinia sclerotiorum* (Lib.) that cause diseases in cucumber. Also reported positive response of fresh cow urine and cow dung in suppression of mycelial growth of *F.* solani, *F. oxysporum* and *S. sclerotiorum*.

Hifsa Kiran and Shabeer Ahmad (2005) evaluated the relative efficacy of different fungicides and phytobiocides, such as garlic, ginger, turmeric and neem oil under field conditions by artificial inoculation for the control of powdery mildew (*Erysiphe pisi*) in pea cv.Meteor. Both fungicides and phytobiocides reduced the disease severity. The lowest disease incidence and higher yield was recorded in plants treated with difenconazole (score) followed by turmeric spray indicating their efficacy against the disease.

Vijaylakshmi *et al*. (2005) reported the effective control of chilli leaf spot by 10 per cent cow urine spray once in 10 days thrice followed by half- liter cow urine along with half- liter sour buttermilk mixed with nine liters of water once in seven days twice.

Nargis *et al*. (2006) reported that the extracts of *Adhatoda vasica* Nees., *Zingiber officinale*.L., *Vinca rosea* and *Azadirachta indica* Juss. in combination with cow dung, *Calotropis procera* (Aiton) W.T. Aiton and cow urine posses high ability to inhibit conidial germination of *Bipolaris sorokiniana* which might be used for controlling phytopathogens of crop plants.

Shabeer Ahmad and Irfan ud Din (2006) studied the effect of turmeric, garlic, pepper extracts and chemicals such as difenconazole and penconazole against powdery mildew (*E. pisi*) of pea. Turmeric extract has significantly reduced the disease severity and increased the number of pods, number of grains and grain yield.

In case of *in vitro* evaluation of botanicals and organics, azadirachtin (0.5%) and NSKE (5%) were found most effective in inhibiting conidial germination. Whereas, in field azadirachtin (69.07% and 7.11 q/ha) and NSKE (66.93% and 7.00 q/ha) managed the disease of powdery mildew and increased yield significantly (Dinesh, 2009).

2.5 Screening of pearl millet genotypes to rust disease

Wilson (1994) attempted field and green house evaluations of pearl millet for partial resistance to *P.substriata* var*. indica*. Pearl millet inbreds Tift-383, 700481-21-8 and ICMP 501 were evaluated for partial rust resistance in comparison to susceptible inbred Tift 23 DB. In field trials area under disease progress curve of the three inbreeds was less than that of Tift 23 DB when disease pressure was severe. Uredinium dimensions on seedling 10 days after inoculation were smaller for the three inbreds then for Tift 23 DB.

Wilson and Gates (1999) studied expression of partial resistance to *P. substriata* var. *indica* and its contribution to digestible biomass production in forage pearl millet hybrids evaluated in field experiments at Tifton, GA. Inbreds Tift 383, Tift 65, and nine inbreds with partial resistance selected from the cross Tift 383 × 'ICMP 501' were crossed to Tift 23DA4. The parental inbreds and hybrids were evaluated in natural epidemics in 1996 and 1997. Because of maturity differences among the lines,slope of the regression of logit rust severity on time (apparent infection rate) and area under the disease progress curve (AUDPC) calculated for a defined interval of plant growth (10 days before to 20 days after anthesis) and adjusted for initial rust severity at 10 days prior to anthesis were the most useful indicators of resistance. Inbred resistance was not a reliable predictor of hybrid resistance when evaluated by either variable.

Panwar *et al.* (2001) reported that most of the pearl millet genotypes were susceptible to rust, but ICMH 451, GHB 235, Eknath 201, X6, ICMA 88001 and ICMB 88001 showed moderate levels of resistance. Hybrid HHB 117 was free from rust.

Wilson and Devos (2004) observed the expression and inheritance of partial rust resistance in pearl millet inbreds 700481-21-8 and ICMP 501 crossed to moderately susceptible Tift 383 and were evaluated in seedling assays in the green house and in generation mean and single seed descent populations in the field. Uredium sizes on seedling leaves on hybrid were generally intermediate to those of the parental inbreds and consistent differences could be described in uredium lengths. Pearlmillet genotypes and the result revealed high level of resistance in 4 entries of *Pennisetum glaucum* (852B, ICMB8701, DIC-14-p23 and PMIN 86-1) against rust. 15 entries showed slow rusting behaviour. The resistance against rust was found under the control of a dominant gene in the entries, 7042-1-4-4 and IP8695-4 where as in the entry 700481-27-5-2, the resistance was found to be governed by 2 genes (1 dominat , 1 recessive)

Sharma *et al.* (2009) screened 214 advanced breeding lines, including 126 designated B-lines, 23 designated R-lines and 65 potential R –lines of pearl millet against rust resistance in the disease nursery during the post rainy season 2008-09 under natural epiphytotic conditions. one B line and 7 R-lines showed resistance (<10%rust severity) in the field screen were further evaluated in the green house by artificial inoculation to confirm their resistance. One B line (ICMB 96222) and three R lines (ICMR 0699, ICMP 451-P8 and ICMP 451-P6) were resistant while the other four R lines were susceptible.

Hanna *et al.* (2011) discovered rust resistance in three *Pennisetum americanum* (L.) Leeke subspecies *monodil* (Maire) Brunken accessions from Senegal. Resistant plants were free of rust, although the bottom one or two leaves of some plants did develop a brown discoloration without pustules. Resistance was controlled by a dominant gene and assigned the gene symbol Rr_1. Backcrossing has been effective in transferring resistance from the wild grassy, *monodil* to cultivated pearl millet. The Rr_1 gene was found to be useful in the production of rust resistant pearl millet hybrids and cultivars.

Screening of pearl millet genotypes at Agricultural Research Station, Aurangabad and main Agricultural Research Station, Jamnagar to rust has yielded four genotypes viz., MH 1893, MH 1889, MH 1890 and MH 1878 with high level of resistance (Anon, 2012)

Shahin *et al.* (2012) studied the slow rusting resistance in 20 Egyptian 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 (AUDPC) and coefficient of infection (CI). The cultivars viz., Giza 168, Gemmeiza 7 and Sakha 94 exhibited the lower CI and r AUDPC and could have slow rusting resistance. The correlation analysis of different parameters also showed strong relationship of CI with r AUDPC (R^2=0.93).

MATERIAL AND METHODS

3.1 Roving survey of the disease in Bijapur and Bagalkot districts of northern Karnataka

Intensive roving survey was carried out in northern dry zone of Karnataka, during September-October 2012. The pearl millet fields on the survey route were visited and the observations on rust severity, stage of the crop and the condition under which the crop was grown (rainfed or irrigated) was noted down. Rust severity was recorded by following 0 to 9 scales of Mayee and Datar (1986).

Rating values	Description
0	No symptoms on the leaf.
1	Small, dark brown, powdery pustules covering one percent of leaf area.
3	Typical rust pustules covering 1 to 10% of the leaf area.
5	Typical rust pustules covering 11 to 25% of the leaf area.
7	Typical rust pustules covering 26 to 50% of the leaf area.
9	Rust pustules covering 51% or more of the leaf area, withering of leaf.

Further these scales were converted to Per cent Disease Index (PDI) using the formula given by Wheeler (1969).

$$PDI = \frac{\text{Sum of the numerical ratings}}{\text{Number of leaves observed}} \times \frac{100}{\text{Maximum disease rating}}$$

3.2 Loss assessment in pearl millet genotypes due to rust

Field experiment was laid out in split plot design during *kharif* 2012-13 to assess the losses due to rust in ten pearl millet genotypes. Hexaconazole @ 0.1% was sprayed at regular interval for protecting the ten genotypes with rust infection. Unsprayed genotypes block were treated as unprotected treatment. Details of the treatments are given as below.

Design : Split plot

Replications : Three

Treatments : Main plot: Fungicidal spray (Hexaconazole @ 0.1%)

Sub plot: Genotypes (GK 1135, Mahalaxmi Tilak, MLBH 308, Laxmi 234, 86 M 52, MRB 2232, Ajeet 27, ICMV 221, ICTP 8203 and GHB 558).

Plot size : Main plot (fungicidal spray): 18mt x 5mt

Sub plot (genotypes): 1.8mt x 5mt (four rows of 5mt. length)

Spacing : 45cm x 15cm

Observations on rust severity in different treatments were taken at physiological maturity. Other observations recorded are as follows:

1. Ear head length (cm)
2. Ear head seed weight (g)
3. Seed yield (q/ha)
4. 1000 seed weight (g)

3.3 Effect of incubation period for maximum germination of uredospores of *P.substriata* var. *indica*

A drop of uredospore suspension prepared in distilled water was suspended in the cavities on the slide and kept in the moist chamber and incubated at room temperature (25^0 C ± 1^0C). Each treatment was replicated three times. The observations on uredospore germination were recorded at 2, 4, 6, 8, 10, 12 and 14 hours of incubation and then percent germination was worked out and data were analyzed statistically.

3.4 Integrated management of pearl millet rust.

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

Various fungicides, commercially available botanicals and ITK's were evaluated *in vitro* condition on uredospore germination technology against *P. substriata* var.*indica*. 0.05, 0.075 & 0.1 per cent of systemic fungicides viz., hexaconazole, propiconazole, penconazole, triadimefon, difenconazole and benomyl, 0.1, 0.2 and 0.3 per cent concentration of non-systemic fungicides viz., mancozeb, chlorothalonil, carbendzim + mancozeb (SAAF) and propineb, 0.25, 0.50, 0.75 and 1.0 per cent concentrations of commercially available botanicals viz., neem oil, soldier, sainik, dischеck and neem mark and 5, 10, 20 and 30 per cent concentrations of ITK's viz. cow urine, cow milk, butter milk, panchagavya and vermiwash were prepared under aseptic conditions. Finally these were evaluated under *in vitro* condition against uredospore germination by "Cavity slide" method. Required concentrations of each product were prepared in distilled water. In each treatment three replications were maintained. 100 spores were observed after ten hours of incubation in moist chamber. Control treatment was maintained with distilled water. 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 = No. of uredospores observed.

The Percent 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

3.4.1 Evaluation of fungicides

Ten fungicides consisting of six systemic and four non systemic were assayed for their efficacy against uredospore germination of *P. substriata var.indica* under *in vitro* condition. The systemic fungicides were tested at 0.05, 0.075 and 0.1 per cent concentration, whereas non-systemic fungicides were tested at 0.1, 0.2 and 0.3 per cent concentration. The details of the fungicides evaluated are furnished hereunder.

Systemic fungicides

Sl. No	Common name	IUPAC* name	Trade Name
1	Propiconazole	1-(2,4-dichlorophenyl) 4 propyl-1-3-dioxalan-2-methyl) H-1, 4-triazole)	Tilt 25% EC
2	Hexaconazole	(RS)-2-(2,4-dichlorophenyl)-1H-1, 2,4-triazol-1-yl) hexan-2-0*l*)	Contaf 5% EC
3	Triadimefon	1 (4 chlorophenoxy)-3-3 dimethyl-1-(1H-1, 2,4-triazole-1 Y)-butanone	Bayletan 25% WP
4	Penconazole	1-[2-2(2-4-dichlorophenyl)-nphenyl]-1H-1, 2,4,	Topas 10% EC

		triazole	
5	Difenconazole	Cis, trans-3-chloro-4 (4-methyl-2(1H-1,2,4-triazole-1-yl methyl)1,3 dioxalan-2yl) phenyl, 4-chlorophenylether	Score 25% EC
6	Benomyl	Methyl [1-(butylamino)carbonyl]-1H-benzimidazol-2-y1]carbamate	Benlaete 50 WP

Non systemic fungicides

Sl. No	Common name	IUPAC* name	Trade Name
1	Mancozeb	Manganese zinc ethylene bis Dithiocarbomate	Indofil M-45 75 WP
2	Chlorothalonil	2,4,5,6-tetrachloroisophthalonitrile	Kavach 75% WP
3	Carbendazim + Mancozeb	Methyl 1H-benzimidazol-2-1carbamate + manganese ethylenebis (dithiocarbamate) (polymeric) complex with zinc salt	SAAF 75% WP
4	Propineb	polymeric zinc 1,2- propylenebis (dithiocarbamate)	Antracol 75 % WP

* International Union of Pure and Applied Chemistry

3.4.2 Commercially available botanicals

Plant based pesticides are relatively cheaper, safe and non hazardous and they can be used easily and successfully against the plant pathogenic fungi. The present investigation was aimed to study the anti- fungal activity of some of the commercially available botanicals.

The following botanicals were evaluated at 0.25, 0.5, 0.75 and 1.0 per cent concentration.

Sl. No.	Common name / Trade name	Content
1	Neem oil	Azadirachtin
2	Soldier	*Aegle marbelos* (20%), *Ricinus communis* (20%), *Hygrophila spinosa* (20%), *Laminaria spp.* (20%) and *Lantana camera* (20%)
3	Sainik	Organic systemic fungicide
4	Discheck	*Ficus bengalensis* – 0.0001%, *Ficus religiosa* – 0.0001%, *Ficus retusa* – 0.0001% and Aqua solvent – 99.99%
	Neem mark	Azadirachtin 0.03% EC

3.4.3 Indigenous technology knowledge (ITKs)

Various ITK'S such as cow urine, cow milk, butter milk, panchagavya and vermiwash were evaluated *in vitro* condition by spore germination technique against *P. substriata var.indica* at 5, 10, 20 and 30% concentrations.

Panchagavya was taken from Organic Farming Institute, UAS, Dharwad and vermiwash from vermiculturing unit, Regional Agricultural Research Station, Bijapur.

The uredospore suspension was prepared separately in sterile water to obtain $4x10^8$ uredospores per ml. Then a drop of a spore $4x10^8$ suspension was mixed with one drop of ITK'S solution in a cavity slide to achieve the required concentration. In each treatment three replications were maintained. Slides were incubated at room temperature ($25^0C \pm 1^0$ C) for 10 hours. The observation on spore germination was recorded at 10 hr. after incubation under microscope at 40 X magnification. A control treatment was maintained with sterile water. Per cent uredospore germination was calculated as mentioned in case of fungicides evaluation.

3.4.4 Integrated Management of the Disease

Field experiment was laid out in a randomized block design with three replications at Agricultural Research Station, Almel during *kharif* 2012. The economically viable and effective fungicide, botanical and ITK under *in vitro* evalution were tested under field condition using the rust susceptible pearl millet genotype (MRB 2232). The integration of fungicide, botanical and ITK were evaluated with the spraying schedule given below.

Treatments	Spraying schedule	
	1st Spray	2nd Spray
T1	B	B
T2	ITK	ITK
T3	F	F
T4	B	F
T5	F	B
T6	ITK	F
T7	F	ITK
T8	Unsprayed control	

B: Botanical, ITK: Indigenous Technology Knowledge and F: Fungicide

Recommended package of practices was followed to raise the crop. Two sprays were given in each treatment at 15 days interval starting from the onset of disease. Observations on rust severity were taken at physiological maturity by following 0 to 9 scales of Mayee and Datar (1986). Seed yield per plot and 1000 grain weight were noted down after the harvest of the crop.

3.4.5 Screening of pearl millet genotypes to rust

A total of 42 genotypes involving 19 B lines, 21 R lines and two hybrids of pearl millet as listed below, were screened under field condition at ARS, Almel. Each genotype was sown in a single row of 5mt length with a spacing of 45cm X 15cm. The disease severity was recorded using 0-9 scale by randomly selecting five plants in each genotype (Mayee and Datar, 1986). Based on their reaction genotypes were categorized into immune, resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible.

Sl. No	Entry	Pedigree	Sl. No	Entry	Pedigree
1.	RLT-2	LPRT10-9	22.	RLT-10	SGRT10-12
2.	BLT-1	LSBLT10-1	23.	BLT-13	EBLT10-56
3.	BLT-4	LSBLT10-24	24.	RLT-8	SGRT10-5
4.	RLT-19	DPRT10-10	25.	BLT-14	CPBLT10-2
5.	RLT-1	LPRT10-5	26.	ICMB 94555	B Line of GHB 558
6.	RLT-11	SGRT10-15	27.	BLT-6	LSBLT10-26
7.	BLT-2	LSBLT10-11	28.	RLT-3	LPRT10-11
8.	BLT-12	EBLT10-44	29.	RLT-18	DPRT10-4
9.	RLT-4	LPRT10-13	30.	BLT-16	CPBLT10-13
10.	RLT-6	LPRT10-22	31.	RLT-17	EMRT10-33
11.	RLT-16	EMRT1O-30	32.	BLT-15	CPBLT10-9
12.	BLT-9	EBLT10-25	33.	BLT-3	LSBLT10-12
13.	RLT-7	LPRT10-26	34.	GHB558	ICMA 94555 × J2290
14.	BLT-7	LSBLT10-27	35.	RLT-14	EMRT10-16
15.	RLT-9	SGRT10-7	36.	RLT-15	EMRT10-17
16.	BLT-10	EBLT10-32	37.	BLT-8	EBLT10-3
17.	BLT-11	EBT10-37	38.	BLT-18	CPBLT10-21
18.	BLT-5	LSBLT10-25	39.	RLT-20	DPRT10-13
19.	RLT-12	SGRT10-17	40.	BLT-17	CPBLT10-14
20.	RLT-5	LPRT10-14	41	J 2290	R Line of GHB 558
21.	RLT-13	EMRT10-12	42.	MRB2232	Private hybrid

EXPERIMENTAL RESULTS

The results of the experiment conducted on various aspects of pearl millet rust caused by *Puccinia substriata* var.*indica* with reference to survey, loss assessment aspects of the disease, *in vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against pathogen, integrated management of the disease, screening of genotypes for resistance are presented below.

4.1 Survey

A roving survey was carried out in Bijapur and Bagalkot districts of northern Karnataka during September-October 2012 to find out the severity of rust of pearl millet. Twenty four places in Bijapur and twelve in Bagalkot districts (total 36 pearl millet fields) were surveyed as explained in Material and Methods. The results are presented in Table 1a and 1b, Fig. 1 and Plate 1a & 1b.

Maximum mean percent disease severity (PDI) was observed in Bijapur district (36.17). Whereas, minimum per cent disease severity (PDI) was noticed in Bagalkot district (26.70).

In Bijapur district, five taluks were surveyed, *viz.,* Bijapur, Indi, Muddebihal, Basavana Bagewadi and Sindgi. In Bijapur taluk, the survey was conducted in six villages. Among them, the maximum disease severity (62.92%) was recorded in Shivanagi (Plate 1a.) followed by Jumnal village (51.84%) whereas least severity (18.51%) was recorded in Kaggod village. Similarly in Indi taluk, the maximum severity (40.73%) was recorded in Nagatana village followed by Chadachana with the severity of 37.03%. The least severity (14.81%) was recorded in Atarga. Similarly in Muddebihal taluk, the maximum severity (33.33%) was recorded in Dannur village followed by Gangur with the severity of 22.22%. In Basavana Bagewadi taluk, the maximum severity (70.36%) was recorded in Kudagi village followed by Masuti with the severity of 44.44%. The least severity (29.62%) was recorded in Muttagi. And in Sindgi taluk, the maximum severity (55.55%) was recorded in Padaganur (Plate 1b.) village followed by Kannolli with the severity of 48.14%. The least severity (22.22%) was recorded in Jalwad. Among the taluks surveyed in Bijapur district, the maximum severity (42.96 %) was recorded in Basavanabagewadi followed by Bijapur and (40.11%). The least severity (27.80 %) was observed in Muddebihal taluk.

In Bagalkot district, three taluks were surveyed, *viz.,* Bagalkot, Hunagund and Badami. In Bagalkot taluk, the survey was conducted in five villages. Among them, the maximum severity (29.62%) was recorded in Nagarhal followed by Sirur village with severity of 22.22%. The least severity (7.40%) was recorded in Choudapur. Similarly in Hunagund taluk, the maximum severity (48.14%) was recorded in Pochapur followed by Chittargi with the severity of 40.73%. The least severity (14.81%) was recorded in Ilkal. In Badmi taluk, the maximum severity (40.73%) was recorded in Katageri followed by Kerur with the severity of 33.33%. The least severity (7.40%) was observed in Kerkalmatti (Plate 1b). Among the taluks surveyed in Bagalkot district, the maximum severity (35.18%) was recorded in Hunagund followed by Badami taluk (27.15%). Whereas, the least severity was recorded in Bagalkot (17.77%) (Fig. 1).

The disease severity was also increased towards maturity irrespective of the crop grown either in rainfed or irrigation.

4.2 Effect of incubation period for maximum germination of uredospores of *P. substriata* var. *indica*

The effect of different incubation period for uredospore germination of *P.substriata* var. *indica* and are presented Table 2.

The results on effect of incubation period on uredospore germination indicated that, maximum germination was observed at 10 hrs of incubation (76.65%) followed by 14 hrs (70.37%), 12 hrs (68.33%) and 8 hrs (56.60%) and were on par with each other. Next maximum germination was recorded at 6 hrs of incubation (48.50%) and it was on par with 4 hrs (37.84%) and 2 hrs (29.80%).

4.3 Estimation of loss due to rust

An experiment was conducted during *kharif* 2012 at Agricultural Research Station, Almel to assess the losses due to rust in ten pearl millet genotypes. Hexaconazole 0.1% was sprayed at regular interval for protecting the ten genotypes with rust infection. Unsprayed genotypes block were treated as unprotected treatment.

Table 1a. Survey on severity of pearl millet rust in Bijapur and Bagalkot districts of Karnataka during September – October 2012

District	Taluk	Village name	Stage of the crop	Crop grown condition	Percent disease index
Bijapur	Bijapur	Hadagali	Grain development	Rainfed	37.03
		Honnutagi	Grain development	Rainfed	40.73
		Hittanalli	Grain development	Rainfed	29.62
		Jumnal	Grain development	Rainfed	51.84
		Kaggod	Grain development	Rainfed	18.51
		Shivanagi	Grain development	Rainfed	62.92
		Mean			**40.11**
	Indi	Nagatana	Grain development	Rainfed	40.73
		Jhalaki	Grain development	Rainfed	33.33
		Atarga	Grain development	Rainfed	14.81
		Horti	Grain development	Rainfed	29.62
		Chadachana	Grain development	Rainfed	37.03
		Mean			**31.10**
	Muddebihal	Gangur	Grain development	Rainfed	22.22
		Dannur	Grain development	Rainfed	33.33
		Mean			**27.80**
	Basavan bagevadi	Masuti	Grain development	Rainfed	44.44
		Muttagi	Grain development	Rainfed	29.62
		Kudagi	Grain development	Rainfed	70.36
		Gholsanghi	Grain development	Rainfed	37.03
		Managoli	Grain development	Rainfed	33.33
		Mean			**42.96**
	Sindgi	Devara hipparagi	Grain development	Rainfed	25.92
		Devoor	Grain development	Rainfed	40.73
		Mannur	Grain development	Rainfed	40.73
		Jalwad	Grain development	Rainfed	22.22
		Padaganur	Grain development	Rainfed	55.55
		Kannolli	Grain development	Rainfed	48.14
		Mean			**38.88**
	District average				**36.17**
Bagalakot	Bagalkot	Hallur	Grain development	Rainfed	14.81
		Choudapur	Grain development	Rainfed	7.40
		Sirur	Grain development	Rainfed	22.22
		Nagsampige	Grain development	Rainfed	14.81
		Nagarhal	Grain development	Rainfed	29.62
		Mean			**17.77**
	Hunagund	Koujagnur	Grain development	Rainfed	37.03
		Ilkal	Grain development	Rainfed	14.81
		Pochapur	Grain development	Rainfed	48.14
		Chittargi	Grain development	Rainfed	40.73
		Mean			**35.18**
	Badami	Katageri	Grain development	Rainfed	40.73
		Kerkalmatti	Grain development	Rainfed	7.40
		Kerur	Grain development	Rainfed	33.33
		Mean			**27.15**
	District average				**26.70**

Table 1b. Mean survey data of districts and taluks

Sl. No	District	Taluk	Mean Percent Disease Index		
			Crop grown condition	Taluk	District
1	Bijapur	Bijapur	Rainfed	40.11	36.17
		Indi	Rainfed	31.10	
		Muddebihal	Rainfed	27.80	
		Basavana Bagewadi	Rainfed	42.96	
		Sindgi	Rainfed	38.88	
2	Bagalkot	Bagalkot	Rainfed	17.77	26.70
		Hunagund	Rainfed	35.18	
		Badami	Rainfed	27.15	

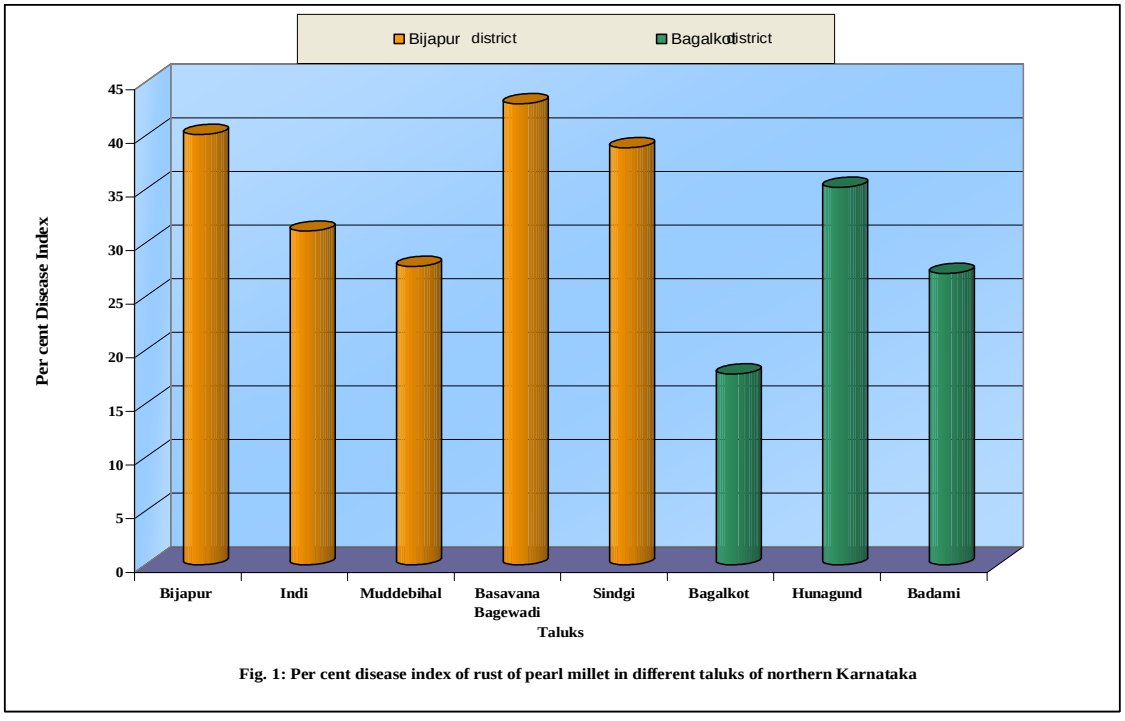


Fig. 1: Per cent disease index of rust of pearl millet in different taluks of northern Karnataka

Fig. 1: Per cent disease index of rust of pearl millet in different taluks of northern Karnataka

Rust infected leaves

Rust Severity at Shivanagi

Plate 1a. Severit of rust in farmers Field during survey.

Rust severity at Padaganur

Rust severity at Kerakalamatti

Plate 1b: Severity of rust in farmers field during survey.

The disease severity, ear head length, seed yield, ear head seed weight, and test weight were recorded as explained in “Material and Methods” and are presented in Table 3, 4, 5, 6, and 7, Fig. 2 and 3. Plate 3a and 3b

4.3.1 Per cent disease index (PDI)

The differences in the per cent disease index as influenced by different genotypes were found significant. The differences in (Table. 3) the per cent disease index in sprayed block were found significantly lower (9.41 %) compared to unsprayed block (41.54 %).

Among different genotypes, irrespective of the fungicidal spray significantly higher per cent disease index was recorded in the genotype MRB 2232 (32.33 %) compared to other genotypes. Next genotype which was recorded higher per cent disease index was ICTP 8203 (26.16%) and it was on par with all the remaining genotypes.

The differences in the PDI within the genotype, MRB 2232 recorded higher per cent disease index (12.83 %) and it was on par with Ajeet 27 (10.36 %), GHB 558 (10.24 %), ICTP 8203 (9.99 %) and Laxmi 234 (9.87 %) in sprayed block. Similarly the genotypes MRB 3332 was recorded significantly higher PDI (51.84 %) compared to other genotypes in unsprayed block (Fig. 2).

Among all genotypes, MRB 2232 was recorded significantly higher PDI (12.83 %) in sprayed block as well as in unsprayed block (51.84 %).

Among the genotypes, irrespective of the spray highest increase in per cent disease index was recorded in the genotype Mahalaxmi Tilak (530.43 %) followed by GK 1135 (458.30 %). Lowest increase in per cent disease index was recorded in Laxmi 234 (266.36 %).

4.3.2 Ear head length (cm)

The differences in the ear head length as influenced by different genotypes were found significant. The differences in the ear head length in sprayed block were found significantly higher (22.35 cm) compared to unsprayed block (19.80 cm). (Table.4)

Among the genotypes, irrespective of the fungicidal spray higher ear head length was recorded in the genotype GK 1135 (22.85 cm) and followed by Laxmi 234 (22.10 cm) and were on par with each other. Next genotype which was recorded higher ear head length was MLBH 308 (21.30 cm) and it was on par with Mahalaxmi Tilak (21.16 cm), 86 M 52 (21.12 cm), ICTP 8203 (21.11 cm) and GHB 558 (21.07 cm) and significantly least ear head length was recorded in the genotype ICMV 221 (19.05 cm) compared to other genotypes.

The differences in the ear head length within the genotype in sprayed block, higher ear head length was recorded in the genotype GK 1135 (23.26 cm) and it was on par with Laxmi 234 (22.77 cm), ICTP 8203 (22.68 cm), MLBH 308 (22.57 cm) and GHB 558 (22.55 cm). Next genotype has recorded higher ear head length was Mahalaxmi Tilak (22.17 cm) and it was on par with MRB 2232 (22.11 cm), ICMV 221 (21.86 cm), Ajeet 27 (21.82 cm) and 86 M 52 (21.74 cm).

Similarly within the genotype in unsprayed block, the higher ear head length was recorded in the genotype GK 1135 (22.44 cm) followed by Laxmi 234 (21.44 cm) and were on par with each other. Next genotype which has recorded higher ear head length was 86 M 52 (20.50 cm) and it was on par with Mahalaxmi Tilak (20.16 cm), MLBH 308 (20.02 cm), GHB 558 (19.58 cm) and ICTP 8203 (19.53 cm). Significantly least ear head length was recorded in the genotype ICMV 221 (16.24 cm) compare to other genotypes.

Among all genotypes, GK 1135 has recorded significantly higher ear head length (23.26 cm) in sprayed block as well as in unsprayed block (22.44 cm).

4.3.3 Ear head seed weight (g)

The differences in the ear head seed weight as influenced by different genotypes were found significant. The differences in the ear head seed weight in sprayed block were found significantly higher (16.67 g) compared to unsprayed block (15.73 g). (Table.5)

Among the genotypes, irrespective of the fungicidal spray significantly higher ear head seed weight was recorded in the genotype GK 1135 (17.50 g) as compared to other genotypes. Next genotype which recorded significantly higher ear head seed weight was Laxmi 234 (16.69 g) compare to other genotype. Significantly least ear head seed weight was recorded in the genotype ICTP 8203 (15.60 g).

Table 2. Effect of incubation period for maximum germination of uredospores of *P. substriata* var. *indica*

Incubation period (hrs)	Per cent uredospore germination
2	29.80 (33.10)*
4	37.84 (37.98)
6	48.50 (44.16)
8	56.60 (48.82)
10	76.65 (61.14)
12	68.33 (55.78)
14	70.37 (57.05)
Mean	**55.44 (48.15)**
S. Em±	3.05
C.D. at 1%	12.83

*** Arcsine transformed values.**

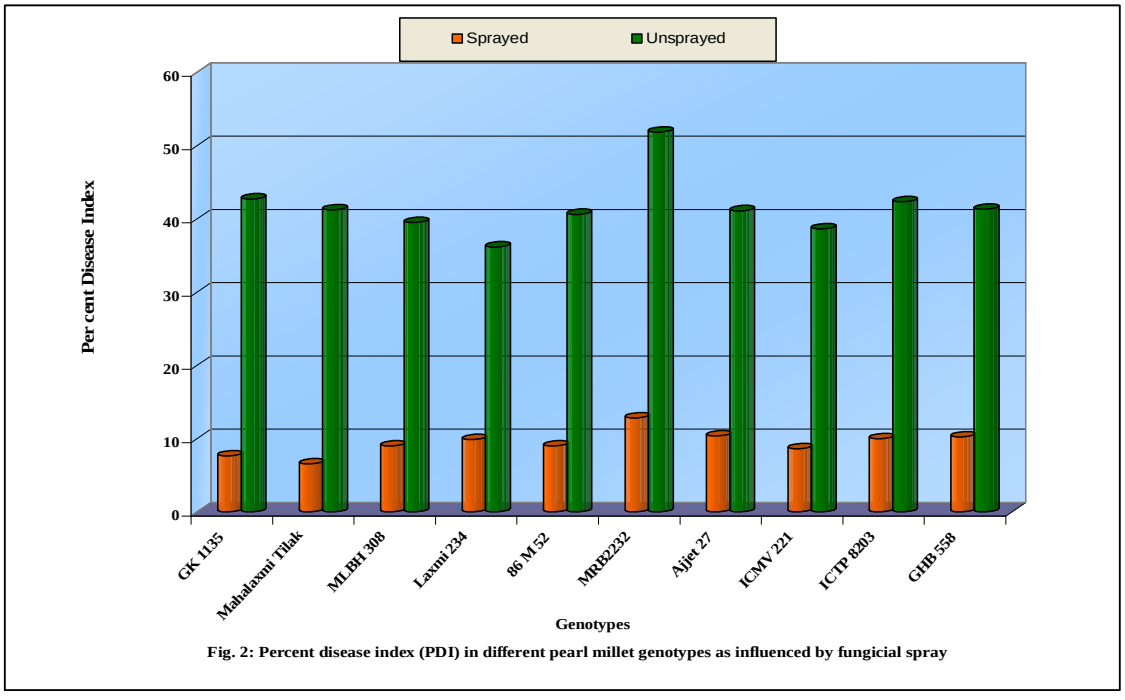
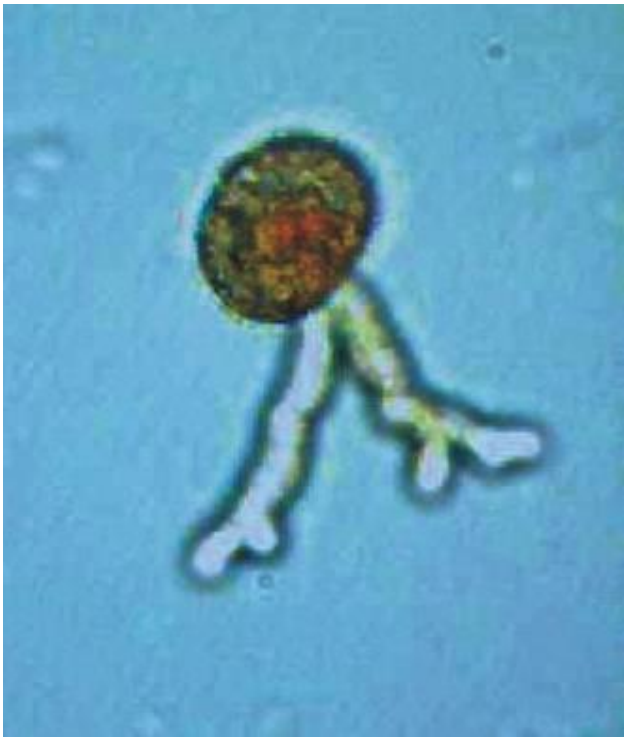


Fig. 2: Percent disease index (PDI) in different pearl millet genotypes as influenced by fungicial spray

Fig. 2: Percent disease index (PDI) in different pearl millet genotypes as influenced by fungicial spray

Uredospore



Uredospore germination

Plate 2: Uredospore and uredospore germination of *P. substriata* var. *indica*

Table 3. Percent disease index (PDI) in different pearl millet genotypes as influenced by fungicidal spray.

Genotypes	Sprayed	Unsprayed	Mean	Per cent increase over sprayed
GK 1135	7.65 (16.06)*	42.71 (40.83)	**25.17 (30.13)**	458.30
Mahalaxmi Tilak	6.54 (14.82)	41.23 (39.97)	**23.88 (29.27)**	530.43
MLBH 308	9.00 (17.47)	39.50 (38.96)	**24.25 (29.52)**	338.89
Laxmi 234	9.87 (18.32)	36.16 (36.98)	**23.01 (28.68)**	266.36
86 M 52	9.00 (17.47)	40.61 (39.61)	**24.81 (29.89)**	351.22
MRB 2232	12.83 (21.00)	51.84 (46.08)	**32.33 (34.67)**	304.05
Ajeet 27	10.36 (18.79)	41.10 (39.89)	**25.73 (30.50)**	296.72
ICMV 221	8.63 (17.09)	38.63 (38.45)	**23.63 (29.10)**	347.62
ICTP 8203	9.99 (18.43)	42.34 (40.61)	**26.16 (30.78)**	323.82
GHB 558	10.24 (18.67)	41.30 (40.01)	**25.77 (30.52)**	303.32
Mean	**9.41 (17.87)**	**41.54 (40.15)**	**25.47 (30.33)**	
For comparing mean	S.Em±	C.D. at 5%		
Fungicidal spray (F)	0.71	4.34		
Genotypes (G)	1.07	3.06		
Interaction (F×G)	1.51	4.66		
Interaction at the same or different level	0.41	1.03		

*** Arcsine transformed values.**

Table 4. Ear head length (cm) in different pearl millet genotypes as influenced by fungicidal spray

Genotypes	Sprayed	Unsprayed	Mean
GK 1135	23.26	22.44	**22.85**
Mahalaxmi Tilak	22.17	20.16	**21.16**
MLBH 308	22.57	20.02	**21.30**
Laxmi 234	22.77	21.44	**22.10**
86 M 52	21.74	20.50	**21.12**
MRB 2232	22.11	18.68	**20.40**
Ajeet 27	21.82	19.43	**20.63**
ICMV 221	21.86	16.24	**19.05**
ICTP 8203	22.68	19.53	**21.11**
GHB 558	22.55	19.58	**21.07**
Mean	**22.35**	**19.80**	**21.08**
For comparing mean	S.Em±	C.D. at 5 %	
Fungicidal spray (F)	0.25	1.55	
Genotypes (G)	0.37	1.07	
Interaction (F×G)	0.53	1.63	
Interaction at the same or different level	0.14	0.36	

Table 5. Ear head seed weight (g) in different pearl millet genotypes as influenced by fungicidal spray

Genotypes	Sprayed	Unsprayed	Mean
GK 1135	18.15	16.85	**17.50**
Mahalaxmi Tilak	16.66	15.63	**16.15**
MLBH 308	16.41	15.75	**16.08**
Laxmi 234	17.36	16.01	**16.69**
86 M 52	16.53	15.80	**16.17**
MRB 2232	16.54	15.66	**16.10**
Ajeet 27	16.20	15.63	**15.91**
ICMV 221	16.29	15.53	**15.91**
ICTP 8203	16.03	15.18	**15.60**
GHB 558	16.51	15.25	**15.88**
Mean	**16.67**	**15.73**	**16.20**
For comparing mean	S.Em ±	C.D. at 5 %	
Fungicidal spray (F)	0.007	0.04	
Genotypes (G)	0.02	0.07	
Interaction (F×G)	0.03	0.10	
Interaction at the same or different level	0.008	0.017	

The differences in the ear head seed weight within the genotype in sprayed block, significantly higher ear head seed weight was recorded in the genotype GK 1135 (18.15 g) as compared to other genotypes. Laxmi 234 (17.36 g) was the next genotype which has recorded significantly higher ear head seed weight as compared to other genotype. Significantly least ear head seed weight was recorded in the genotype ICTP 8203 (16.03 g) compare to other genotype.

Similarly within the genotype in unsprayed block, significantly higher ear head seed weight was recorded in the genotype GK 1135 (16.85 g). Laxmi 234 (16.01 g) was the next genotype which has recorded significantly higher ear head seed weight compare to other genotype. Significantly least ear head seed weight was recorded in the genotype ICTP 8203 (15.18 g) compare to other genotypes.

Among all genotypes, GK 1135 was recorded significantly higher ear head seed weight (18.15 g) in sprayed block as well as in unsprayed block (16.85 g).

4.3.4 Seed yield (q ha^{-1})

The differences in the seed yield as influenced by different genotypes were found significant. The differences in (Table.6) the seed yield in sprayed block were found significantly higher (33.48 q) compared to unsprayed block (25.75 q).

Among the genotypes, irrespective of the fungicidal spray significantly higher seed yield was recorded in the genotype GK 1135 (44.83 q) compared to other genotypes. Next genotype which was recorded significantly higher seed yield was Laxmi 234 (35.96 q) compared to other genotype. Significantly least seed yield was recorded in the genotype ICTP 8203 (23.51 q).

The differences in the seed yield within the genotype in sprayed block, significantly higher seed yield was recorded in the genotype GK 1135 (48.51 q) compared to other genotypes. Laxmi 234 (38.77 q) was the next genotype which has recorded significantly higher seed yield compared to other genotype. Significantly least seed yield was recorded in the genotype ICTP 8203 (27.25 q) compare to other genotype (fig. 3).

Similarly within the genotype in unsprayed block, significantly higher seed yield was recorded in the genotype GK 1135 (41.14 q) compared to other genotypes. Laxmi 234 (33.15 q) was the next genotype which has recorded significantly higher seed yield compared to other genotype. Significantly lowest seed yield of 19.76 q/ha was recorded in the genotype ICTP 8203 compare to other genotypes.

Among all genotypes, GK 1135 was recorded significantly higher seed yield (48.51 q) in sprayed block as well as in unsprayed block (141.14 q).

Among the genotypes, irrespective of the spray highest increase in seed yield was recorded in the genotype GHB 558 (48.81 %) followed by Mahalaxmi Tilak (29.85 %). Lowest increase in seed yield was recorded in Laxmi 234 (16.95 %).

4.3.5 1000 seed weight (g)

The differences in the 1000 seed weight as influenced by different genotypes were found significant. The differences in (Table.7) the 1000 seed weight in sprayed block were found significantly higher (12.13 g) compared to unsprayed block (10.92 g).Among the genotypes, irrespective of the fungicidal spray significantly higher 1000 seed weight was recorded in the genotype GK 1135 (12.81 g) compared to other genotypes.

Next genotype which has recorded significantly higher 1000 seed weight was Mahalaxmi Tilak (11.82 g) followed by MLBH 308 (11.62 g) and GHB 558 (11.63 g) and were on par with each other. Least 1000 seed weight was recorded in the genotype MRB 2232 (10.74 g) and it was on par with Ajeet 27 (10.77 g), ICTP 8203 (10.87 g) and ICMV 221 (10.96 g).

The differences in the 1000 seed weight within the genotype in sprayed block, significantly higher 1000 seed weight was recorded in the genotype GK 1135 (13.44 g) compare to other genotypes. Laxmi 234 (13.13 g) was the next genotype which has recorded significantly higher 1000 seed weight compared to other genotypes. The least 1000 seed weight was recorded in the genotype Ajeet 27 (11.16 g) and it was on par with MRB 2232 (11.30 g).Similarly within the genotype in unsprayed block, significantly higher 1000 seed weight was recorded in the genotype GK 1135 (12.18 g) compared to other genotypes. Laxmi 234 (11.91 g) was the next genotype which has recorded significantly higher 1000 seed weight compare to other genotypes.

Table 6. Seed yield (q ha^{-1}) in different pearl millet genotypes as influenced by fungicidal spray

Genotypes	Sprayed	Unsprayed	Mean	Per cent increase over unsprayed
GK 1135	48.51	41.14	**44.83**	**17.91**
Mahalaxmi Tilak	33.26	23.33	**28.29**	**42.56**
MLBH 308	31.11	24.35	**27.73**	**27.76**
Laxmi 234	38.77	33.15	**35.96**	**16.95**
86 M 52	32.48	24.96	**28.72**	**30.13**
MRB 2232	32.54	23.63	**28.08**	**37.70**
Ajeet 27	28.96	23.33	**26.14**	**24.13**
ICMV 221	29.88	22.29	**26.09**	**34.05**
ICTP 8203	27.25	19.76	**23.51**	**37.90**
GHB 558	32.07	21.55	**26.81**	**48.81**
Mean	**33.48**	**25.75**	**29.616**	
For comparing mean	S.Em±	C.D. at 5 %		
Fungicidal spray (F)	0.06	0.36		
Genotypes (G)	1.09	3.12		
Interaction (F×G)	1.54	4.74		
Interaction at the same or different level	0.38	0.77		

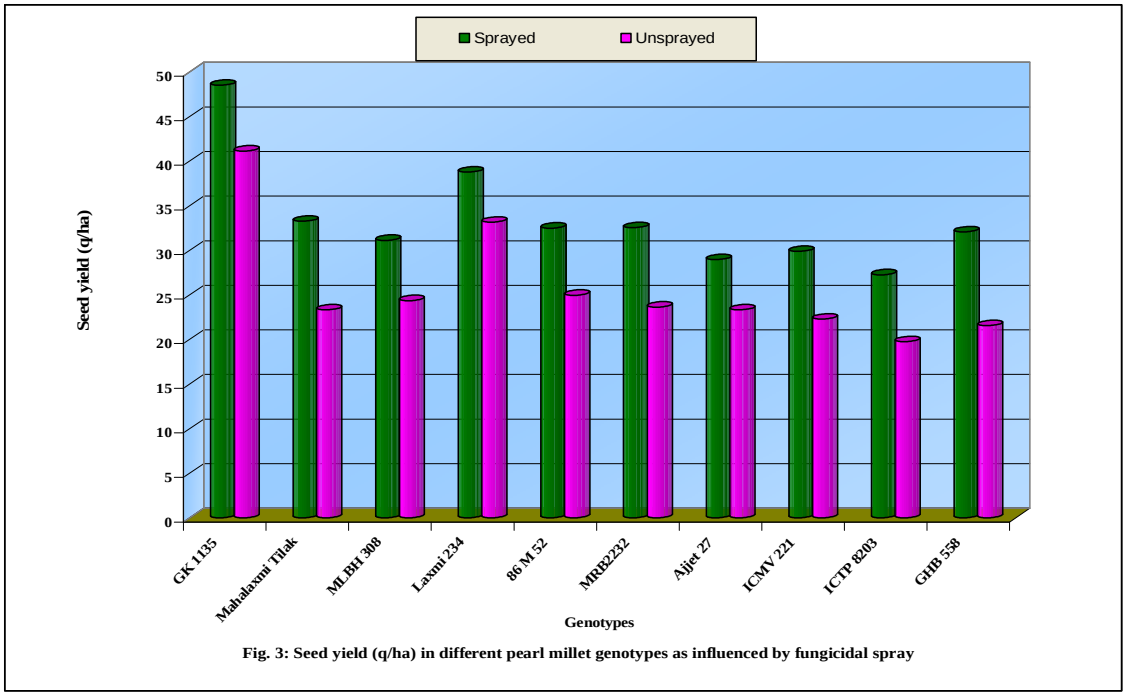


Fig. 3: Seed yield (q/ha) in different pearl millet genotypes as influenced by fungicidal spray

Plate 3a: Rust severity in different genotypes as influenced by fungicidal spray

Plate 3b: Rust severity in different genotypes as influenced by fungicidal spray

Table 7. 1000 seed weight (g) in different pearl millet genotypes as influenced by fungicidal spray

Genotypes	Sprayed	Unsprayed	Mean	Per cent increase over unsprayed
GK 1135	13.44	12.18	**12.81**	10.34
Mahalaxmi Tilak	12.65	10.98	**11.82**	15.21
MLBH 308	12.13	11.11	**11.62**	10.47
Laxmi 234	13.13	11.91	**12.52**	10.24
86 M 52	11.85	11.15	**11.50**	6.27
MRB 2232	11.30	10.18	**10.74**	11.00
Ajeet 27	11.16	10.38	**10.77**	7.51
ICMV 221	11.82	10.10	**10.96**	17.02
ICTP 8203	11.53	10.20	**10.87**	13.04
GHB 558	12.24	11.01	**11.63**	11.17
Mean	**12.13**	**10.92**	**11.52**	
For comparing mean	S.Em ±	C.D. at 5 %		
Fungicidal spray (F)	0.04	0.24		
Genotypes (G)	0.08	0.22		
Interaction (F×G)	0.11	0.33		
Interaction at the same or different level	0.03	0.06		

Least 1000 seed weight was recorded in the ICMV 221 (10.10 g) and it was on par with ICTP 8203 (10.20 g) and MRB 2232 (10.18 g).

Among all genotypes, GK 1135 has recorded significantly higher 1000 seed weight (13.44 g) in sprayed block as well as in unsprayed block (12.18 g).

Among the genotypes, irrespective of the spray highest increase in seed weight was recorded in the genotype ICMV 221 (17.02 %) followed by Mahalaxmi Tilak (15.21 %). Lowest increased in seed weight was recorded in Ajeet 27 (7.51 %).

4.4 Integrated management of pearl millet rust

4.4.1 *In vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against *Puccinia substriata* var.*indica*

4.4.1.1 Fungicides

In vitro evaluation of fungicides was conducted with respect to inhibition of uredospore germination of *P. substriata* var.*indica* at different concentrations of fungicides as explained in "Material and Methods", the data presented in Table 8 and Fig 4a and 4b.

The efficacy of six systemic and four non-systemic fungicides on inhibition of uredospore germination of *P. substriata* var.*indica* was carried out. Among systemic fungicides at 0.05 per cent concentration, maximum inhibition was noticed in hexaconazole (94.76 %) which was on par with propiconazole (94.59 %), benomyl (93.17 %) and triadimefon (92.23 %). Least inhibition of uredospore germination was noticed in difenconazole (87.71 %) followed by penconazole (88.89 %). At 0.075 per cent concentration, maximum inhibition noticed in hexaconazole (99.85 %) which was on par with all other tested fungicides except difenconazole (89.67 %). At 0.1 percent concentration, maximum inhibition noticed in hexaconazole (99.95 %) which was on par with all other tested fungicides except penconazole (96.19 %). Irrespective of fungicide concentration, hexaconazole (98.18 %) was found to be the best in inhibiting the spore germination and remain on par with propiconazole (97.44 %), triadimefon (96.76 %), benomyl (96.08 %) and penconazole (93.49 %).

Among non systemic fungicides at 0.1 per cent concentration, maximum inhibition noticed in chlorothalonil (88.62 %) which was on par with carbendazim + mancozeb (87.88 %) and propineb (86.79 %). Least inhibition of uredospore germination was noticed in mancozeb (86.53 %). At 0.2 per cent concentration, maximum inhibition was noticed in propineb (93.70 %) which was on par with all other tested fungicides except carbendazim + mancozeb (91.60 %). At 0.3 per cent concentration, maximum inhibition was noticed in mancozeb (96.64 %) which was on par with all other tested fungicides except chlorothalonil (95.63 %). Irrespective of fungicide concentration, chlorothalonil (92.46 %) was found to be the best in inhibiting the spore germination and remain on par with propineb (92.28 %), carbendazim + mancozeb (91.76 %) and mancozeb (91.70 %).

As the concentration of fungicides increased, the inhibition of spore germination was also increased.

4.4.1.2 Botanicals

In vitro evaluation of botanicals was carried out with respect to inhibition of uredospore germination of *P. substriata* var. *indica* at different concentrations as explained in "Material and Methods"; the data are presented in Table 9 and Fig 5.

Five test botanicals reduced the inhibition of uredospore germination of *P. substriata* var.*indica* at 0.25 %, 0.5 %, 0.75 % and 1.00 % concentration. At 0.25 % per cent concentration, maximum inhibition was noticed in neem oil (81.74 %) followed by soldier (79.90 %) and were on par with each other. Next best was sainik (76.31 %) and it was on par with neem mark which has recorded 74.27 % inhibition. Significantly least inhibition was noticed in discheck (67.97 %). At 0.5 per cent concentration, maximum inhibition was noticed in neem oil (86.15 %) followed by soldier (84.36 %) and sainik (82.89 %) and were on par with each other. Least inhibition was noticed in neem mark (79.95 %) and it is on par with discheck (73.76 %). At 0.75 per cent concentration, maximum inhibition was noticed in neem oil (91.65 %) followed by soldier (90.71 %), sainik (89.89 %) and neem mark (87.94 %) and were on par with each other. Least inhibition was noticed in discheck (78.19 %). At 1 per cent concentration, maximum inhibition was noticed in neem oil (95.80 %) and it was on par with soldier (93.17 %). Least inhibition was noticed in neem mark (91.20 %) and it was on par with discheck (89.55 %), sainik (92.84 %) and soldier (93.17 %).

Table 8. *In vitro* evaluation of different systemic and non systemic fungicides on uredospore germination of *P. substriata* var. *indica*

Sl. No	Fungicides	Per cent inhibition of uredospore germination at			
	Systemic fungicides	**0.05 %**	**0.075 %**	**0.1 %**	**Mean**
1	**Propiconazole**	94.59 (76.62)*	98.72 (83.59)	99.02 (84.37)	**97.44 (80.83)**
2	**Hexaconazole**	94.76 (76.83)	99.85 (88.23)	99.95 (89.31)	**98.18 (82.29)**
3	**Triadimefon**	92.23 (73.90)	98.57 (83.22)	99.49 (86.07)	**96.76 (79.67)**
4	**Penconazole**	88.89 (70.66)	95.39 (77.97)	96.19 (79.28)	**93.49 (75.26)**
5	**Difenconazole**	87.71 (69.82)	89.67 (71.47)	96.92 (80.48)	**91.43 (73.0)**
6	**Benomyl**	93.17 (74.91)	95.71 (78.14)	99.37 (85.50)	**96.08 (78.62)**
Mean		**91.89 (73.49)**	**96.31 (78.97)**	**98.49 (82.98)**	
			Fungicides (F)	**Concentrations (C)**	**F x C**
S. Em±			0.75	0.49	1.29
C.D. at 1%			2.85	1.87	4.93

Sl. No	Non systemic fungicides	Per cent inhibition of uredospore germination at			Mean
		0.1 %	**0.2 %**	**0.3 %**	
1	**Mancozeb**	86.53 (68.66)*	91.93 (74.15)	96.64 (80.63)	**91.70 (73.29)**
2	**Chlorothalonil**	88.62 (70.63)	93.15 (77.01)	95.63 (78.25)	**92.46 (74.10)**
3	**Carbendazim + Mancozeb**	87.88 (69.23)	91.60 (74.22)	95.80 (78.27)	**91.76 (73.36)**
4	**Propineb**	86.79 (68.86)	93.70 (75.58)	96.37 (79.63)	**92.28 (73.91)**
Mean		**87.45 (69.29)**	**92.59 (74.24)**	**96.11 (78.66)**	
			Fungicides (F)	**Concentrations (C)**	**F x C**
S. Em±			1.28	0.99	2.21
C.D. at 1%			4.86	3.77	8.42

*** Arcsine transformed values.**

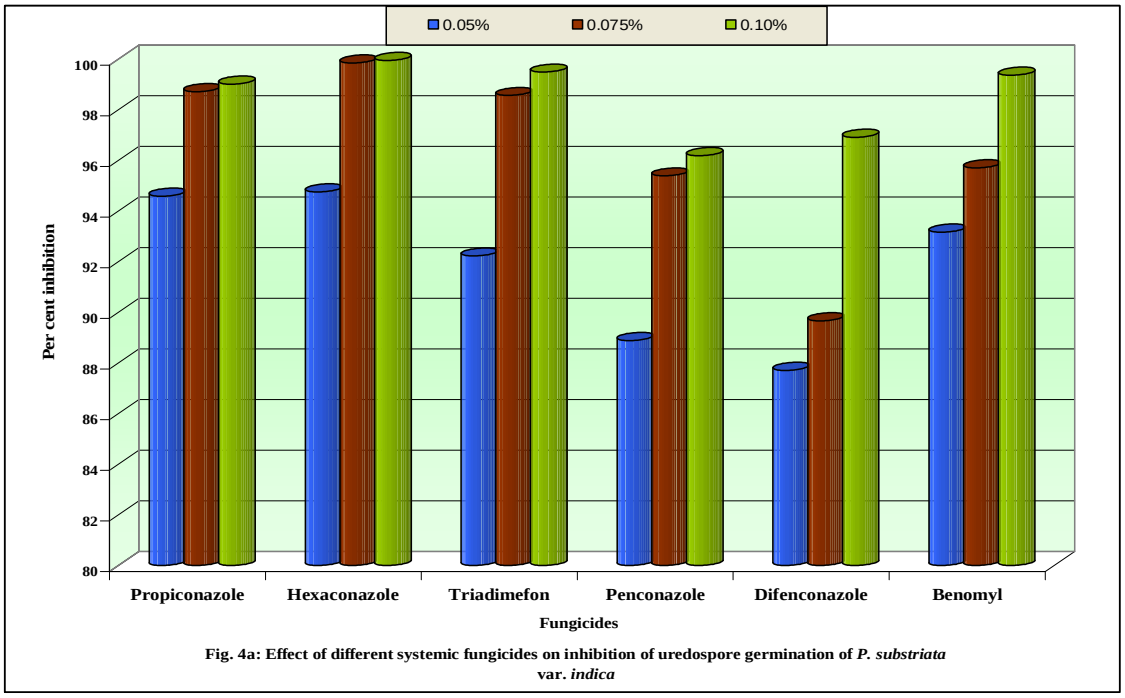


Fig. 4a: Effect of different systemic fungicides on inhibition of uredospore germination of *P. substriata* var. *indica*

Fig. 4a: Effect of different systemic fungicides on inhibition of uredospore germination of P. substriata var. indica

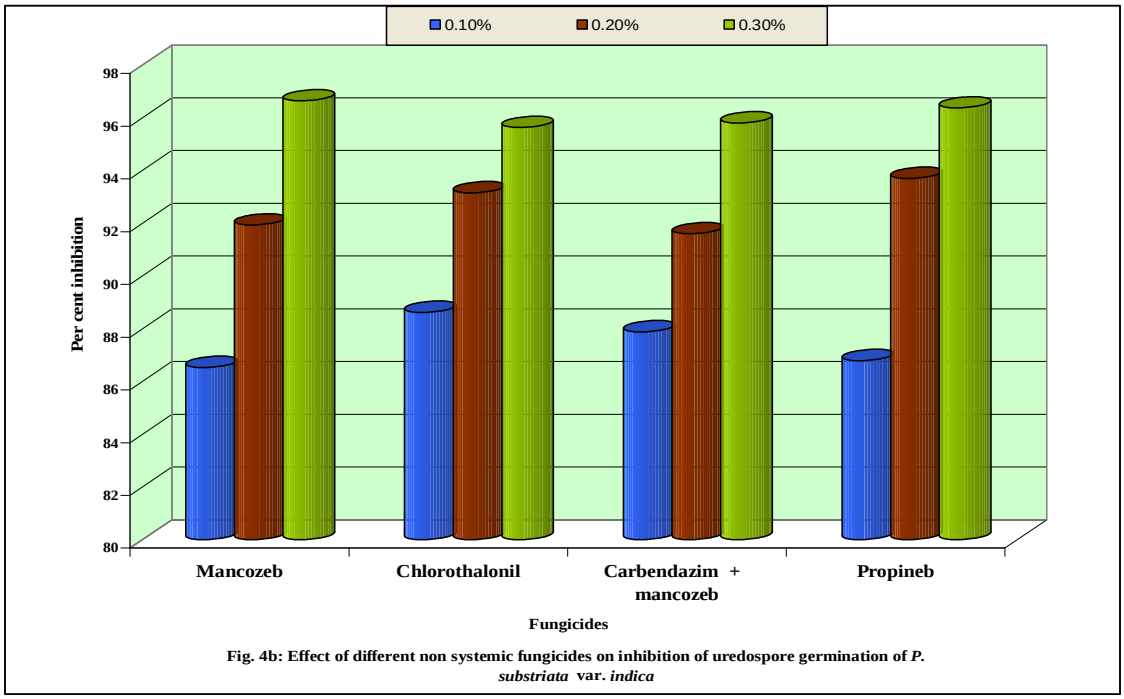


Fig. 4b: Effect of different non systemic fungicides on inhibition of uredospore germination of *P. substriata* var. *indica*

Fig. 4b: Effect of different non systemic fungicides on inhibition of uredospore germination of P. substriata var. indica

Table 9. *In vitro* evaluation of commercially available botanicals on uredospore germination of *P. substriata* var. *indica*

Sl.No	Botanicals	Per cent inhibition of uredospore germination at				Mean
		0.25 %	0.5 %	0.75 %	1.00 %	
1	Sainik	76.31 (60.91)*	82.89 (65.72)	89.89 (71.62)	92.84 (74.98)	**85.48 (67.64)**
2	Soldier	79.90 (63.44)	84.36 (67.08)	90.71 (72.54)	93.17 (75.63)	**87.03 (68.93)**
3	Dischеck	67.97 (55.56)	73.76 (59.23)	78.19 (62.21)	89.55 (75.31)	**77.36 (61.62)**
4	Neem mark	74.27 (59.57)	79.95 (63.49)	87.94 (70.61)	91.20 (73.08)	**83.34 (65.94)**
5	Neem oil	81.74 (65.61)	86.15 (68.52)	91.65 (73.34)	95.80 (79.48)	**88.83 (70.51)**
Mean		**76.03 (60.72)**	**81.42 (64.50)**	**87.67 (69.48)**	**92.51 (74.15)**	
				Botanicals (B)	**Concentrations (C)**	**B x C**
S. Em±				1.07	0.87	2.14
C.D. at 1%				4.06	3.32	8.12

*** Arcsine transformed values.**

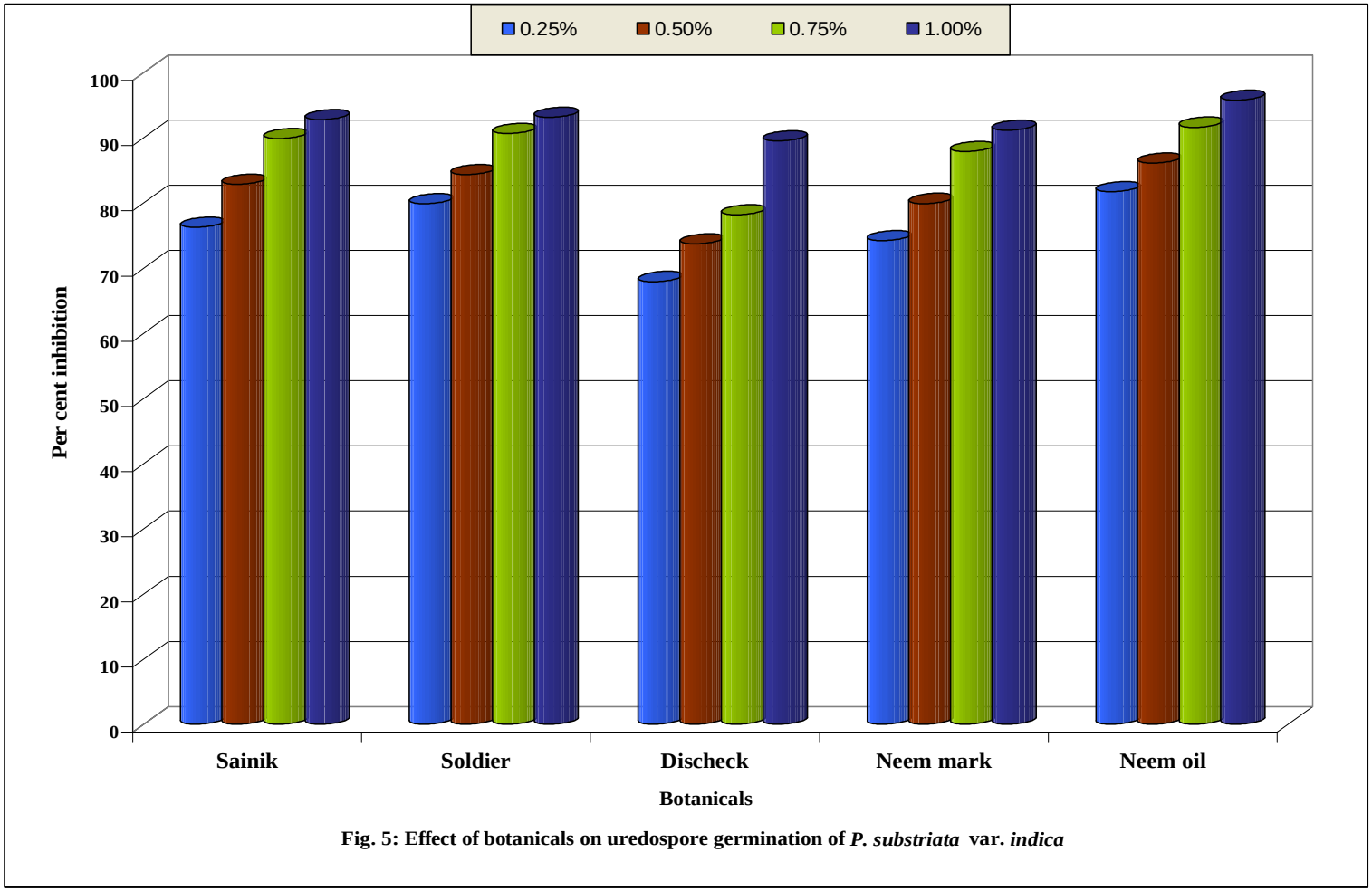


Fig. 5: Effect of botanicals on uredospore germination of *P. substriata* var. *indica*

Fig. 5: Effect of botanicals on uredospore germination of P. substriata var. indica

Maximum inhibition of uredospore germination irrespective of the botanical concentration was noticed with neem oil (88.83%) followed by soldier (87.03 %) and sainik (85.48 %) whereas least inhibition of uredospore germination was observed in neem mark (83.34 %) and discheck (77.36 %).

4.4.1.3 ITK'^{S}

In the present experiment, five ITKS were evaluated and results obtained are presented in Table 10 and Fig. 6.

The effect of ITK'^{S} on uredospore germination was significant over control. Five test ITK'^{S} reduced the inhibition of uredospore germination of *P. substriata* var.*indica* at 5 %, 10 %, 20 % and 30 % concentrations. At 5 per cent concentration, maximum inhibition was noticed in cow urine (74.13%) followed by cow milk (72.80 %) and were on par with each other. Next best was panchagavya (69.45 %) and it was on par with butter milk (66.07 %). Significantly least inhibition was noticed in vermiwash (44.78 %). At 10 per cent concentration, similar trends were observed. Maximum inhibition was noticed in cow urine (79.16 %) followed by cow milk (76.61 %) and were on par with each other. Next best was panchagavya (73.91 %) and it was on par with butter milk (72.24 %). Significantly least inhibition was noticed in vermiwash (62.83 %). At 20 per cent concentration, significantly highest inhibition was noticed in cow urine (86.25%) compare to other ITK'^{S}. Next best was cow milk (82.90 %) and it was on par with panchagavya (76.17 %) and butter milk (74.78 %). Significantly least inhibition was noticed in vermiwash (71.28 %).

At 30 per cent concentration, cow urine had shown maximum inhibition of uredospore germination of 89.03 per cent followed by cow milk (87.39 %) and were on par with each other. Panchagavya was found next best (83.84 %) and it was significantly superior over other treatments.

Irrespective of ITK concentration, cow urine (82.14 %) was found to be the best in inhibiting spore germination and 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 on par with each other. Significantly least inhibition was noticed in vermiwash (65.47 %).

4.4.2 Effect of spray schedule on disease severity

A field experiment was conducted in randomized block design with three replications during *kharif* 2012 at Agricultural Research Station, Almel on integrated management of pearl millet rust using susceptible genotype MRB 2232. Based on *in vitro* evalution results, effective and economically viable fungicide (hexaconazole), commercially available botanical (neem oil) and ITK (cow urine) were included in the spray schedule as mentioned in the "Material and Methods" and the results obtained are presented in Table 11and Fig. 7.

The data presented in Table 11 indicated that significant differences among the spray schedule was evident in respect of per cent disease index.

Among the seven spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded the least per cent disease index of 15.30 which was significantly superior to other spray schedules combinations. Next best schedule was hexaconazole @ 0.1 % - neem oil @ 1.0 % and it was significantly superior to other spray schedule combinations. The spray schedules combinations neem oil @ 1.0 % - hexaconazole @ 0.1 % (T_5), neem oil @ 1.0 % - neem oil @ 1.0 % (T_2) and hexaconazole @ 0.1 % - cow urine @ 10 % (T_6) were recorded 22.50, 23.56 and 23.68 per cent disease index respectively. However, all these treatments were on par with each other. The control treatment T_8 recorded significantly highest per cent disease index of 46.83.

Highest per cent decrease in disease severity over unsprayed control was recorded in the spraying schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (67.33 %) followed by hexaconazole @ 0.1 % - neem oil @ 1.0 % (57.29%) and neem oil @ 1.0 % - hexaconazole @ 0.1 % (51.95). Least per cent decrease in disease severity over unsprayed control was recorded in cow urine @ 10 % - hexaconazole @ 0.1 % (45.50 %).

4.4.2.1 Effect of spray schedule on seed yield and 1000 seed weight.

The seed yield and 1000 seed weight were recorded after harvest (Table 11). The spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest seed yield of 30.50 q ha^{-1} and it was statistically on par with all the other spray schedule treatments, T_2 (27.50 g ha^{-1}), T_4 (26.15 q ha^{-1}), T_6 (24.60 q ha^{-1}), T_5 (24.00 q ha^{-1}), T_7 (23.95 q ha^{-1}) and T_3 (22.90 q ha^{-1}) except unsprayed control which was recorded 20.60 q ha^{-1}.

Table 10. *In vitro* evaluation of ITK's on uredospore germination of *P. substriata* var.*indica*

Sl. No	ITK's	Per cent inhibition of uredospore germination at				Mean
		5 %	10 %	20 %	30 %	
1.	Cow urine	74.13 (59.48)*	79.16 (62.91)	86.25 (68.33)	89.03 (70.70)	**82.14 (65.03)**
2.	Cow milk	72.80 (58.60)	76.61 (61.12)	82.90 (65.61)	87.39 (69.24)	**79.92 (63.41)**
3.	Butter milk	66.07 (54.43)	72.24 (58.24)	74.78 (59.89)	80.41 (63.77)	**73.37 (58.96)**
4.	Vermiwash	44.78 (43.74)	62.83 (52.57)	71.28 (57.63)	80.02 (63.53)	**65.47 (54.04)**
5.	Panchagavya	69.45 (56.48)	73.91 (59.39)	76.17 (60.83)	83.84 (66.35)	**75.84 (60.59)**
	Mean	**66.04 (54.38)**	**72.95 (58.69)**	**78.27 (62.25)**	**84.13 (66.56)**	
				ITK's (I)	**Concentrations (C)**	**I x C**
			S.Em ±	0.56	0.46	1.13
			C.D. at 1%	2.14	1.74	4.27

*** Arcsine transformed values.**

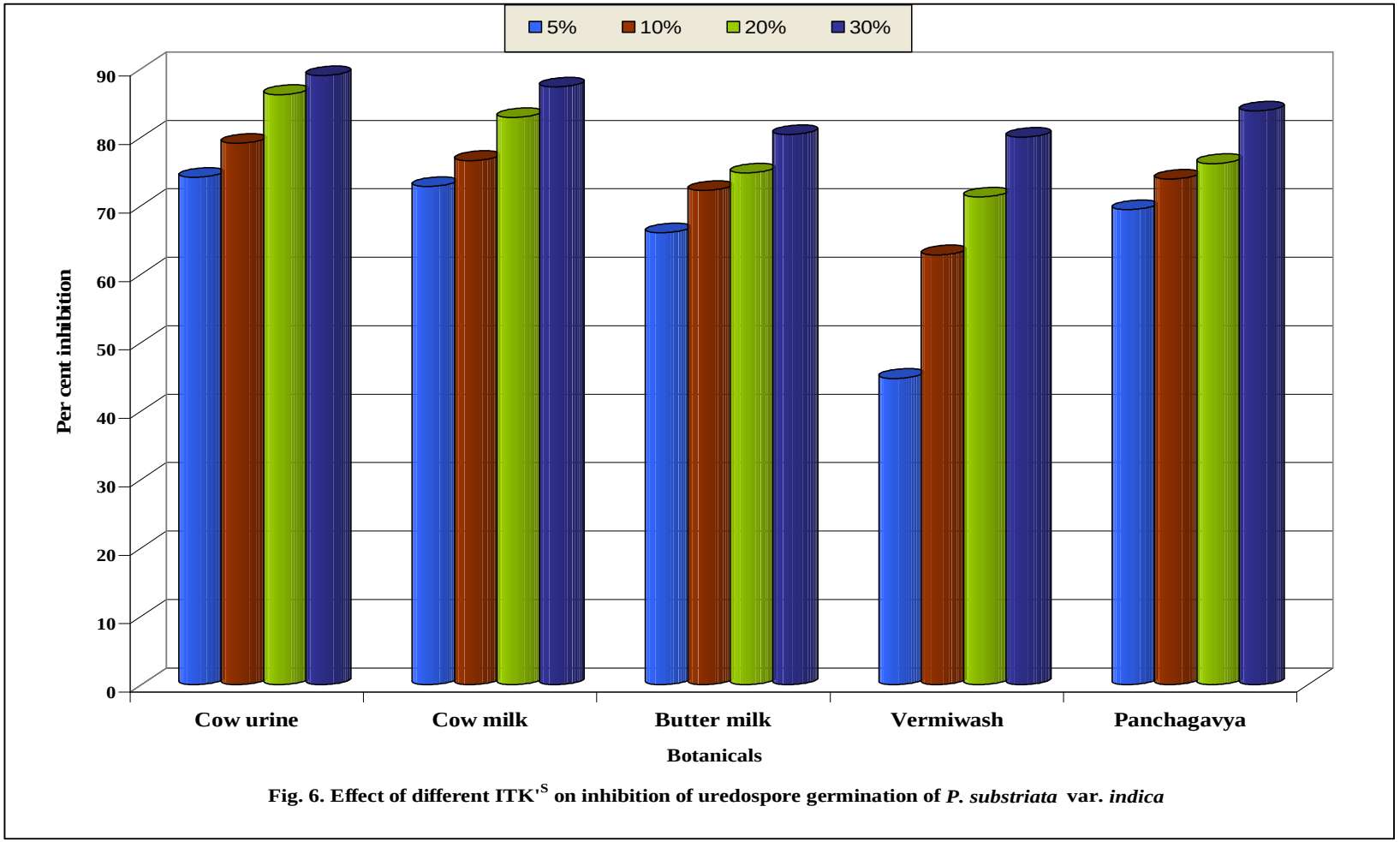


Fig. 6. Effect of different ITK's on inhibition of uredospore germination of *P. substriata* var. *indica*

Fig. 6. Effect of different ITK'S on inhibition of uredospore germination of P. substriata var. indica

Table 11. Evalution of spray schedule involving fungicide, commercially available botanical and ITK on pearl millet rust during *kharif* 2012.

Tr. No	Spray schedule		Percent disease index	Per cent decrease in severity over control	Seed yield (q/ha)	Per cent increase in seed yield over control	1000 seed wt (g)	Per cent increase in 1000 seed wt over control	B : C ratio
	I Spray	II Spray							
T_1	Hexaconazole @ 0.1%	Hexaconazole @ 0.1%	15.30 (23.04)*	67.33	30.50	48.05	10.51	23.91	2.40
T_2	Neem oil @ 1.0%	Neem oil @ 1.0%	23.56 (29.05)	49.69	27.50	33.49	10.04	18.39	1.76
T_3	Cow urine @ 10%	Cow urine @ 10%	24.44 (29.64)	47.81	22.90	11.16	9.04	6.60	1.48
T_4	Hexaconazole @ 0.1%	Neem oil @ 1.0%	20.00 (26.58)	57.29	26.15	26.94	9.90	16.74	1.75
T_5	Neem oil @ 1.0%	Hexaconazole @ 0.1%	22.50 (28.33)	51.95	24.00	16.50	9.18	8.25	1.55
T_6	Hexaconazole @ 0.1%	Cow urine @ 10%	23.68 (29.13)	49.43	24.60	19.41	9.43	11.20	1.70
T_7	Cow urine @ 10%	Hexaconazole @ 0.1%	25.52 (30.36)	45.50	23.95	16.26	9.22	8.72	1.63
T_8	Unsprayed control		46.83 (43.20)	-	20.60	-	8.48	-	1.54
		S. Em±	0.34		2.52		0.18		
		C.D. at 5 %	1.03		7.67		0.54		

*** Arcsine transformed values.**

Cost of grain @ Rs. 1300 /q, Cost of fungicides/botanicals/ITK's in Rs. /l : hexaconazole (550), neem oil (150) and cow urine (8).

Labour charges for two sprayes per hectare:Rs. 800

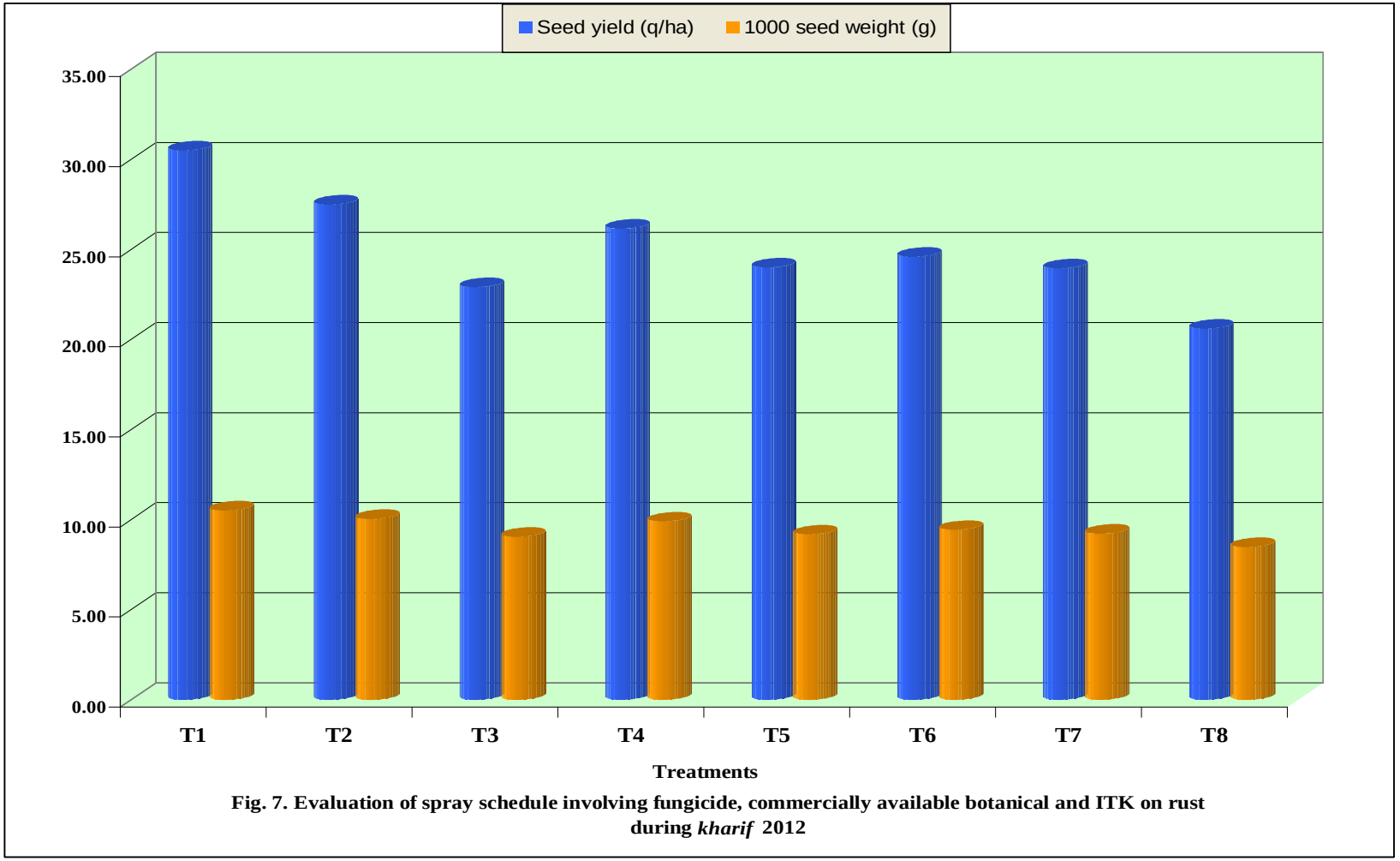


Fig. 7. Evaluation of spray schedule involving fungicide, commercially available botanical and ITK on rust during *kharif* 2012

Fig. 7. Evaluation of spray schedule involving fungicide, commercially available botanical and ITK on rust during kharif 2012

Highest per cent increase in seed yield over unsprayed control was recorded in the spray schedule hexaconzole @ 0.1 % - hexaconazole @ 0.1 % (48.05 %) followed by neem oil @ 1 % - neem oil @ 1 % (27.50 %) and hexaconazole @ 0.1 % - neem oil 1 % (26.15 %). Least increase in seed yield over unsprayed control was observed in ' spray schedule.

Similar trend were observed in case of 1000 seed weight. Hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest seed weight of 10.51 g and it was statistically on par with neem oil @ 1.0 % - neem oil 1.0% (10.04 g). Next best schedule which recorded higher seed weight was hexaconzole @ 0.1 % - neem oil @ 1.0 % (9.90 g) and it was on par with the spraying schedule hexaconzole @ 0.1 % - cow urine @ 1.0 % (9.43 g). Unsprayed control recorded significantly lowest seed weight of 8.48 g.

Per cent increase in thousand seed weight over unsprayed control was recorded in the spray schedule hexaconzole @ 0.1 % - hexaconzole @ 0.1 % (23.91 %) followed by neem oil @ 1.0 % - neem oil @ 1.0 % (18.39 %) and hexaconzole @ 0.1 % - neem oil @ 1.0 % (16.74 %). Least increase in 1000 seed weight over control was recorded in the spray schedule of Cow urine @ 10 % - Cow urine @ 10 % (6.60 %).

4.4.2.2 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 % - hexaconzole @ 0.1 % (1:2.4) followed by neem oil @ 1.0 % - neem oil 1.0 % (1:1.76). Most of the remaining spray schedules treatments, T_4, T_6, T_5, and T_3 recorded next highest B: C ratio of 1: 1.75, 1:1.70, 1: 1.55 and 1: 1.48, respectively.

4.4.3 Screening of pearl millet genotypes to rust

Forty two pearl millet genotypes were screened during *kharif* 2012 against *P. substriata* var.*indica* under artificial epiphytotic condition in the field to identify the resistant sources as described in “Material and Methods” and results are presented in Table 12a and 12b & Plate 4a and 4b. The results from the table revealed that, out of 42 genotypes screened, none of them were found immune or highly resistant. Four genotypes *viz.,* EBT10-37, EBLT10-3, LPRT10-11 and EMRT10-17 recorded resistant. Eighteen genotypes each as moderately resistant (LSBLT10-1, LSBLT10-24, LPRT10-5, LSBLT10-11, SGRT10-7, EBLT10-32, LSBLT10-25, SGRT10-12, EBLT10-56, SGRT10-5, DPRT10-4, CPBLT10-13, CPBLT10-9, ICMA 94555 × J2290, EMRT10 16, DPRT10-13, CPBLT10-14 and R Line of GHB 558) and as susceptible (LPRT109, DPRT10-10, SGRT10-15, EBLT10-44, LPRT10-13, LPRT10-22, EMRT1O-30, EBLT10-25, LPRT10-26, SGRT10-17, LPRT10-14, EMRT10-12, CPBLT10-2, B Line of GHB 558, LSBLT10-26, EMRT10-33, LSBLT10-12 and CPBLT10-21) and remaining two genotypes *viz.,* LSBLT10-27 and MRB 2232 (Table 12b) showed highly susceptible reaction.

Table12a. Screening of pearl millet genotypes against rust disease during *kharif* 2012.

Sl. No	Pedigree	Per cent disease index (PDI)	Sl. No	Pedigree	Per cent disease index (PDI)
1.	LPRT10-9	27.00	22.	SGRT10-12	15.00
2.	LSBLT10-1	18.00	23.	EBLT10-56	13.00
3.	LSBLT10-24	21.00	24.	SGRT10-5	24.00
4.	DPRT10-10	44.00	25.	CPBLT10-2	28.00
5.	LPRT10-5	19.00	26.	B Line of GHB 558	45.00
6.	SGRT10-15	50.00	27.	LSBLT10-26	27.00
7.	LSBLT10-11	22.96	28.	LPRT10-11	10.00
8.	EBLT10-44	41.00	29.	DPRT10-4	17.00
9.	LPRT10-13	40.00	30.	CPBLT10-13	19.00
10.	LPRT10-22	44.00	31.	EMRT10-33	29.00
11.	EMRT1O-30	38.00	32.	CPBLT10-9	25.00
12.	EBLT10-25	44.00	33.	LSBLT10-12	9.00
13.	LPRT10-26	39.00	34.	ICMA 94555 × J2290	24.00
14.	LSBLT10-27	64.00	35.	EMRT10-16	25.00
15.	SGRT10-7	20.00	36.	EMRT10-17	7.00
16.	EBLT10-32	22.22	37.	EBLT10-3	34.00
17.	EBT10-37	6.00	38.	CPBLT10-21	29.00
18.	LSBLT10-25	14.00	39.	DPRT10-13	21.00
19.	SGRT10-17	39.00	40.	CPBLT10-14	25.00
20.	LPRT10-14	36.00	41	R Line of GHB 558	14.00
21.	EMRT10-12	33.00	42.	Private hybrid	59.00

Table 12b. Reaction of pearl millet genotypes against *P. substriata* var. *indica*

Sl. No	Disease grade	Disease reaction	Genotypes	No. of genotypes
1	0	Immune	----------	Nil
2	1	Highly resistant	----------	Nil
3	3	Resistant	EBT10-37, EBLT10-3, LPRT10-11and EMRT10-17	4
4	5	Moderately resistant	LSBLT10-1, LSBLT10-24, LPRT10-5, LSBLT10-11, SGRT10-7, EBLT10-32, LSBLT10-25, SGRT10-12, EBLT10-56, SGRT10-5, DPRT10-4, CPBLT10-13, CPBLT10-9, ICMA 94555 × J2290, EMRT10-16, DPRT10-13, CPBLT10-14 and R Line of GHB 558	18
5	7	Susceptible	LPRT10-9, DPRT10-10, SGRT10-15, EBLT10-44, LPRT10-13, LPRT10-22, EMRT1O-30, EBLT10-25, LPRT10-26, SGRT10-17, LPRT10-14, EMRT10-12, CPBLT10-2, B Line of GHB 558, LSBLT10-26, EMRT10-33, LSBLT10-12 and CPBLT10-21	18
6	9	Highly susceptible	LSBLT10-27 and MRB 2232	2

Susceptible genotype RLT 13 (EMRT 10 – 12)

Highly susceptible genotype BLT 7 (LsblT10 – 27)

Resistant genotype BLT 8 (EBLT10 - 3)

Moderately resistant genotype BLT 15 (CPBLT10 – 10)

Plate 4a and 4b: Reaction of pearl millet genotypes to rust

DISCUSSION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most important drought and heat tolerant crop. It occupies fourth place in cereals and second place among coarse cereals. In India, it occupies an area of 9.61m.ha.with production of 10.37mt. (Anon, 2011). Among the important pearl millet growing states in the country, Karnataka ranks seventh, occupying an area of 0.31m.ha.with an annual production of 0.33mt. Several factors are attributed to limit the yield of pearl millet and the diseases play a major role. Rust caused by the fungus *Puccinia substriata* var. *indica* is one of the major disease affecting both forage and grain production in pearl millet. Rust has been observed throughout India. In northern India, the disease does not frequently occur until flowering time in September when temperatures are somewhat moderate. In other regions of the country, rust may attack even at seedling stage, causing substantial reduction in yield. The disease is of major concern in peninsular India where pearl millet is planted during the post rainy season (*rabi*) and rust infection and disease development is favoured by lower temperatures during this season. However, pearl millet rust has also been reported in central and peninsular India in the summer season (March–May) crop where seed production is carried out. All growth stages of the plant are susceptible to rust attack, and under favourable environment, plants can wither before flowering due to severe rust infection (Ramakrishnan and Sundaram 1956). Rust infection of pearl millet forage has been reported to cause up to 51 % reduction in digestible dry matter yield (Monson *et al*., 1986).

Among the foliar diseases rust caused by *P. substriata* var. *indica* is a potential destructive disease in recent years causing severe yield loss.

In spite of its destructive nature not much work with respect to different aspects has been carried out. Hence, the present study was undertaken considering different aspects like survey of the disease to know the disease severity in different districts of northern Karnataka, studies on loss assessment aspects of the disease, identification of resistant sources and *in vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against *P. substriata* var. *indica* have been attempted.

Integrated management of the disease involving economically viable and effective fungicides, commercially available botanicals and indigenous technology knowledge using highly susceptible genotype were carried out at ARS, Almel. And results of the above investigations are discussed here under.

5.1 Survey

Survey on the severity of rust of pearl millet reveals the magnitude of the problem on hand and serves as precursor for evolving management strategies. Sudarshan Rao (1975) stated that survey and surveillance form the basis for any successful plant protection that depends on early detection of the diseases followed by timely adaption of control measures. Hence in the present investigation, roving survey was undertaken in major pearl millet growing areas of northern Karnataka. The roving survey on rust of pearl millet was carried out in two districts of northern Karnataka *viz*., Bijapur and Bagalkot during September-October 2012. The overall severity of the disease generally varied from taluk to taluk. Such variations in the disease severity have also been observed by earlier workers (Rashid, 1991; Rashid and Platford, 1991).

Maximum disease severity was recorded in Bijapur (36.17%) and Bagalkot (26.70%) districts where pearl millet crop was grown under rainfed condition. When individual taluk were compared, Bijapur (40.11%), Indi (31.10%), Muddebihal (27.80%), Sindgi (38.88%) and Basavana Bagewadi (42.96%) recorded highest severity during September-October 2012. This may be due to susceptibility of the cultivar and favorable environmental condition like temperature and rainfall experienced in Bijapur taluk during the period under study. Similar observations were made by Trivedia and Pandya (2007) and opined that, the range of 0.0 to 15.84percent of rust was recorded in three districts. The mean severity of rust in Bhind, Morena and Gwalior was 6.93, 2.36 and 1.56 per cent, respectively.

5.2 Estimation of loss due to rust

In the present investigation the differences in pearl millet yield differed significantly with sprayed block and it recorded higher pearl millet yield (33.48 q/ha) compared to unsprayed block (25.75q/ha) and higher to an extent of 30.01 per cent .(Table 6). This improvement may be due to spraying of hexaconazole @ 0.1% in sprayed block. This technique also resulted in increase in yield attributing characters viz; ear head length, ear head seed weight and 1000 seed weight.

These findings are also in accordance with Sokhi *et al.* (1978) and they appear to be the first to report that a fungicide, Dithane M-45, when applied to prevent rust development increased yield components (including number of tillers bearing panicles) over the untreated check.

Singh and Sokhi (1983) reported that rust reduced the average number of panicles per plant, grain yield per plant and 1000 grain weight in both slow rusting and fast rusting cultivars. The reductions were more in fast rusting cultivars than in slow rusting ones.

Kim and Brewbaker (1976) tried eight agronomic trials on maize in Hawaii for estimation of crop loss. They reported that the average reductions caused by rust were 35 per cent for grain yield, 27 per cent for fresh plant weight, 11 per cent for ear length, 10 per cent for kernel weight and ear diameter and less than 5 per cent for plant and ear height and days to silk.

5.3 *In vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against *P. substriata* var.*indica*

5.3.1 *In vitro* evaluation of fungicides

Different fungal pathogens need different incubation period for the maximum spore germination. In the present studies, the germination of uredospore started two hours after incubation and attained the maximum 10 hours after incubation. Therefore, the incubation period of 10 hours was employed for further *in vitro* studies.

In vitro evaluation of newly released fungicides is very much necessary before they are planned to be used under field experiments. In the present study, *In vitro* evaluation of systemic fungicides at 0.05 per cent concentration, maximum inhibition was noticed in hexaconazole (94.76 %) which was on par with propiconazole (94.59 %), benomyl (93.17 %) and triadimefon (92.23 %). Least inhibition of uredospore germination was noticed in difenconazole (87.71 %) followed by penconazole (87.71 %). At 0.1 percent concentration maximum inhibition noticed in hexaconazole (99.95 %) which was on par with all other tested fungicides except penconazole (96.19 %). Four non-systemic fungicides at 0.1 per cent concentration, maximum inhibition noticed in chlorothalonil (88.62 %) which was on par with carbendazim + mancozeb (87.88 %) and propineb (86.79 %). Least inhibition of uredospore germination was noticed in mancozeb (86.53 %). At 0.3 per cent concentration maximum inhibition was noticed in mancozeb (96.64 %) which was on par with all other tested fungicides except chlorothalonil (95.63 %). Similar observations were made by Utpal Dey e*t al.* (2011) to confirm that tebuconazole (0.1 %) found most effective against uredospore germination of *Puccinia sorghi* Schw. Hexaconazole (0.1 %), difenconazole (0.1 %) and mancozeb (0.025 %) were found equally effective and recorded lower percentage germination of uredospores. Several workers have reported the effectiveness of triazole fungicides on rust of different crops (Kettlewell *et al*., 1982; Navi 1986 and Mihova *et al*., 1989). Inhibition of 100 per cent uredospore germination of *P.arachidis* with propiconazole, mancozeb and tridemorph has been reported by Benagi (1991). The effectiveness of fungicides, dithane M-45 and tebuconazole against *P. sorghi* has been reported by Gupta (1978).

5.3.2 *In vitro* evaluation of botanicals

Continuous use of chemical fungicides in the management of diseases also brought new problems along with them and alarming among them are the pollution of air, water, soil residual toxicity and development of resistance of pathogen against chemical, there by the need to apply them with their escalating prices and harmful effects on non target organisms.

Botanicals are ecofriendly renewable, inexhaustible, indigenously available and easily assessable largely non phytotoxic, thus redially biodegradable, relatively cost effective and hence constitute suitable plant protection in the strategy of integrated disease management. Hence screening of botanicals for their effective and antifungal activity against the pathogen is essentially required to minimize the use of fungicides and to consider as one of the component in the integrated disease management (Khadar, 1999).

The present investigation was carried out to evaluate the different commercially available botanicals against uredospore germination of *P. substriata* var.*indica*. In the present study, *in vitro* evaluation of commercially available botanicals was carried out with respect to inhibition of uredospore germination of *P. substriata* var.*indica* at different concentrations (0.25, 0.5, 0.75 and 1 %). Maximum inhibition of uredospore germination irrespective of the botanical concentration was noticed with neem oil (88.83 %) followed by soldier (87.03 %) and sainik (85.48 %) whereas least inhibition of uredospore germination was observed in neem mark (83.34 %) and discheck (77.36 %).

These results are in agreement with Utpal Dey e*t al.* (2011) who studied the effect of botanicals on uredospore germination of *P. sorghi* revealed that neemazol F5 % @ 20 per cent showed less per cent uredospore germination followed by nimbicidine, neemazol F1 % and cristol 56 SL. And also by Hurali (2008) who tested 25 plant extracts on urediospore germination of *P.pachryrhizi* and found that *Allium sativum, Azadirachta indica* and *Amaranthus viridis* at 5 and 10 per cent concentration showed maximum per cent inhibition.

5.3.3 *In vitro* evaluation of ITKS

In the present study, *in vitro* evaluation of ITK's was carried out with respect to inhibition of uredospore germination of *P. substriata* var.*indica* at different concentrations (5, 10, 20 and 30 %). At 10 per cent concentration, maximum inhibition was noticed in cow urine (79.16 %) followed by cow milk (76.61 %) and were on par with each other. Next best was panchagavya (73.91 %) and it was on par with butter milk (72.24 %). Significantly least inhibition was noticed in vermiwash (62.83 %). These results are coincides with Utpal Dey e*t al.* (2011) who tested ITK'S against *P. sorghi*, jeevamruta @ 20 per cent concentration caused significantly less uredospore germination of 22.69 % followed by panchagavya @ 20 per cent (33.67 %).

5.4 Integrated management of pearl millet rust

The concept of organic farming and ecofriendly management encouraged the plant protection specialists to go for the use of plant extracts for the management of pest and diseases. This can also avoid the pollution of air, water and soil. Use of chemicals has been discouraged. In evaluation of fungicides new generation of systemic molecules were tested both in laboratory and field conditions along with recommended fungicides to know their relative efficacy against pathogen. Cultivation of resistant genotypes is an effective and cheapest method combats the diseases as compared to chemical control.

In this experiment spray schedule was made 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 to know the individual and their combinations spray effect. In the present investigation, highest per cent decrease in disease severity over unsprayed control was recorded in the spraying schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (67.33 %) followed by hexaconazole @ 0.1 % - neem oil @ 1.0 % (57.29 %) and neem oil @ 1.0 % - hexaconazole @ 0.1 % (51.95). Least per cent decrease in disease severity over unsprayed control was recorded in cow urine @ 10% - hexaconazole @ 0.1 % (45.50 %). Whereas hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest seed yield of 30.50q ha^{-1} and it was statistically on par with all the other spray schedule treatments, T_2 (27.50 q ha^{-1}), T_4 (26.15q ha^{-1}), T_6 (24.60 q ha^{-1}), T_5 (24.00 q ha^{-1}), T_7 (23.95 q ha^{-1}) and T_3 (22.90 q ha^{-1}) except unsprayed control which was recorded 20.60 q ha^{-1} (Table 13). Similar trend were observed in case of 1000 seed weight. Hexaconazole @ 0.1 % - hexaconazole @ 0.1 % (T_1) recorded highest seed weight of 10.51 g and it was statistically on par with neem oil @ 1.0 % - neem oil 1.0 % (10.04 g). Next best schedule which recorded higher seed weight was hexaconzole @ 0.1 % - neem oil @ 1.0 % (9.90 g) and it was on par with the spraying schedule hexaconzole @ 0.1 % - cow urine @ 1.0 % (9.43 g).

Unsprayed control recorded significantly lowest seed weight of 8.48 g. The highest B: C ratio was obtained with spray schedule, hexaconazole @ 0.1 % - hexaconzole @ 0.1 % (1:2.4) followed by neem oil @ 1.0 % - neem oil 1.0 % (1:1.76). Most of the remaining spray schedules treatments, T_4, T_6, T_5 and T_3 recorded next highest B: C ratio of 1: 1.75, 1:1.70, 1: 1.55 and 1: 1.48, respectively (Table 11).

These results are in agreement with Hurali (2008) who confirmed least disease severity of 26.07 per cent in hexaconazole alone spray followed by cristol 56SL – hexaconazole – cristol 56SL (27.71 %) spray schedule. Whereas, neem oil – hexaconazole – neem oil spray schedule recorded maximum (23.16 q ha^{-1}) seed yield followed by hexaconazole (22.67 q ha^{-1}) and cow milk – hexaconazole – cow milk (22.66 q ha^{-1}) spray schedule against soybean rust. The present findings are also in agreement with Patil (2008) who reported that among the seven commercially available plant based products tested *viz*., neem oil, margotricure, nimbicidine and neem gold at 0.5 per cent and wanis at 1.0 per cent, sprayed thrice at an interval of 10 days starting from the onset of disease were found promising in reducing the soybean rust severity with significant increase in seed yield and 100 seed weight. Among the botanicals highest B : C ratio (2.74) was recorded in neem oil followed by margotricure (1.12) and nimbicidine (0.96).

Response of different botanicals varied with rust of pearl millet, which might have happened due to several reasons, such as uneven distribution of inoculum in natural infections, physiological differences in their sensitivity to toxic materials and availability of less or varied number of active spores of rust.

5.5 Screening of pearl millet genotypes to rust disease

Management of the disease through host plant resistance has been the best choice in all the crop improvement programmes. Utilization of resistant cultivars in farming system is the most simple, effective and economical method in the management of disease. Besides this, these resistant cultivars conserve natural resources and reduce the cost, time and energy when compared to the other methods of disease management. In the present study 42 pearl millet genotypes were screened under natural condition for resistance against rust. The study revealed that none of the genotypes were found to be immune or highly resistant. Such differences in pearl millet genotypes to rust resistance have been observed by earlier workers (Wilson., 1994, and Sharma e*t al*., 2009).

Thus the promising high yielding rust resistant pearl millet genotypes identified through this investigation can be deployed in disease endemic areas to aim for sustainable productivity or can be used in resistance breeding programme.

Future line of work

For better understanding of the pearl millet rust and its management it is necessary to focus attention on the following future line of work.

- Survey and surveillance of the disease have to be undertaken every year in future to observe rhythmic changes in the severity of the disease and also the status and regional severity of the disease.
- The yield loss model should be developed to predict the losses due to rust disease.
- There is a need to develop rust resistant genotypes of pearl millet for commercial cultivation.

SUMMARY AND CONCLUSIONS

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most important drought and heat tolerant crop. It occupies fourth place in cereals and second place among coarse cereals. In India, it occupies an area of 9.61 m. ha with production of 10.37 mt. (Anon, 2011). Among the important pearl millet growing states in the country, Karnataka ranks seventh, occupying an area of 0.31 m. ha with an annual production of 0.33 mt.

Among the foliar diseases rust caused by *Puccinia substriata* var. *indica* is a potential destructive disease in recent years causing severe yield loss.

In spite of its destructive nature not much work with respect to different aspects has been carried out. Hence, the present study was undertaken considering different aspects like survey of the disease to know the disease severity in different districts of northern Karnataka, studies on loss assessment aspects of the disease, identification of resistant sources and *in vitro* evaluation of fungicides, commercially available botanicals and indigenous technology knowledge against *P. substriata* var. *indica* have been attempted.

Integrated management of the disease involving economically viable and effective fungicides, commercially available botanicals and indigenous technology knowledge using highly susceptible genotype were carried out at ARS, Almel during *kharif 2012*-13.

The survey during 2012 revealed that, the disease was noticed in varying intensities in two districts surveyed. Maximum disease severity was noticed in Kudagi village (70.36 %) of Basavana Bagewadi taluka followed by Shivanagi village (62.92 %) of Bijapur. The disease severity was higher in Basavana Bagewadi taluk (42.96 %) followed by Bijapur (40.11 %) and Sindgi (38.88 %) taluk. The congenial condition like high temperature, relative humidity and drizzling rainfall must have helped in building up disease in Bijapur (36.17 %) followed by Bagalkot (26.70 %) districts.

In loss assessment studies among different pearl millet genotypes to rust, irrespective of the fungicidal spray significantly higher per cent disease index was recorded in the genotype MRB 2232 (32.33 %) compared to other genotypes. Next genotype which was recorded higher per cent disease index was ICTP 8203 (26.16 %).

Among different genotypes, irrespective of the fungicidal spray ear head length (22.85 cm), ear head seed weight (17.50 g), seed yield (44.83 q ha^{-1}) and 1000 seed weight (12.81 g) was recorded in the genotype GK 1135 compared to other genotypes. Laxmi 234 was the next genotype which has recorded higher ear head length (22.10 cm), ear head seed weight (16.69 g) and seed yield (35.96 q ha^{-1}). Least ear head length (19.05 cm), ear head seed weight (15.60 g), seed yield (23.51 q ha^{-1}) and 1000 seed weight (10.74 g) were recorded in ICMV 221, ICTP 8203, ICTP 8203 and MRB 2232, respectively.

Irrespective of the spray highest increase in per cent disease index was recorded in the genotype Mahalaxmi Tilak (530.43 %) followed by GK 1135 (458.30 %). Lowest increase in per cent disease index was recorded in Laxmi 234 (266.36 %). Irrespective of the spray highest increase in seed yield was recorded in the genotype GHB 558 (48.81 %) followed by Mahalaxmi Tilak (29.85 %). Lowest increase in seed yield was recorded in Laxmi 234 (16.95 %). Irrespective of the spray highest increase in seed weight was recorded in the genotype ICMV 221 (17.02 %) followed by Mahalaxmi Tilak (15.21 %). Lowest increase in seed weight was recorded in Ajeet 27 (7.51 %).

Irrespective of fungicide concentration hexaconazole (98.18 %) was found to be the best in inhibiting the uredospore germination and remain on par with propiconazole (97.44 %), triadimefon (96.76 %), benomyl (96.08 %) and penconazole (93.49 %). Maximum inhibition of uredospore germination irrespective of the botanical concentration was noticed with neem oil (88.83 %) followed by soldier (87.03 %) and sainik (85.48 %) whereas least inhibition of uredospore germination was observed in neem mark (83.34 %) and discheck (77.36 %). Irrespective of ITK concentration cow urine (82.14 %) was found to be the best in inhibiting uredospore germination followed by cow milk (79.92 %). Significantly least inhibition was noticed in vermiwash (65.47%).

In integrated disease management, the spray schedule hexaconazole @ 0.1 % - hexaconazole @ 0.1 % showed least disease severity. Hexaconazole @ 0.1 % - hexaconazole @ 0.1 % schedule reduced the disease severity of rust effectively and also enhanced the yield and 1000 seeds weight. Hexaconazole @ 0.1 % -neem oil @ 0.1 % schedule was next best treatment in disease control as well as in increasing seed yield and 1000 seed weight.

Highest benefit: cost ratio was obtained in hexaconazole @ 0.1 % - hexaconzole @ 0.1 % (1:2.4) followed by neem oil @ 1.0 % - neem oil 1.0 % (1:1.76) and least was in cow urine @ 10 % - cow urine @ 10 % (1:1.48)

Among the 42 pearl millet genotypes screened under natural epiphytotic condition for resistance against rust, none of the genotype showed immune or highly resistant reaction, four genotypes showed resistant, 18 genotypes each as moderately resistant and susceptible and remaining two genotypes as highly susceptible.

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PEARL MILLET RUST (*Puccinia substriata* Ell. and Barth. var. *indica* Ramachar and cummins) AND ITS INTEGRATED MANAGEMENT IN NORTHERN DRY ZONE OF KARNATAKA

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ABSTRCT

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the most drought and heat tolerant crop with highest water use efficiency under drought stress. It is grown as a nutrient rich food source for human and as a fodder crop for livestock. In Karnataka pearl millet is largely cultivated in northern districts comprising Bijapur, Bagalkot, Gulbarga, Raichur, Koppal and Belgaum accounting for 87 per cent of the area and production in the state. Pearl millet in Karnataka presently suffers from many fungal diseases. Among them rust caused by *Puccinia substriata* var. *indica* is a potential destructive disease in recent years causing severe yield loss. Hence, the present investigation was carried out with different objectives aiming at the integrated management of this disease.

Roving survey conducted during *Kharif* 2012 in different taluks of Bijapur and Bagalkot districts indicated varying intensities in different taluks. Rust severity was higher in Basavana Bagewadi taluk (42.96 %) followed by Bijapur (40.11 %) and Sindagi (38.88 %) taluks of Bijapur district and in Bagalkot district, Hunagund taluk recorded maximum rust severity (35.18%) followed by Badami (27.15 %) and Bagalkot (17.77 %) taluk.

In loss assessment studies among different pearl millet genotypes to rust, irrespective of the fungicidal spray significantly higher per cent disease index was recorded in the genotype MRB 2232 (32.33 %). And higher seed yield (44.83 q ha-1) and 1000 seed weight (12.81 g) was recorded in the genotype GK 1135 compared to other genotypes.

Under *in vitro* condition irrespective of the concentrations, hexaconazole among fungicides, neem oil among botanicals and cow urine among ITK's recorded maximum inhibition of uredospore germination of 98.18, 88.83 and 82.14 per cent, respectively. In Integrated Disease Management (IDM), the spray schedule hexaconazole @ 0.1% -hexaconazole @ 0.1% recorded least rust severity (15.30 %), higher seed yield (30.50 q ha^{-1}) with higher benefit : cost ratio (1 : 2.40) followed by the spray schedule hexaconazole @ 0.1% - neem oil @ 1.0 %. Among 42 pearl millet genotypes screened against rust, none of the genotype showed immune or highly resistant reaction, four genotypes showed resistant (EBT 10-37, EBLT 10-3, LPRT 10-11 and EMRT 10-17), 18 genotypes each as moderately resistant and susceptible and remaining two genotypes as highly susceptible.