Reaction of Wheat Varieties to Rust Diseases at Mid and Low Altitudes in Bhutan

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ABSTRACT

Wheat rusts are the important fungal diseases that limit the production and downgrade wheat grain quality. This study was conducted to determine the reaction of wheat varieties to rust diseases at different altitudes. Field experiments were conducted from December 2016 to March 2017 at Mendagang for mid altitude (1332 masl) and at Samtenling for low altitude (378 masl). The experiment followed a randomized complete block design with three replications and 15 varieties. Of the 15 varieties three were from Bhutan, eight from SAARC, and four from ICARDA. Disease assessments were performed approximately at 60, 90 and 120 days after sowing following the modified Cobb's disease rating scale. Only leaf rust was observed at both the sites and all 11 germinated varieties were evaluated. Leaf rust incidence ranged from 2.5 to 10% and 2.5 to 16% at mid and low altitudes respectively. Disease severity of 5 to 20%, corresponding to field response of immune to moderately resistant was observed at mid altitude; while 5 to 100%, with immune to susceptible was observed at low altitude. There was a significant difference in disease incidence by site (p=.038) but not in disease severity (p=.129). The disease severity was positively correlated (r=.359); (r=.034) with mean minimum and maximum temperature respectively and (r=.361) with mean minimum relative humidity. Correlation was highly significant (p=0.003). This study found variety ICARDA 1, with 100% severity as highly susceptible to leaf rust at low altitude while Bajosokha Kaa remained immune in both the sites. The results indicate that leaf rust can occur in both low and mid altitudes; however, selection of suitable leaf rust tolerant varieties requires more extensive studies.

Keywords: *Altitude; Resistant, Rust, Severity, Susceptible, Temperature, Relative humidity*

1. Introduction

Wheat (*Triticum aestivum* L.) is the world's most extensively grown cereal. Wheat ranks third to rice and corn in total production globally. It is one of the main staple food in both developed and developing countries (Getie, 2015) providing food for over 10 billion people (Ahanger, Gupta, Bhat & Dar, 2014). In Bhutan, wheat together with barley comprises the third important cereal in term of consumption and production. However, the production of wheat is low with the current productivity of 1.76 Mg ha^{-1} (DoA, 2014), which is lower than global average yield of 3 Mg ha^{-1} (Tshewang, Park, Chuahan & Joshi, 2017).The total production of wheat was 4286 Mt from an area of 5441 acres in 2013 (MoAF, 2015). This resulted in importation of 2,326 Mt worth Nu

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416 million to meet the demand in 2014 alone (NSB, 2015). Wheat is used mainly for human consumption and supports nearly 35% of the world population (Dreisigacker, 2004). According to Doty (2012), because of its rich content of gluten, wheat is used for making flour which is used in production of baked goods and cereal products. Sustainable productivity of wheat is important to meet future demand for grains. However, wheat production is limited significantly by several abiotic and biotic stresses.

Wheat rusts are one of the most important diseases that limit wheat production worldwide (Aquino, Carrion & Calvo, 2002; Singh, Sethi & Chaudhary, 2004). Wheat rust diseases are caused by fungi belonging to the class Basidiomycetes and order Pucciniales (McIntosh, Wellings & Park, 1995; Agrios, 2005). The three rust diseases of wheat are stem rust or black rust caused by *Puccinia graminis* Pers. f. sp. *Tritici* Eriks.; stripe rust or yellow rust caused by *Puccinia striiformis* West end. f. sp. *Tritici* Eriks*.,* and leaf rust or brown rust caused by *Puccinia triticina* Eriks. Rust pathogens differ in morphology, life cycle and environmental preferences for growth and development. *Puccinia graminis* f. sp. *tritici* develops well under hot and humid climatic conditions, while *Puccinia striiformis* f. sp. *Tritici* prefers a cooler climate. In contrast, *Puccinia triticina* is adapted to a relatively broader range of conditions, making it the most widespread of the three rust diseases (Bariana et al., 2007; Getie, 2015).

The three species of rust pathogens in wheat cause the most destructive diseases affecting cereals (Stubbs 1985; Kolmer, 2005). The yield loss is usually high when the disease becomes severe before grain formation. Disease severity, however, depends on the resistance level of the cultivar grown, environmental conditions and the time of onset of the disease (Afzal et al., 2008; Brar, 2015).

In Bhutan, with the exception to stem rust, stripe and leaf rusts have been a recurrent threat to wheat production. Stripe rust epidemics in 1985 and 1986 caused losses of more than 50% of wheat production in *Punakha-Wangdue* valley (Mann and Hobbs, 1988; Tshewang, 2014). A survey conducted in April 2012 in 46 sites of *Gasa, Punakha, Wangdue, Paro*and *Haa dzongkhags* detected stripe rust in 13 sites and leaf rust in 11 sites (Om et al., 2012). The same study did not record stem rust incidence in any of the sites. Similarly, the results of the annual rusts surveillance of National Plant Protection Centre (NPPC) has repeatedly recorded stripe and leaf rusts as the most common rust diseases of wheat in Bhutan (Tshewang, 2014). The recurrent problem of stripe and leaf rusts in Bhutan coupled with wide cultivation of a susceptible variety necessitated the assessment of resistance in both local and global wheat germplasm against rusts. Although improvement of wheat varieties has been initiated and progress made, varietal improvement research needs to be extended in respect to performance of such varieties at different altitudes. Therefore, the current study is done to determine the reactions of wheat varieties to rust diseases at mid and low altitudes. This study has significance in selection of varieties for a particular cropping zone as a part of rust management strategy.

2. Materials and Methods

Field experiments were conducted at two locations; in farmers field at *Mendagang* (27.5886°N; 089.8711°E), representing mid altitude (1,332 masl) and at Agriculture Research and Development Centre (ARDC), *Samtenling* (26.9058°N; 090.4308°E), for low altitude (378 masl) in the cropping season of 2016-2017. Mendagang which is under *Dzomi gewog* of Punakha district experiences dry sub-tropical climatic conditions with annual average rainfall of 880 mm. While Samtenling under *Sarpang* district falls under Wet-subtropical agro-ecological zones and is humid with heavy rainfall of 2,500-5,500 mm per year.

Field temperature and relative humidity during the study period were recorded using tinytags (PLUS 2-TGP-4500, Omni Instrument Australia Pty Ltd) which was set to log (record) every hour. The Tinytag Plus 2 is a self-contained temperature and relative humidity data logger that has a high reading resolution and accuracy.

Experiment in each site was laid out in randomized complete block design (RCBD) with fifteen treatments and three replications. An area of 40 m^2 comprising 45 plots was established in each site. Each plot measured 1.1 m × 0.8 m and was assigned a treatment randomly. Plots were separated by 0.3 m wide spacing between the plots (treatments). Replicates were separated by 0.5 m spacing. Treatments were represented by 15 wheat varieties (Table 1). The wheat varieties consisted of three released Bhutanese varieties, eight SAARC varieties (four Bangladeshi, three Indian and one Nepali) and four varieties from International Center for Agricultural Research in the Dry Area (ICARDA). Seeding rate used was 100 Kg ha^{-1} with planting spacing of 10-16 cm by 20-25 cm. Therefore, around 50 gram of each variety was sown with a planting distance of 11 cm × 14 cm in each plot. Experimental plots were irrigated four times with first irrigation at 15 days after sowing (DAS). Subsequent irrigations were done at an interval of two weeks. Three hand weedings were done to keep the plots free of weeds.

Table 1.Details of Wheat varieties used in the study

Varieties	Description	Reaction type to rust	Reference
Bajosokha Kaa	Improved wheat variety released by ARDC, Bajo in 2014.	resistant to stripe rust & leaf rust	Joshi (2014); Tshewang et al. (2017); Tshewang. pers.comm.
Gumasokha Kaa	Improved wheat variety released by ARDC, Bajo in 2014.	resistant to stripe rust & leaf rust	Joshi (2014); Tshewang et al. (2017); Tshewang. pers.comm.
Bumthang Kaa Drukchu (Danphe)	Improved wheat variety released by ARDC, Bajo in 2015.	resistant to stripe rust, leaf rust & stem rust	Joshi (2014); Tshewang et al. (2017); Tshewang. pers.comm.
BARI GOM-25	Bangladesh variety received thorough SARRC Regional	resistant to leaf rust	Hossain et al (2013); Malaker& Reza (2011)
BARI GOM-26	Bangladesh variety received thorough SARRC Regional	resistant to leaf rust & moderately resitant to stem rust (Ug99)	Hossain et al (2013); Malaker& Reza (2011)
BARI GOM-27	Bangladesh variety received thorough SARRC Regional	resistant to leaf rust & resistant to stem rust (Ug99 & its variants)	Hossain et al (2013); Malaker& Reza (2011)
BARI GOM-28	Bangladesh variety received thorough SARRC Regional	resistant to leaf rust	Hossain et al (2013); Malaker& Reza (2011)
DBW-39 (Bajokaa 2014)	Indian variety received thorough SARRC Regional	NA	
Bajoka 2967	Indian variety received thorough SARRC Regional	resistant to leaf rust & strip rust	http://ztmbpd.iari.res.in/technologies /varietieshybrids/cereals/wheat/
Bajoka 107	Indian variety received thorough SARRC Regional	resistant to leaf rust	Singh et al. (2014)
NL-1073 (Francolin; BARI GOM-27)	Nepal variety received thorough SARRC Regional	resistant to Ug 99 and its variants	https://www.cimmyt.org/francolin-ug99-tolerant-wheat-variety-released-in-bangladesh/

NA= information not available

Table 1contd… Details of Wheat varieties used in the study

Varieties	Source and Description
Bajosokha Kaa	Bhutan, Improved wheat variety released by ARDC, Bajo,(2012-2013
Gumasokha Kaa	Bhutan, Improved wheat Variety released by ARDC, Bajo, (2012-2013
Bumthang Kaa Drukchu	Bhutan, Improved wheat variety released by ARDC, Bajo, 2015
BARI GOM-25	Bangladesh variety received thorough SARRC Regional
BARI GOM-26	Bangladesh variety received thorough SARRC Regional
BARI GOM-27	Bangladesh variety received thorough SARRC Regional
BARI GOM-28	Bangladesh variety received thorough SARRC Regional
DBW-39 (Bajokaa 2014)	Indian variety received thorough SARRC Regional
Bajoka 2967	Indian variety received thorough SARRC Regional
Bajoka 107	Indian variety received thorough SARRC Regional
NL-1073	Nepal variety received thorough SARRC Regional
ICARDA 1	Varieties adapted in dry areas
ICARDA 2	Varieties adapted in dry areas
ICARDA 3	Varieties adapted in dry areas
ICARDA 4	Varieties adapted in dry areas

Disease incidence and severity were assessed three times starting from tillering to ripening stage according to Zadoks, Chang and Konzak (1974). The first assessment commenced at approximately 60 days after sowing (DAS) followed by two assessments at 90 and 120 DAS. Sample size of 45 plants from each variety was assessed for both disease incidence and severity. Disease incidence was determined by using the following formula after recording the total number of infected plants from the sample size during each assessment date.

$$\text{Disease incidence} = \frac{\text{Number of diseased plants}}{\text{Total plants assessed}} \text{ x } 100$$

The same plants were also used for assessment of disease severity. Disease severity which is the percentage of plant tissue covered by the disease was determined by using the modified Cobb's disease rating scale (Roelfs et. al, 1992). Disease scores were interpreted based on the descriptions and the reaction type of each score (Table 2.) that was developed by Research Institute for Plant Protection (IPO) and International Maize and Wheat Improvement Center (CIMMYT).

The prevailing rust disease for each site was further assessed to determine the level of infection. In both sites, only leaf rust was recorded. The level of infection was determined by considering the severity of the disease for varieties inspected in the respective sites. The Coefficient of Infection (C.I.) was calculated using the methods outlined by Roelfs et al. (1992) in which the values of severity were multiplied by a constant number of host response such as immunity:

(O) = 0.05, resistant (R) =0.1, moderately resistant (MR) = 0.2, intermediate (M) = 0.4, moderately susceptible (MS) =0.6, and susceptible (S) = 1(Table 2.).

Table 2.Rust reaction rating scale and field response developed by IPO and CIMMYT

Descriptions	Disease severity (%)	Reaction type (field response)
No visible infections on plant	5	No reaction (O)
Visible chlorosis or necrosis, no *uredia* are present (Few minute lesions on leaves)	10	Resistant (R)
Small *uredia* are present and surrounded by either chlorotic or necrotic areas	20	Moderately resistant (MR)
Variable sized *uredia* are present, some with chlorosis, necrosis or both	40	Intermediate (M)
Medium sized *uredia* are present and possibly surrounded by chlorotic areas. (typical lesions surrounded by distinct chlorotic halos covering)	60	Moderately susceptible (MS)
Large *uredia* are present, generally with little or no chlorosis and no necrosis	100	Susceptible (S)

Data was compiled in Microsoft Excel 2013 spreadsheet and organized for analyses using Statistical Packages for Social Science (SPSS). The data was subjected to normality test using box plot method. The disease incidence and severity between the sites were assessed using non-parametric Kruskal-Wallis test that determined the significant difference (p<0.05). The spearman's rho correlation test was conducted to determine the correlation between disease severities and mean monthly minimum and maximum temperature and relative humidity according to Khan, Yaqub and Nasir (1998).

3. Results and Discussion

3.1. Weather data during the study period and development of rust diseases

Weather data on field temperature and relative humidity were recorded from December 2016 to March 2017 using Tinytags (data logger). Average monthly minimum and maximum temperature and relative humidity for each site are given in Figure 1 (1 denote Mendagang and 2 Samtenling). Overall, the average monthly minimum temperatures at mid altitude in Mendagang are lower than at low altitude in Samtenling. However, average monthly maximum temperatures in both sites are comparable except for the month of December. Based on the average monthly minimum temperature, the lowest temperatures observed were in January with 3.2°C and 14.2°C temperatures at mid and low altitude sites respectively. The average monthly maximum temperatures ranged from 30.5°C to 32.4°C and 30.2°C to 30.8°C in mid and low altitudes respectively. The overall mean minimum relative humidity is higher in low altitude site compared to mid altitude. The average monthly relative humidity for both sites were lowest in January with 18.6% at mid altitude and 29.4% at low altitude.

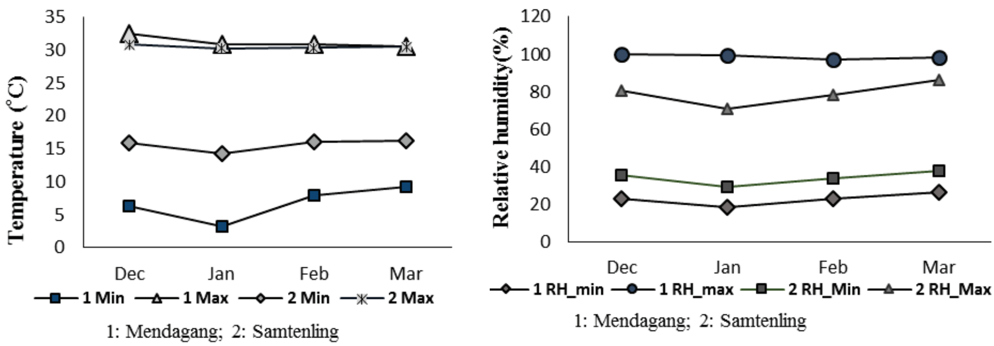

Figure 1.Mean minimum and maximum temperature (left) and relative humidity (right) recorded at mid and low altitudes sites

These results indicate that the mean temperatures and relative humidity in both sites were within the conditions favourable for the development of rust pathogens. Urediospores of stem rust pathogen are reported to germinate at a minimum temperature of 2°C and maximum of 30°C though optimum temperature requirement range from 15°C to 24°C (Roelfs et al., 1992) and high relative humidity near to 100% (Line, 2002). Similarly, spores of stripe rust pathogen germinate at minimum of 0°C and maximum 23°C (Chen, 2005) with optimal temperature range of 9°C to 13°C and relative humidity of 100% (Kansu, 2011). The leaf rust pathogen develops at about 20°C with dew periods of three hours or less (Roelfs et al., 1992).

3.2. Observation of wheat rust

Rust was scored from only 11 varieties out of the 15 varieties sown in both the sites. The varieties that did not germinate were Bajoka 2967, NL-1073, ICARDA 2 and CARDA 4. Hence all observations and data analyses were based on those 11 varieties. Plant responses were measured based on disease incidence and severity of stem, stripe and leaf rusts. Among the three wheat rust diseases studied, only leaf rust was observed in both the study sites. Stem rust and yellow rusts did not occur during the study period. Stem rust occurs only in summer with high relative humidity in hot places (Kolmer, Chen & Jin, 2009). Also Om et al. (2012) did not record any incidence of stem rust in Bhutan during their survey in April 2012. It is possible that wheat grown in hot places such as Samtenling escapes stem rust infection either due to absence of inoculums or due to unfavourable weather conditions. The present study was conducted from December to March which is a relatively cooler period with low relative humidity compared to humid and high temperatures of spring and summer months. As for stripe rust, the disease is common in higher elevation of temperate region with altitude of more than 2,500 masl. Previous surveys have recorded leaf rust in warm places in the mid to low altitude areas and stripe rust in areas of high altitudes (Tshewang & Ghimirey, 2016; Om et al., 2012). The results of the present study support the earlier observations of leaf rust in mid to low altitude areas. The leaf rust incidences ranged from 2.5 to 16% in both sites and disease severity of 5 to 20% at mid altitude and 5 to 100% at low altitude were recorded.

3.3. Leaf rust incidence and severity at mid-altitude site in Mendagang

At mid altitude site, eight of 11 varieties were evaluated for leaf rust. The leaf rust incidence ranged from 2.5 to 10% and severity of 5 to 20%. Among the 11 varieties; BARI-GOM 25, 27 and 28 were infected at 60 DAS, each with incidence and severity levels of 2.5% (Figure 2) and 10% (Figure 3) respectively. Highest incidence was observed in variety Gumasokha Kaa and BARI-GOM 28 at 90 DAS but the incidences in these two varieties decreased at 120 DAS (Figure 2). While highest disease severity was recorded at 90 DAS on BARI-GOM 26 and 28 with severity score of 20% each (Figure 3) the lowest severity (5%) was recorded for Bajosokha Kaa which remained immune throughout the assessment.

The observation of low disease incidence and severity of leaf rust at mid altitude could be due to dry weather during the study period and resistance within the varieties. According to Tshewang et al. (2017) and Joshi and Tshewang (2015), Bajosokha Kaa, Gumasokha Kaa and Bumthang Kaa Drukchu have good disease resistance in addition to having yield advantage and water stress tolerance. The present study did not analyze yield data, however, low disease severity observed in these varieties support the earlier findings.

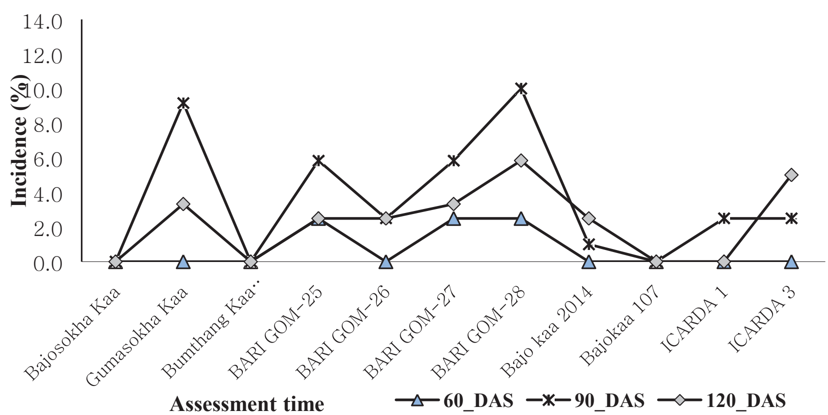

Figure 2.Leaf rust disease incidence (%) during different assessments at Mendagang

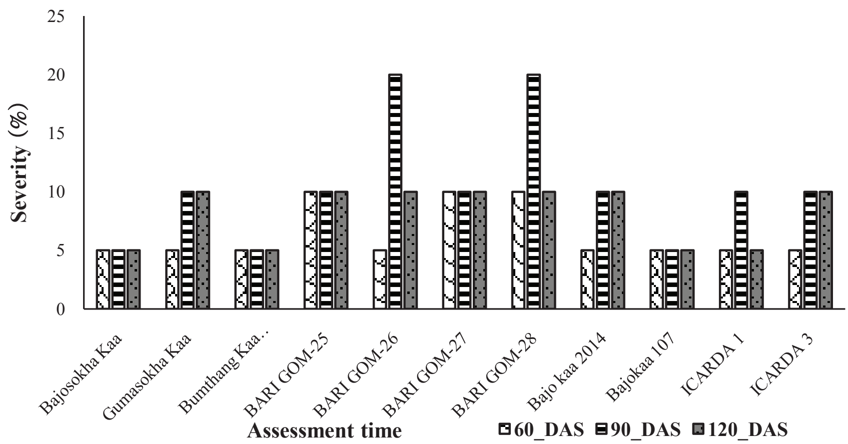

Figure 3.Severity (%) of leaf rust disease in the varieties at Mendagang

3.4. Leaf rust incidence and severity at low altitude in Samtenling

Leaf rust disease incidence and severity at Samtenling ranged from 2.5 to 16% (Figure 4) and 5 to 100% (Figure 5) respectively and all 11 germinated varieties were infected. At 60 DAS, leaf rust incidence was recorded only on two varieties, BARI GOM-27 and 28, though most varieties exhibited leaf rust by 90 or 120 DAS. Highest leaf rust incidence was observed in variety BARI-GOM 25 with 16% at 90 DAS followed by BARI-GOM 27 with 8% (Figure 4.). However, at 120 DAS leaf rust incidence decreased in BARI-GOM 25. In contrast, leaf rust incidence in ICARDA 1 increased from 6% at 90 DAS to 15% at 120 DAS.

As for leaf rust severity differences among the varieties, ICARDA 1 showed the most severe infection with severity score of 60% and 100% at 90 and 120 DAS respectively. The observation of increase in leaf rust severity on ICARDA 1 could be due to the late germination of this variety and exposure of young plants to more favourable weather conditions and inoculums in the fields. The remaining varieties showed comparable disease responses to leaf rust.

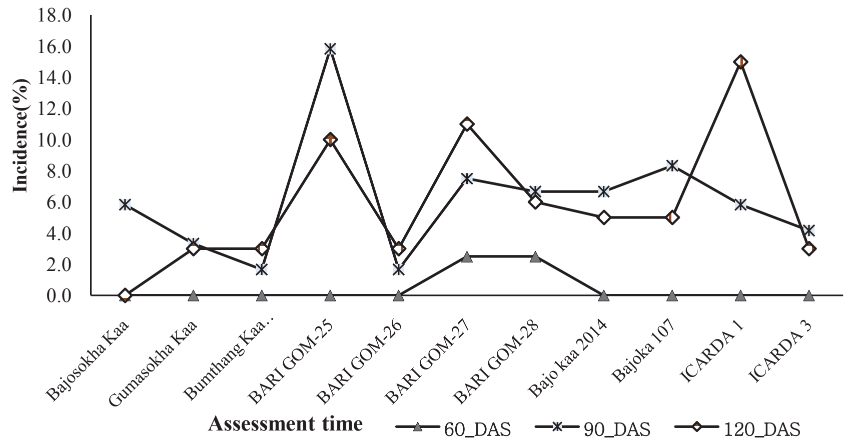

Figure 4.Leaf rust incidence (%) at 60, 90 and 120 DAS during different assessments at Samtenling

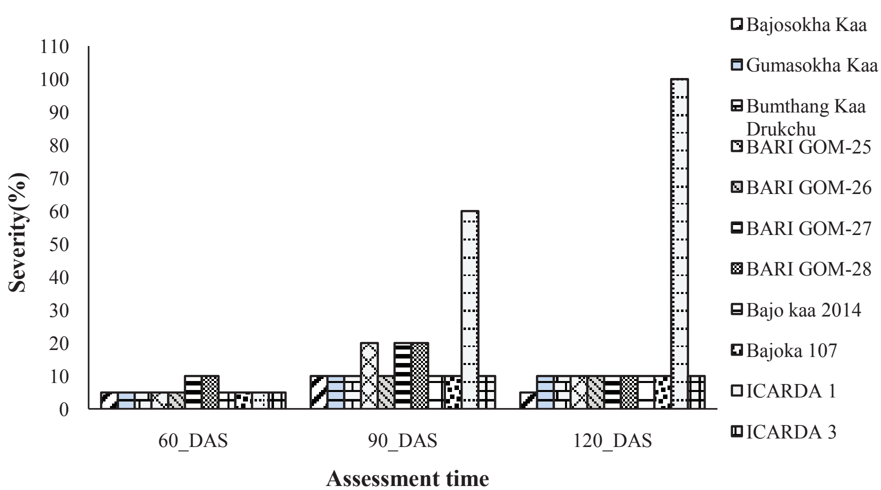

Figure 5.Leaf rust severity of the varieties grown at Samtenling

3.5. Comparison of leaf rust incidence and severity between sites

The mean of the three assessments were computed for comparison between the sites. Significant difference in disease incidence between the two sites was observed ($\chi 2\ (1) = 4.311$, p=0.038). However, disease severity was not significant between the sites ($\chi 2\ (1) = 2.307$, p= 0.129). Likewise based on the disease severity scores determined at 120 DAS, disease severity ranged from 5 to 20% and 5 to 100% at Mendagang and at Samtenling respectively. This indicates that the plant responses to leaf rust in the mid altitude correspond to immune (5O) to moderately resistant (20MR) while that of the low altitude corresponds to immune (5O) to susceptible (100S) (Table 3.). This seems to suggest that though leaf rust is prevalent in both mid and low altitude, it is more severe in low altitude. Based on disease reaction types all the three local varieties Bajosokha Kaa, Gumasokha Kaa and Bumthang Kaa Drukchu can be categorized as immune (5O) to resistant (10R) while BARI-GOM varieties are moderately resistant (20MR) to resistant (10R) in both the sites. Bajosokha Kaa is said to possess good resistance to rust but ICARDA varieties are still being evaluated at ARDC, Bajo (Tshewang, 2014). Interestingly, IACRDA 1 showed an immune (5O) field response when grown at mid altitude but became susceptible (100S) to leaf rust at low altitude with severity scores of 60% and 100%. The results seem to indicate that while most of the varieties are suitable for both low and mid altitudes; ICARDA 1 may not be suitable for low altitude areas due to its high severity scores. However, the high severity of ICARDA 1 in low altitude site in Samtenling could be due to late germination.

Table 3.Severity and reaction of leaf rust at 120 days after sowing

	Mendagang			Samtenling		
Varieties	% Severity	Reaction type[1]	C. I values	% Severity	Reaction type[1]	C. I values
Bajosokha Kaa	5	5O	0.25	5	5O	0.25
Gumasokha Kaa	10	10R	1	10	10R	1
Bumthang Kaa Drukchu	5	5O	0.25	10	10R	1
BARI GOM-25	10	10MR	1	10	10R	1
BARI GOM-26	10	10R	1	10	10R	1
BARI GOM-27	10	10R	1	10	10R	1
BARI GOM-28	10	10MR	1	10	10R	1
Bajokaa 2014	10	10R	1	10	10R	1
Bajoka 107	5	5O	0.25	10	10R	1
ICARDA 1	5	5O	0.25	100	100S	100
ICARDA 3	10	10R	1	10	10R	1

C.I=coefficient interval
[1]O=immune; R= resistant; MR=moderately resistant; MS= moderately susceptible; S= susceptible

3.6. Relation of disease development to weather (Temperature and Humidity)

The leaf rust disease incidence was positively correlated with mean minimum temperature (r=.454) and mean minimum relative humidity (r= .455) (Table 4.) and the correlation was significant (p= 0.01). However, it is negatively correlated (r= -.153) with mean maximum relative humidity but the correlation was not significant (p>0.05). Similarly, disease severity was positively correlated with mean minimum temperature (r=.359) and mean minimum relative humidity (*r*= .361) with significant (*p*=0.003). As for correlation between leaf rust incidence and severity with mean maximum temperature and relative humidity, leaf rust incidence was negatively correlated with mean maximum relative humidity (*r*= -.128) but the correlation was is not significant (*p*= 0.307). In contrast, leaf rust incidence (*r*=.006) and severity (*r*= .034) were positively correlated with mean maximum temperature but were not significant (*p*>0.05).

Infections of leaf rust can occur at a temperature range of 3°C to 25°C with more than three to six hours of leaf wetness (Roelfs et al., 1992; Bolton, Kolmer & Garvin, 2008). Grabow (2016) found that temperature, leaf wetness, and relative humidity variables were the most highly correlated variables in the disease development. The latent period of rust disease decrease with increase in temperature thus increasing the amount of spore production over time (Tomerlin, Eversmeyer, Browder & Kramer, 1983; Eversmeyer & Kramer, 2000). The current study also found that increase in temperature and relative humidity from January till March increased the disease severity due to condition conducive for the disease development in both the sites.

Table 4.Correlation between disease incidence, severity and weather data (temperature/relative humidity) at mid and low altitudes

		Mean_Tmin	Mean_Tmax	Mean_RHmin	Mean_RHmax
Spearman's rho	Incidence (%)	.454**	.006	.455**	-.153
		.000	.960	.000	.220
	Severity (%)	.359**	.034	.361**	-.128
		.003	.787	.003	.307

**. Correlation is significant at the 0.01 level (2-tailed)
Mean_Tmin/ Tmax= mean minimum and maximum temperature; Mean_RHmin/RHmax = mean minimum and maximum relative humidity

4. Conclusion

The results from this study indicate that reactions of the wheat varieties to leaf rust differed at different altitude zones. Leaf rust of wheat was observed on eight of 11 varieties in mid-altitude, while all 11 varieties showed leaf rust infection at low altitude. Disease severity varied from immune to moderately resistant in mid altitude site while in the low altitude site, plant responses varied from immune to susceptible. This seems to indicate that low altitude site is more conducive for leaf rust development.

In both the sites, the local released varieties showed more resistant than the varieties from SAARC and ICARDA. At mid altitude, Bajosokha Kaa, which is a local variety and widely cultivated by farmers remain immune to leaf rust while SAARC varieties and ICARDA varieties depicted resistant to moderately resistant field responses. Exceptionally, ICARDA 1 developed severe rust symptom resulting in susceptible field response at low altitude but of moderately resistant at mid altitude. This, however, could be due to differences in germination time, as ICARDA 1 germinated late and was exposed to inoculums load. The study also analysed the relationship between leaf rust severity, temperature and humidity which were found to be positively correlated.

The assessment of yield performance for different varieties could not be undertaken as the wheat plant did not reach full maturity during the study period (December to March). Also the varieties included in the study comprised mostly resistant varieties, as shown in Table 1 and no comparison could be made with a susceptible line or variety. Therefore, it is necessary to include susceptible lines/checks which would be useful in detecting the inception of disease and level of severity in a particular site. Moreover, the study was conducted for only one season and comprised only of two altitudinal zones. As such, the study does not provide sufficient evidence for choosing varieties at different sites. Hence, similar studies that include sites in high altitude area would be required to have more comparative and reliable results to draw definitive conclusions.

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Postharvest Damage and Losses of Mandarin Fruits in Bhutan

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ABSTRACT

Postharvest damage and losses in the horticultural production chain is a major challenge in a developing country like Bhutan. Though there are significant damages and losses of mandarin fruits in Bhutan, no reliable data is available. This study through field surveys assessed the extent of damages and losses due to postharvest conditions in the field as well as natural factors. Data were randomly collected from the fields of eight districts (Samdrup Jongkhar, Pema Gatshel, Zhemgang, Sarpang, Tsirang, Dagana, Chukha and Samtse). Postharvest damages of mandarin fruits due to postharvest handling was found to be 25.57% while the complete loss of mandarin due to same factor stands at 5.63%. Partial damages from natural causes such as diseases, birds, pests and physiological disorders stands at 10.26% while, 3.82% were completely damaged in the field. This accounts to 31.20% of the total mandarin fruits harvested being damaged (including losses) due to postharvest handling operations and 14.08% of the mandarin fruits were damaged (including losses) at the time of harvesting due to natural causes making the total damage to the mandarin fruits at 45.28%. Only about 54.73% of the mandarin fruits were marketed without damages or defects. Harvesting operations contributed to about 9.37% while, physiological disorders accounted for the maximum damages with 11.63% among the natural causes. Lack of proper storage and transportation facilities were the leading factors. Mandarin growers need to be supported with proper storage and transportation facilities as well as educate players in the value chain.

Keywords: *Mandarin fruits, Postharvest damages, Losses*

1. Introduction

Agriculture is the main source of livelihood in Bhutan as about 66 % of the Bhutanese population live in rural areas and depend on agricultural resources for their livelihood (MoAF, 2014). The diverse agro-climatic conditions of Bhutan are favourable for production of wide-range of horticultural crops. Citrus is the most widely grown fruit plants in Bhutan along with numerous other horticultural crops. The most common and widely grown types of citrus in Bhutan are local mandarin (*Citrus reticulata*) (Dorjee, Bockel, Punjabi & Chhetri, 2007). Currently about 60% of the Bhutanese farmers are directly or indirectly involved in mandarin farming (Joshi & Gurung, 2009).

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