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Research Article

Effects of Soil Amendments Using Potassium in Elevating Resistance against Wheat Blast Disease

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ABSTRACT

Potassium (K) is unique among the essential nutrient elements for its diversified role in plant metabolic processes. Potassium improves crop output, protects the crop from diseases and insect-pest infestation, prevents lodging, and reduces the effects of terminal heat stress. Based on this information, it was hypothesized that K will enhance host plant resistance and blast control while increasing yields. A pot experiment was conducted by artificially inoculating *Magnaporthe oryzae Triticum* (MoT) on a susceptible wheat (*Triticum aestivum* L.) variety (BARI Gom 26) to determine the effect of soil application of K on blast disease management and the growth and yield. The experiment was carried out in separate plastic pots containing 18 kg of virgin soil at the net house of the farm of the Bangladesh Institute of Nuclear Agriculture headquarters, Mymensingh for two growing seasons of 2018-19 and 2019-20 following a completely randomized design with five treatments and three replications. The doses for soil application were 0, 50, 75, 100 and 125 K kg ha^{-1}, respectively. Disease incidence (%) and severity (%) of the wheat blast were evaluated at 11, 13 and 15 days after inoculation (DAI). At 15 DAI, the highest disease incidence (95.45%) was found in absolute control followed by K_0 (0 kg K ha^{-1}) (91.98%) and the lowest blast incidence (64.49%) was found in K_4 (125 kg K ha^{-1}) which was statistically similar with K_3 (100kg K ha^{-1}) (70.87%). At 15 DAI, the highest blast severity matrix (90%) was found in absolute control followed by K_0 (0 kg K ha^{-1}) (76.02%) and the lowest (46.18%) was found in K_4 (125kg K ha^{-1}) which was significantly different with others. Among the treatments, 125 kg K ha^{-1} produced the highest grain yield (26.97 g pot^{-1}) and the lowest (5.79 g pot^{-1}) was found from the absolute control. Flag leaf samples were randomly collected before head emergence from each pot and analyzed in the laboratory for plant nutrient content. The K concentration of flag leaves sample ranged from 1.71% to 5.51% with an average concentration of 3.02%, where the highest K content (%) was recorded in K_4 (5.51%) and the lowest was found in absolute control (1.71%). Potassium fertilization appeared to reduce the severity and improve the yield of wheat. Correlations suggested that improving dry matter production and K uptakes at the boot stage by K fertilization can reduce severity later in the growing season and increase wheat grain yield. It can be concluded that high K concentration on leaf tissue was important to decrease wheat blast symptoms.

Introduction

Wheat is grown all over the world, under a variety of climatic settings ranging from subtropical to temperate. However, widespread wheat production has always attracted a variety of restrictions, resulting in the establishment of biotic and abiotic constraints. Among these, blast is one of the most devastating wheat diseases (Saharan et al., 2016). Wheat blast is a fast-acting and devastating fungal disease that threatens food safety and security in tropical areas in South America and South Asia. The disease was first identified in the state of Parana, Brazil in 1985 (Igarashi et al., 1986) and caused large-scale destruction of wheat. Later on, it was observed in Bolivia, Paraguay, Argentina and Uruguay (Kohli et al., 2011). Recently the occurrence of wheat blast in Bangladesh (Callaway, 2016; Malaker et al., 2016) has rung alarm bells for many wheat-growing nations. Wheat blast caused by *Magnaporthe oryzae* (synonymous with *Pyricularia oryzae*) Pathotype *Triticum* (MoT) (Zhang et al., 2016;

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Gladieux et al., 2018). Wheat blast can cause up to 100% yield loss under favourable conditions (Kohli et al., 2011; Cruz et al., 2012; Martínez et al., 2019). Higher yield losses occur when favourable weather conditions coincide with the vulnerable growth stages of the host during infection (Urashima et al., 2009). When favorable weather conditions coincide with the host's vulnerable growth stages during infection, higher yield losses occur (Urashima et al., 2009). Increasing evidence suggests that mineral nutrients play a critical role in plant stress resistance (Amtmann et al., 2008; Romheld and Kirkby, 2010; Marschner et al., 2012). Out of all the mineral nutrients, K plays a particularly critical role in plant growth and metabolism, and it contributes greatly to the survival of plants that are under various biotic and abiotic stresses. The importance of K fertilizer for the formation of crop production and its quality is known. As a consequence, potash consumption has increased dramatically in most regions of the world (Pettigrew, 2008).

Host resistance against infection by pathogens can be affected by nutrient deficiency or toxicity (Marschner, 1995). Potassium (K) is involved in increasing root growth, improving water and nutrients uptake by roots, increasing cell wall strength and reducing lodging, reducing respiration, promoting photosynthesis, helping in the translocation of sugars and starch, increasing protein content, preventing chlorophyll degradation and more importantly reducing the intensity of several diseases (Marschner, 1995; Prabhu et al., 2007a; Rice, 2007). In many circumstances, plants with insufficient K are more sensitive to infection than those with sufficient K. For example, when there was no supply of K, the rate of rice borer infestation was highest, but when the K concentration increased, the rate of infestation reduced rapidly (Holzmueller et al., 2007). Similar results were found with a *Discula destructiva* Redlin infection in *Cornus florida* L. (Holzmueller et al., 2007). In several host plants, K fertilizer has been shown to reduce pest infestation and disease incidence. Perrenoud (1990) reviewed 2449 references and found that the use of K significantly decreased the incidence of fungal diseases by 70%, bacteria by 69%, insects and mites by 63%, viruses by 41% and nematodes by 33%. Meanwhile, K increased the yield of plants infested with fungal diseases by 42%, bacteria by 57%, insects and mites by 36%, viruses by 78% and nematodes by 19%. Mann et al. (2004) reported that spraying with KCl suppresses infection of powdery mildew and septoria leaf blotch in wheat due to an inhibition of fungal spore germination. Information related to the effect of K on wheat resistance or susceptibility to blast is, for the best of our knowledge, missing in the literature. Therefore, the objective of this study was to investigate if the severity of wheat blast might be reduced and, as a result, the effect of enhanced K availability on yield contributing parameters.

Materials and Methods

Experimental site and plant material

The experiments were conducted during the cropping seasons of 2018-19 and 2019-20 in the net house of Plant Pathology Division, Bangladesh Institute of Nuclear Agriculture and Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh. Blast susceptible wheat variety BARI Gom 26 was used in the research work.

Climatic Conditions

The climate of the experimental area was under the subtropical climate zone. The zone is characterized by high rainfall, high humidity, high temperature and relatively long day (up to 14 hours) during April to September 2018 and scanty rainfall, low humidity, low temperature and short -day period during October 2019 to March 2020.

Pot preparation, potassium fertilizer treatment

Sieved soils (<2 mm) were well mixed with basal nutrients and individual treatments of K were filled into undrained plastic pots (diameter 280 mm, depth 2800 mm) at 18 kg pot^{-1}. Five levels of added K were applied to the pot using a Completely randomized design (CRD) with three replications (Table 1).

Table 1. Treatments used to determine the effect of potassium on blast disease incidence of wheat

Treatment ID	Treatment symbol	Rate of K (kg ha^{-1})	Source of K	Other Fertilizers dose
K_A	Absolute Control	0	0	0
K_0	T_0	0	0	Recommended
K_1	T_{50}	50	MoP	Recommended
K_2	T_{75}	75	MoP	Recommended
K_3	T_{100}	100	MoP	Recommended
K_4	T_{125}	125	MoP	Recommended

Muriate of potash (MoP) was used as it is the dominant K fertilizer (Moore, 2004). The K treatments were created by amending the soil with finely ground MoP at the appropriate rate and mixing it evenly through the soil by hand. Except in the absolute control, all treatments were fertilized with N, P, S, Mg, Zn, and B as basal doses @ 100, 20, 13, 6, 2, and 1.1 kg ha^{-1}, respectively according to fertilizer recommendation guide (BARC, 2018) from Urea, TSP, gypsum, magnesium sulphate, zinc sulphate heptahydrate, and solubor, respectively during pot preparation. Thirty wheat seeds were sown at a depth of 2 cm in each pot and were thinned to fifteen seedlings after emergence. One-third dose of urea and full doses of other fertilizers were applied during the pot preparation. The rest two-third doses of urea were applied at 20 and 40 days after sowing (DAS). All pots were managed and maintained according to conventional Bangladeshi wheat production practices (Table 2). A diagram showing the pre-boot stage of wheat variety BARI Gom 26 at different levels of K application has been shown in Fig. 2.

Table 2. Agronomic data and disease incidence and severity parameters during the cultivation cycles of 2018-19 and 2019-20

Variables	1st cropping season	2nd cropping season
Date of sowing	Nov. 29, 2018	Nov. 29, 2019
Variety	BARI Gom26	BARI Gom26
No. of seeds sown	30	30
No. of plants preserved	15	15
Irrigation beginning	12 DAS	12 DAS
Irrigation interval	Every alternate day	Every alternate day
Soil loosening	15 and 30 DAS	15 and 30 DAS
Weed control	15, 30 and 45 DAS	15, 30 and 45 DAS
Potassium fertilization	KCl was applied as basal with the recommended fertilizer before sowing	KCl was applied as basal with the recommended fertilizer before sowing
Date of inoculation	65 DAS	65 DAS
Disease severity data collection	11, 13 & 15 DAI	11, 13 & 15 DAI
Date of harvest	March 12, 2019	March 12, 2020

Culture of M. oryzae Triticum and Inoculation

Pure culture of MoT was collected from Molecular Lab, Bangladesh Institute of Nuclear Agriculture (BINA). The culture was multiplied in Oatmeal agar media. For sporulation, the medium plates were incubated at 30°C with continuous NUV light (650 lux) for 15-20 days. The density of the spores was calculated by harvesting the conidia/mycelia by flooding the Petri dish with 5 ml of sterile distilled water and dislodging the conidia with a bent glass rod. Spore density was 1 x 10^5 per mL as it was calculated in the Hemocytometer count. Wheat plants grown in the pot were inoculated with *Magnaporthe oryzae* Triticum spores at 58 (emergence of inflorescence just completed) to 62 (beginning of anthesis) Zadok's growth stages (Zadok et al., 1974). After inoculation, the plants were kept covered under polythene shed for 48 h to maintain high humidity (>80% RH) and a temperature of 30±1°C. Observations were made for the expression of blast disease symptoms. Isolation of the causal organism was made from the infection court for the confirmation of successful infection by *Magnaporthe oryzae* pathotype *Triticum*.

Assessment Procedures of Disease

On the 11th, 13th, and 15th days after inoculation (DAI), data on disease incidence and severity were obtained. Visual estimation on spikes (Fig. 1) was used to evaluate disease on a 0-100 scale (Stubbs et al., 1986). The incidence of wheat blast disease in each pot was determined using the following formula developed by Rajput and Bartaria (1995) Number of spikes infected per replication expressed in percentage;

% Blast incidence = Pi/Pt x 100

Where, Pi = Number of spikes infected, and Pt = Total number of spikes counted.

Disease severity was calculated following the formula according to Roy et al. (2021);

Disease Severity (%) = (% spike incidence × % damaged area on a spike) × 100

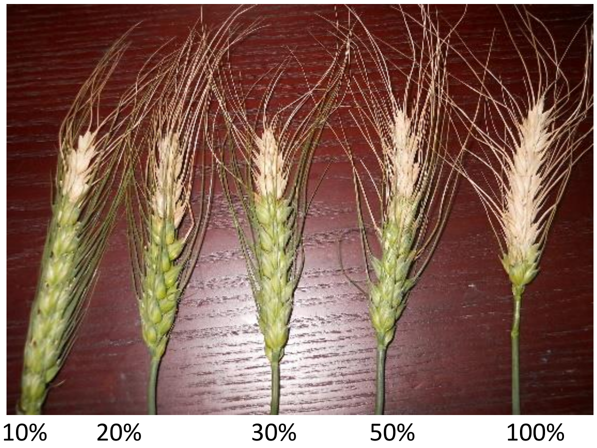

Figure 1. Diagram of % severity of blast in wheat spike

Crop harvesting and yield data collection

The crop was harvested when it was fully mature, and data on yield and yield-related parameters were recorded. Grains were kept in a zippered lock polybag at a temperature of 4°C until further testing. A digital balance was used to record the weight of thousands of grains.

Collection of plant samples

Flag leaf samples were randomly collected before head emergence from each pot and after proper labeling, the samples were brought to the laboratory. All chemical analyses were done at the Department of Agricultural Chemistry of Bangladesh Agricultural University, Mymensingh.

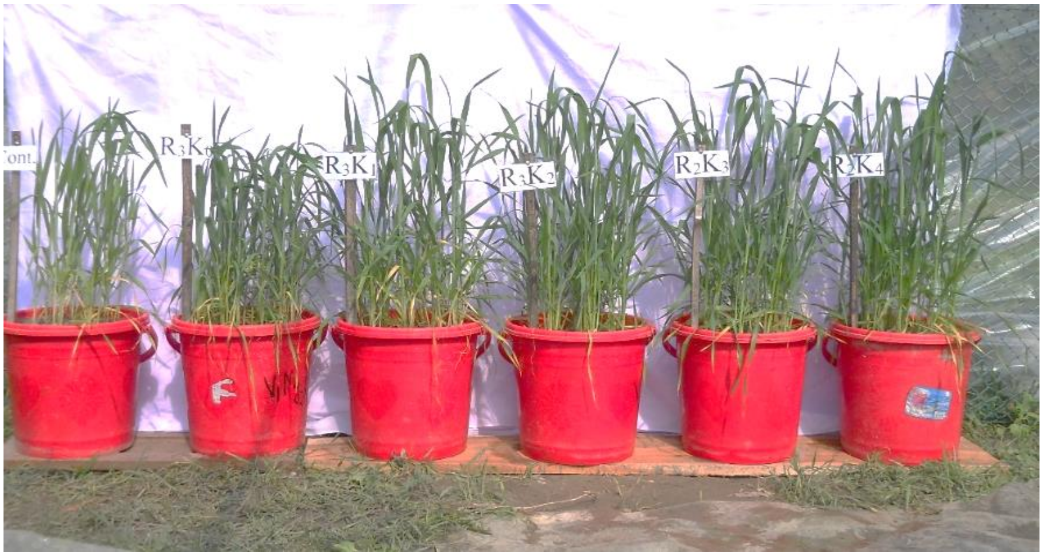

Figure 2. Diagram showing pre-boot stage of wheat variety BARI Gom 26 at different levels of potassium application

Preparation of plant extract

Flag leaves samples of wheat plants from each pot were collected before panicle initiation and oven-dried (at 65°C for 48 hours), crushed and stored in plastic bottles. The plant extract was prepared following the wet oxidation technique reported by Singh et al. (1999). Extracts of wheat plants were stored in separate plastic bottles for further chemical analysis. The separate plant extract was prepared according to the technique suggested by Estefan et al. (2013) for silicon analysis.

Determination of the mineral nutrients

Calcium, Mg, P, Na, K and S of plant and soil samples were determined following standard methods of analyses (Ghosh et al., 1983 and Page et al., 1982). Boron (B) was quantified in plant and soil samples using the Azomethine-H technique (Page et al., 1982). Silicon was analyzed in plant and soil samples using the spectrophotometric method developed by Estefan et al. (2013).

Data analyses

Statistical analysis of phenotypic and yield data was performed using Minitab version 17.0 of the statistical program (MiniTab, State College, PA, USA). When compared to the main effects of treatments, the experiment-treatment interactions were not significant ($P \leq 0.05$). The data from the variable under study were subjected to analysis of variance (ANOVA) and t-test ($P \leq 0.05$) treatment mean comparisons.

Results and Discussion

Incidence (%) and severity (%)

Incidence (%) and severity (%) of blast in wheat plants inoculated by MoT were evaluated at 11, 13 and 15 days after inoculation (DAI) (Fig. 3). Significant differences of percent blast incidence were observed among the different levels of K fertilizer at different DAI. At 11 DAI, the highest blast incidence (41.7%) was found in K_0 (0 kg K ha^{-1}) followed (41.69%) by K_3 (100kg K ha^{-1}) and the lowest disease incidence (30.77%) was found in K_2 (100kg K ha^{-1}). At 13 DAI, the highest blast incidence (67.44 %) was found in K_1 (100kg K ha^{-1}) followed (66%) by K_0 (0 kg K ha^{-1}) and the lowest disease incidence (57.01%) was found in K_4 (125kg K ha^{-1}). All the levels of K showed statistically similar blast incidence percentages at 11 and 13 DAI. At 15 DAI, the highest disease incidence (95.45%) was found in absolute control followed by K_0 (0 kg K ha^{-1}) (91.98%) and the lowest blast incidence (64.49%) was found in K_4 (125 kg K ha^{-1}) which was statistically similar with K_3 (100 kg K ha^{-1}) (70.87%). In the case of the percent blast severity matrix of wheat plants, significant differences were observed among the different varieties at different DAI.

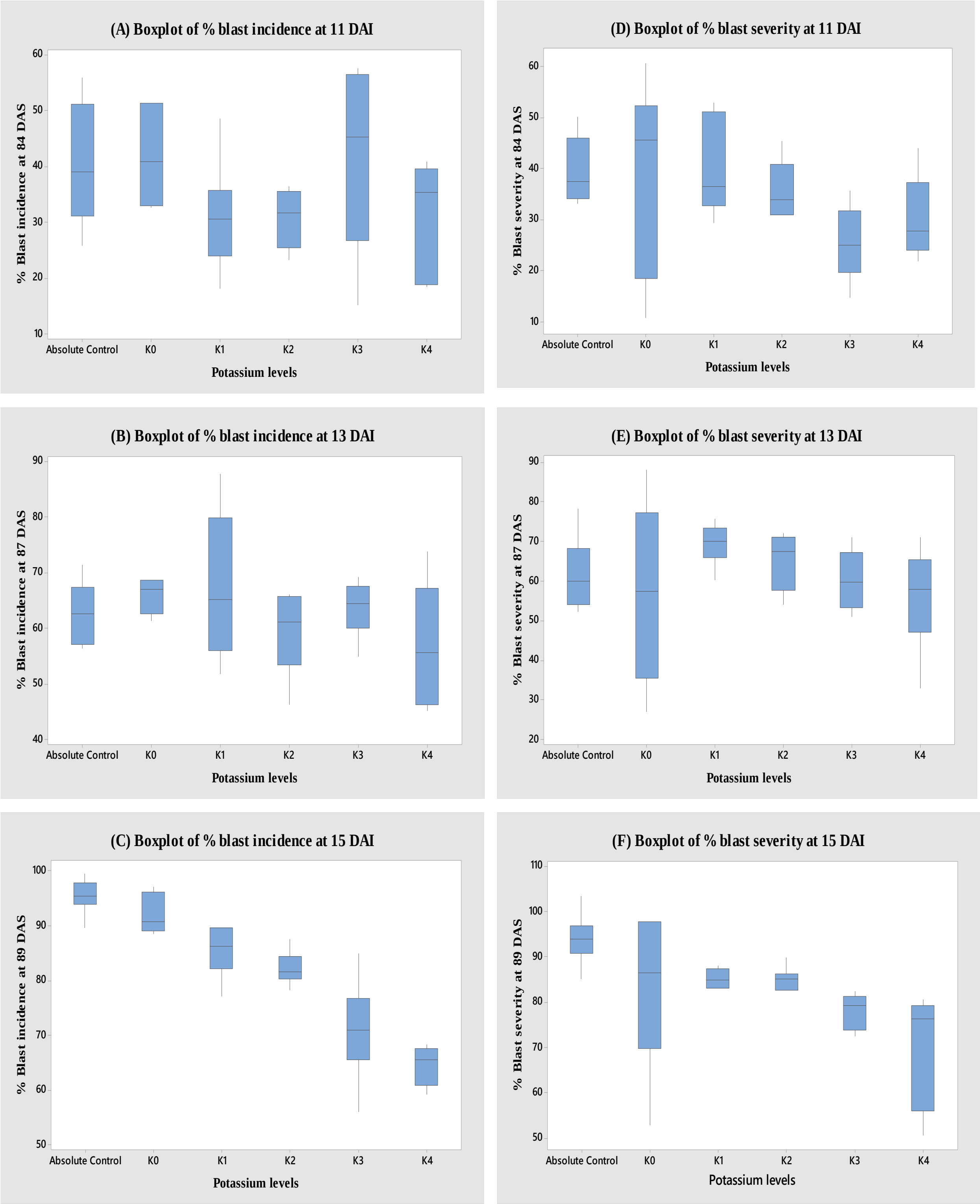

Figure 3. Boxplot distribution of blast incidence and severity observed on heads of wheat (*Triticum aestivum*) cv. BARI Gom 26 after inoculations with *Magnaporthe oryzae* pathotype *Triticum*. Heads were not detached from the plant. Boxplots A, B and C represent blast incidence and D, E and F represent blast severity as mean disease index assessed at 11, 13 and 15DAI, respectively. Median values are denoted by solid lines within the box while box boundaries show the 25th and 75th percentiles. Box whiskers indicate the highest and lowest data values. Head tissue was considered diseased when it was chlorotic and/or covered in pathogen spores.

At 11 DAI, the highest blast severity matrix (15.04 %) was found in absolute control followed by K_0 (0 kg K ha^{-1}) (13.94%) and the lowest blast severity matrix (7.26 %) was found in K_4 (125 kg K ha^{-1}) which was significantly different from all other treatment. At 13 DAI, the highest blast severity matrix (47.23%) was recorded in K_1 (100 kg K ha^{-1}) followed by absolute control (41.22%) and the lowest blast severity matrix (33.52%) was observed in K_4 (125 kg K ha^{-1}) but all the treatment showed statistically similar blast severity matrix. At 15 DAI, the highest blast severity matrix (90%) was found in absolute control followed by K_0 (0 kg K ha^{-1}) (76.02%) and the lowest blast incidence (46.18%) was found in K_4 (125kg K ha^{-1}) which was significantly different with others. A view of the effect of different levels of K on blast incidence and severity in wheat variety BARI Gom 26 has been shown in Fig. 4.

Our findings showed that the severity of infection by MoT was greatest at zero K^+ supply, but decreased rapidly as K^+ was increased. Similar results were obtained with Helminthosporium cynodontis on bermudagrass (Matocha and Smith, 1980), wheat infected with the rust Puccinia striiformis (Kovanci and Colakoglu, 1976), the powdery mildew fungus Erysiphe (now Blumeria) graminis (Boquet and Johnson, 1987) and the take-all fungus G. graminis (Brennan, 1995), and onion infected with the downy mildew fungus Peronospora destructor (Develash and Sugha, 1997). Our result was also lined with Prabhu et al. (1999), who reported that panicle blast severity in rice decreased with increasing rates of K in the absence of nitrogen (N0). Similar results were found with a *Discula destructiva* Redlin infection in *Cornus florida* L. (Holzmueller, et al., 2007). Williams and Smith (2001) also reported that increased K fertilizer significantly reduced the disease incidence of stem rot and aggregate sheath spot (AgSS), and negative correlations were found between the percentage of K in leaf blades and disease severity. Our result also agrees with the limited previous findings by Regmi et al. (2002) and Sharma et al. (2004), who reported that K application reduced the severity of foliar blight in wheat. Sweeney et al. (2000) suggested that the reduced disease severity and increased yield obtained with K^+ fertiliser might have been, at least in part, because of Cl_2 in the KCl fertiliser. Marschner (2012), reported that increasing K supply decreased stem rot incidence in rice and enhanced shoot growth, indicating that high K supply increases resistance/tolerance of plants. Results similar to those in rice have been obtained with oil palms infected with *Fusarium* (Ollagnier and Renard, 1976) and wheat infected with stripe rust (Kovanci and Colakoglu, 1976). Decreased cell permeability and decreased susceptibility of tissue to maceration and penetration during pathogen infection are some of the physiological functions of K on host resistance to rice diseases (Prabhu et al., 2007a). Wheat plants were more resistant to *Septoria nodorum* when plants were grown under high levels of K (Cunfer et al., 1980). The high susceptibility of K-deficient plants is related to the metabolic functions of this macronutrient (Marschner, 1995).

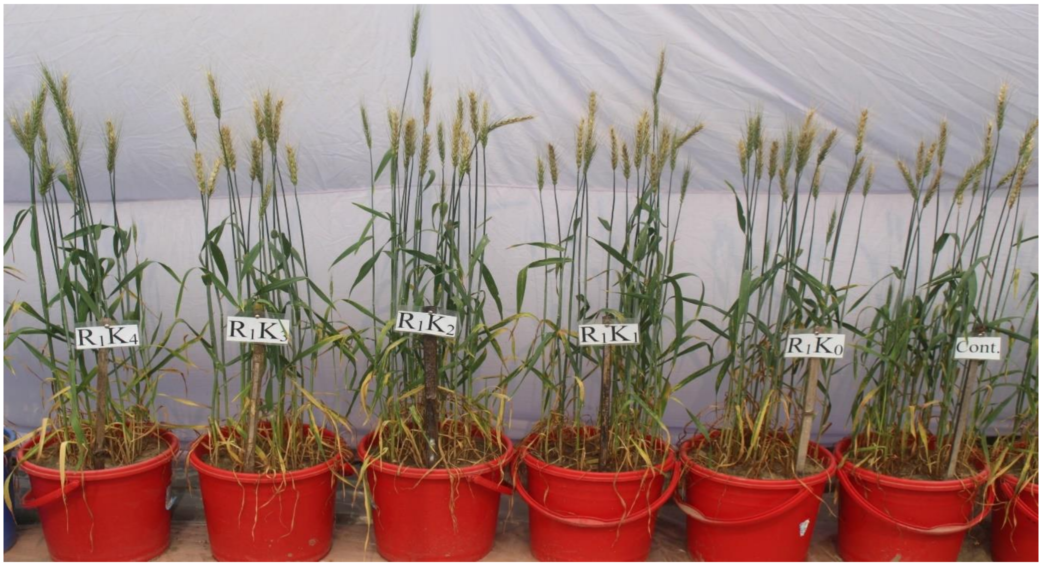

Figure 4. Effect of different levels of K on blast incidence and severity in wheat variety BARI Gom 26

Effect of different levels of K on agronomic parameters of wheat crop

Number of total spike pot^{-1}

The number of total spike pot^{-1} was unaffected by the application of K (Table 3). The maximum number of total spike pot^{-1} (30.5) was obtained from75 kg ha^{-1} K and the minimum number (18) was from absolute control. Although the differences were not significant statistically, the applied treatments showed a higher number of total spike pots^{-1} as compared to the absolute control. Talukder (1992) found that the application of K increased the number of panicles unit^{-1} area.

Total number of seed pot^{-1}

K had a significant effect on the total number of seed pot^{-1} (Table 3). The highest total number of seed pot^{-1} (1092) was found when the crop was fertilized with 125 kg K ha^{-1} which was statistically identical to 100 kg K ha^{-1} and the lowest (367) was recorded in absolute control. It can be concluded that the increase in K levels caused a considerable increase in the total number of seeds pot^{-1}.

Table 3. Mean yield and yield components of wheat variety BARI Gom 26 as affected by different levels of potassium

Treatment	No. of total spike pot^{-1}	No. of seed pot^{-1}	No. of seed spike^{-1}	wt. of seed spike^{-1}(g)	Yield pot^{-1} (g)	WTS (g)
K_A	18.0b	367d	20.15c	0.31d	5.79e	14.83c
K_0	28.8a	606cd	21.36c	0.36cd	11.19de	17.16bc
K_1	27.5a	777bc	27.83bc	0.46cd	13.38cd	16.38bc
K_2	30.5a	882ab	27.49c	0.53bc	17.70bc	19.15b
K_3	29.3a	1044a	35.38ab	0.71b	22.66ab	19.98ab
K_4	27.5a	1092a	38.04a	0.91a	26.97a	23.37a

Grouping was done using the Tukey method at 95% level of confidence. Values with the same letter are not significantly different based on Tukey test. N=6. Note: K_A: Absolute control, K_0: 0 kg ha^{-1} potassium, K_1: 50 kg ha^{-1} potassium, K_2: 75 kg ha^{-1} potassium, K_3: 100 kg ha^{-1} potassium and K_4: 125kg ha^{-1} potassium

Number of seed spike^{-1}

It is an important yield contributing parameter which greatly influences crop production. The influence of K on the number of seed spike^{-1} was statistically significant (Table 3). The number of seed spike^{-1} was highest (38.04) at 125 kg K ha^{-1} and the lowest (20.15) was at absolute control. The application of K improved the number of seeds per spike which might be due to the favorable effects of K on nutrient uptake, photosynthetic activity, and improving its mobilization (Zeng, 1996). The results are in conformity with Sorour et al. (1998) who reported that adding K fertilizer significantly increased grain number panicle^{-1}. Zhu et al. (1998) also observed that the number of grains panicle^{-1} was the highest with 11.5 kg N and 27.5 kg K_2O. Kalita et al. (1992) concluded that the number of grains particle^{-1} increased significantly with up to 40 kg K_2O ha^{-1}. Debnath (1999) stated that a higher level of P and K significantly increased the grain number of bearing tillers plant^{-1}.

Weight of seed spike^{-1}

The influence of K on the weight of seed spike^{-1} was statistically significant (Table 3). The weight of seed spike^{-1} increased with the increasing dose of K. Weight of seed spike^{-1} was highest (0.91g) at 125kg ha^{-1} K ha^{-1} and the lowest (0.36g) was at absolute control. Sweeney et al. (2000) found that fertilization with K increased kernel weight by nearly 8% and tended to reduce the number of kernels head^{-1}, but had no effect on heads m^{-2}.

Thousand grain weight

The weight of 1000 grains showed significant variation due to K application (Table 3). Numerically, the highest 1000-grain weight (23.37 g) was found by applying K at the rate of 125 kg K ha^{-1} and the second-highest 1000-grain weight (19.98g) was found at 100 kg K ha^{-1} and the lowest (14.83 g) was obtained from absolute control. Positive effects of K application on 1000-grain weight were also reported by Talukdar (1992) who stated that application of K up to 60 kg K_2O ha^{-1} increased 1000-grain weight. Mondal et al. (1989) pointed out that, increasing rates of N and/or K_2O increased the 1000 grain weight similarly, application of N and K_2O at 60 + 40 kg ha^{-1} at transplanting and in two equal split dressing increased 1000-grain weight. Islam (1999) observed that application of K up to 30 kg ha^{-1} significantly increased the 1000 grain weight. Mann et al. (2013) reported that there was a significant increase 1000 grains weight of wheat under higher K application rates.

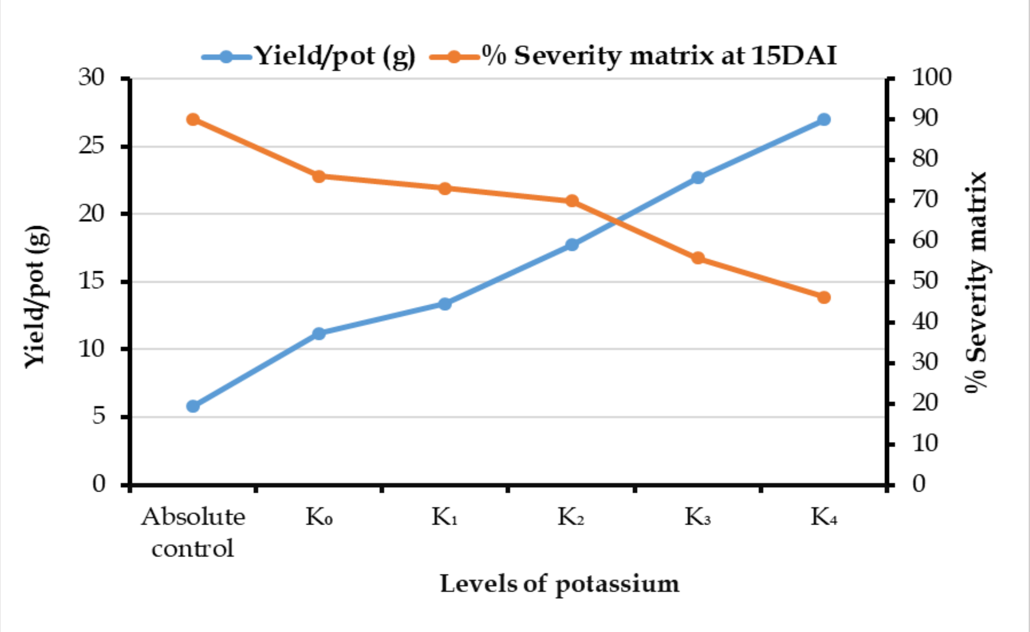

Figure 5. Response of different levels of potassium-treated wheat cv. BARI Gom-26 to yield pot^{-1} (g) and blast disease severity matrix (%).

Yield pot^{-1}

Generally, the five components influence the grain yield namely, number of effective tillers plant^{-1}, number of spike plant^{-1}, number of spikelets spike^{-1}, number of grains spike^{-1} and individual grain weight. Different K levels showed significant variations in the grain yield of wheat (Table 3). Among the treatments, 125 kg K ha^{-1} produced the highest grain yield (26.97 g pot^{-1}) and the lowest (5.79 g pot^{-1}) was found from the absolute control. The second highest was (22.66 g pot^{-1}) obtained from 100 kg ha^{-1} K (Table 3). These results agree with Vijayalakshmi and Mathan (1994) who observed that direct application of 25 kg K_2O increased grain yield significantly. They also found that grain yield was not increased by further K application. This result is also in agreement with the findings of Mesbah (2009), Saha et al. (2010) and Hamouda et al. (2015) who indicated that the application of K fertilizer had significant increasing effects on yield and its components of the wheat plant (No. of spikes character and yield of straw, grain and biological yield as well as 1000-grain weight) as compared with untreated plants. Yield per pot showed negative correlation with the disease severity matrix (Fig. 5). With the increased of level of K yield increases but the disease severity matrix decreases.

Mineral nutrients content in flag leaves

Mineral concentration in the plant depends essentially on the processes of absorption, transport, and accumulation. Several non-ionic factors have been identified as affecting interactions between K and other nutrients in the plant (Dibb and Thompson, 1985). Balanced nutrition is a factor that increases resistance to plant disease (Fageria, 2009). The results pertaining to the effect of the application of K at different levels on leaf nutrient content are presented in Table 4. Phosphorus, a vital plant macronutrient, makes up about 0.2% of a plant's dry weight. It is one of the major limiting factors for plant growth (Schachtman et al., 1998). This study revealed that the concentration of P ranges from 0.26% to 0.35% with an average concentration of 0.31%. The phosphorous content of wheat increased with increasing levels of K in comparison to control. Similar results were reported by Arya and Kalra (1988). Research has shown that K interacts with phosphorus (P) and that together they may interact with other nutrients. Stukenholtz et al. (1966) observed that with increasing levels of soil or applied K, the severity of P induced Zn^{2+} deficiency of corn decreased. Ward et al. (1963) showed that higher soil K saturation levels reduced P-induced Zn^{2+} deficiency. Previous results also confirmed the effects of K on the nutrient status of the wheat plant and found that K had a significant increase in nutrient concentrations (N, P, K) of wheat leaves, straw and grains such as Gaj and Górski (2014) and Hamouda et al. (2015).

Table 4. Effect of different levels of potassium application on calcium, magnesium, phosphorus, potassium, sulphur, boron, sodium and silicon content of flag leaves of wheat

Treatment	% Ca	% Mg	% P	% K	% S	ppm B	% Na	% Si
K_A	0.14a	0.53a	0.26b	1.71c	0.47a	26.47ab	0.35a	3.53b
K_0	0.17a	0.71a	0.30ab	2.11bc	0.47a	27.58ab	0.35a	4.60ab
K_1	0.22a	0.67a	0.32ab	2.88bc	0.48a	15.84b	0.37a	4.85ab
K_2	0.37a	0.74a	0.29ab	2.24bc	0.52a	23.07ab	0.36a	4.57ab
K_3	0.40a	0.69a	0.35a	3.67ab	0.62a	32.73ab	0.35a	6.13a
K_4	0.26a	0.71a	0.34a	5.51a	0.50a	34.01a	0.35a	4.43ab
Minimum	0.14	0.53	0.26	1.71	0.47	15.84	0.35	3.53
Maximum	0.40	0.74	0.35	5.51	0.62	34.01	0.37	6.13
Average	0.26	0.67	0.31	3.02	0.51	26.62	0.35	4.68

Grouping was done using the Tukey method at 95% level of confidence. Values with the same letter are not significantly different based on Tukey test. N=6. Note: K_A: Absolute control, K_0: 0 kg ha^{-1} potassium, K_1: 50 kg ha^{-1} potassium, K_2: 75 kg ha^{-1} potassium, K_3: 100 kg ha^{-1} potassium and K_4: 125kg ha^{-1} potassium

Potassium plays an important role in strengthening the cell walls of plants and being involved in tissue sclerenchyma lignification associated with plant resistance to disease (Sugiyanta, 2007). This vital nutrient prevents plant diseases by encouraging the growth of thicker outer walls in epidermal cells. While there are a significant number of observations on the function of K and plant diseases, there appears to be little quantifiable evidence on the concentration of K in soil or plant tissue that results in the observed effect on the expression of the disease (Prabhu et al., 2007b). The K concentration of flag leaves sample ranged from 1.71% to 5.51% with an average concentration of 3.02%, where the highest K content (%) was recorded in K_4 (5.51%) and the lowest was found in absolute control (1.71%). The result revealed that with an increase in K supply, the nutrient continues to be increasingly absorbed as seen in increased leaf K content. Venkitaswamy et al. *(*2011) also reported results in similar lines. Schurt et al. (2015) reported that the foliar K concentration on leaf sheaths of rice tissue increased by 61.48 and 116.05% to cultivars BR-IRGA 409 and Labelle, respectively, as the K rates increased from 0 to 100 mM. Plant metabolism is influenced by K, and low K concentrations in the plant may change metabolism, causing favorable conditions for some plant diseases (Mengel and Kirkby, 1982).

Calcium, Mg^{2+}, and K^+ are dominant cations in plant nutrition and have received considerable attention in the scientific literature. Calcium content of plant samples ranged from 0.14 % to 0.40 % with the average concentration was 0.26%, where the highest Ca content (%) was recorded in K_3 (0.40 and the lowest Ca content (0.14%) was found in absolute control. Rhodes et al. (2018) reported that K treatments (0, 100, 200 and 300 kg K ha^{-1}, as KCl) resulted in significant ($P < 0.001$) increases in leaf K concentrations, along with relatively consistent increases in sugarcane and sucrose yields with increasing leaf K. Increased leaf K concentrations led to decreases in leaf Ca and Mg in sugarcane.

Magnesium (Mg) content ranges from 0.53%to 0.74% with an average concentration of 0.67%, where the highest Mg content (%) was recorded in K_2 (0.74%) and the lowest (0.53%) was found in absolute control. Synergistic and antagonistic effects between K and Mg occur during their transport from root to shoot and distribution within plants. Mg^{2+} transport from roots into shoots markedly decreased with increasing K supply in wheat plants (Karlen et al., 1978; Ohno and Grunes, 1985). Similar depressive effect of high K^+ on Mg^{2+} transport was also found in rice (Ding et al., 2006), tomato (Ohno and Grunes, 1985), and Pinus radiate (Sun and Payn, 1999). Omar and Kobbia (1966) observed that added K decreased Mg dramatically, whereas added Mg depressed K^+ concentration only slightly. They concluded that there was a "one-way" competition between K^+ and Mg^{2+}. Ohno and Grunes (1985) reported that both in soil and hydroponics experiments, Mg^{2+} concentration in the shoot was depressed with increasing K supply because of the inhibitory effect of K^+ on Mg^{2+} translocation; however, Mg supply did not affect the total uptake or concentration of K+ in plants. It is clear that K exerts a strong antagonistic effect on Mg transport, while Mg exerts either a synergistic or no effect on K transport into shoots. Our results also showed that the concentration of Mg decreased with increasing K supply. Sulphur (S) content ranges from 0.47%to 0.62% with an average concentration of 0.51%. Sulphur nutrition of barley plants influences the effect of K on Zn uptake from nutrient solutions. Apparently, good S levels along with adequate K improve Zn uptake (IPNI, 1998). Boron has a direct function in cell wall structure and stability and has a beneficial effect on reducing disease severity. Boron plays a significant function in phenol metabolism and lignification related to plant defensive pathways (Stangoulis and Graham, 2007). The concentration of B in this study showed a significant difference. It ranges from 15.84 ppm to 34.01 ppm with an average concentration of 26.62 ppm. The highest B content (34.01 ppm) was recorded in K_4 and the lowest

Boron content (ppm) was found in absolute control (15.84). Graham and Webb (1991) reported that the most beneficial effects of B are the reduction of the pathogenic fungus *Plasmodiophora brassicae* Woronin in Brassica species (Stangoulis and Graham, 2007) as the movement of fungal hyphae through the cortex is sometimes prevented by B. Silicon (Si) is not classified as an essential element for plants, but numerous studies have demonstrated its beneficial effects in a variety of species and environmental conditions, including low nutrient availability. Plants species differ greatly in their ability to accumulate Si with values ranging from 0.1% to 10% Si on a dry weight basis (Epstein, 1994, 1999). The concentration of Si in this study ranges from 3.53% to 6.13% with an average concentration of 4.68%. The highest Si content (6.13%) was recorded in K_3 and the lowest (3.53%) was found in absolute control. The main positive role of Si in K-deficient plants has been reported as increased K absorption and restored physiological performance that had been impaired by K deprivation (Pavlovic et al., 2021). In K deprived maize and sorghum, Si supplementation did not improve K intake, but it did restore physiological activity that had been harmed by a K deficiency i.e., water use efficiency and photosynthesis (Chen et al., 2016). Chen et al. (2016), showed that increased K^+ concentration in the xylem sap of Si-fed plants was accompanied by up-regulated transcript levels of *SKOR* genes mediating K secretion from root cortex cells into the xylem. There were no significant interactions observed between K and Na supply for flag leaf Na concentrations. The average concentration of Na was 0.35%. In a pot experiment with wheat Krishnasamy et al. (2014) reported that soil K levels did not influence shoot Na concentration and content. However, they found an interesting observation between K and sodium (Na) interaction on alfalfa. When K was deficient, the classical K deficiency symptom was quite apparent. Alfalfa grown on soils high in Na, the K deficiency symptom had a somewhat different appearance in their study.

Table 5. Correlation matrix among blast incidence (%), severity matrix (%) and various nutrients concentration in wheat flag leaf

Parameters	***% Incident***	***% Severity matrix***	***% Ca***	***% Mg***	***% P***	***% K***	***% S***	***ppm B***	***% Na***
% Severity matrix	0.66								
% Ca	-0.22	-0.68							
% Mg	-0.38	-0.68	0.64						
% P	-0.19	-0.74	0.58	0.59					
% K	-0.36	-0.83	0.35	0.40	0.82				
% S	0.20	-0.43	0.85	0.32	0.63	0.35			
ppm B	0.42	-0.30	0.24	0.12	0.37	0.56	0.44		
% Na	-0.66	-0.42	0.32	0.52	0.46	0.17	0.07	-0.63	
% Si	0.15	-0.39	0.74	0.56	0.79	0.33	0.84	0.20	0.43

Relationship among blast incidence (%), severity matrix (%) and various nutrients concentration in wheat flag leaf

Disease incidence and severity have a close relationship with the availability of nutrients in plants. Among the available nutrients in wheat, K showed a strong negative correlation (r =-0.83) with disease severity (Table 5). Plants with nutrient deficiency are more susceptible to disease and pests, and supplementing the necessary nutrient(s) may improve their tolerance. The Si concentration of plants is negatively correlated with disease severity and incidence indicating greater resistance to the wheat blast disease which is fully supported by Huber et al. (2012).

Conclusion

This study was conducted over two wheat seasons. It included five levels of K treatment to determine precisely how wheat yield losses are caused by the blast, and how this is influenced by potash fertilization. It was carried out under semi-controlled conditions. Application of K decreased wheat severity and increased grain yield in both years. The present study also revealed that the high K concentration on flag leaf tissue contributed to increasing wheat resistance to blast and which supports other reports in the literature. Potassium uptake and utilization is closely related to the availability and uptake of other nutrients. Improved response to other nutrients and increased profitability can occur only when interactions are taken into account. Future improvements in disease management, yield and quality will require a better understanding and management of these interactions. Wheat with adequate K fertilization suffers less economic damage caused by the blast. This study underlines the importance of K nutrition in minimizing blast damage to wheat as part of a holistic crop management approach.

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