Management of yellow rust (*Puccinia striiformis* f. sp. *tritici*) and stem rust (*Puccinia graminis* f.sp *tritici*) of bread wheat through host resistance and fungicide application in Southern Ethiopia

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Management of yellow rust (*Puccinia striiformis* f.sp. *tritici*) and stem rust (*Puccinia graminis* f.sp *tritici*) of bread wheat through host resistance and fungicide application in Southern Ethiopia

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**Abstract:** Field experiment was carried at Burji, Bonke and Chencha during the 2018 cropping season to evaluate the effects of host resistance and fungicide application on yellow and stem rusts and grain yield (GY) of bread wheat. Five wheat varieties and four different fungicides were included as treatment and laid out in factorial arrangement in randomized complete block design with three replications. Significant (*p* ≤ 0.01) difference was observed in the magnitude of the parameters of disease and crop measured between treatments. Results showed that the mean terminal severities of yellow and stem rusts were highest at Chencha than at Burji and Bonke. Yellow and stem rust terminal severities as low as 46.41%, 40.69%, 29.22%, 28.24% and 21.74% and 43.67%, 42.54%, 40.93%, 16.07% and 17.15% were recorded on Hidase, Kubsa, Ogolcho, Wane and Shorima varieties, respectively, due to the integrated use of Tilt 250 EC, Rex® Dou and Natura 250 EW foliar applications across the three locations. Crosswise assessment revealed that the lowest area under the disease progress curve (AUDPC) of yellow rust of 15.73%,
14.93%, 10.42%, 8.79% and 7.67%-days was recorded on Hidase, Kubsa, Ogolcho, Wane and Shorima varieties, respectively, and that of stem rust of 18.96%, 17.33%, 16.36%, 6.80% and 6.37%-days was registered on Kubsa, Ogolcho, Hidase, Shorima and Wane varieties, respectively, as a result of combined use of Tilt 250 EC, Rex® Dou and Natura 250 EW foliar applications. The combined effect of variety and fungicide application in addition to environmental variability exhibited pronounced effects on the epidemic development of yellow and stem rusts through their effects on disease progress rate and spike infection. Rex® Dou and Natura 250 EW fungicides in combination with all the evaluated varieties proved to be effective against the rust management and gave the higher values of yield parameters and monitory advantage over the unsprayed plots. GY loss of up to 69.64% was recorded on unsprayed plots of Ogolcho as compared to fungicide sprayed plots of other varieties evaluated. Thus, Rex® Dou and Natura 250 EW fungicides in combination with wheat variety having a different level of resistance to wheat rusts could be suggested to the farmers in the study areas and elsewhere with similar agro-ecological conditions for efficient management and optimization of the GY. Further studies have to be sought in similar and other agro-ecologies elsewhere in Ethiopia for at least two consecutive years over locations to come up with a solid recommendation.

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Entomology; Epidemiology; Environmental Issues

Keywords: AUDPC; fungicides; severity; stem rust; wheat varieties; yellow rust; yield; loss

1. Introduction

Wheat (Triticum aestivum L.) is the world’s leading cereal grain which is used by more than one-third of the population of the world as a staple food (FAO et al., 2018; United State Department of agriculture [USDA], 2018). Similarly, it is one of the most important cereal crops of Ethiopia next to Tef in relation to production and distribution (Central Statistical Agency [CSA], 2018). Thus, wheat cultivation accounts for 18.23% and 19.80% in terms of area coverage and production as compared to the total cultivated area and production of cereals (CSA, 2018). According to research reports in 2018, the productivity of wheat is more than 7 t ha⁻¹ under demonstration and more than 4 t ha⁻¹ under farmers’ condition (Ministry of Agriculture and Natural Resources [MoANR] & Ethiopian Agricultural Transformation Agency [EATA], 2018). Despite the availability of wheat varieties with a high yield potential, the national average yield of wheat in the country is very low (1.83 t ha⁻¹) (CSA, 2018), which is far below than the world’s average yield (3.47 t ha⁻¹) (FAO et al., 2018; USDA, 2018). Even though the environmental condition is favorable for wheat production in Chencha, Bonke and Burji districts, the districts’ average yield is very low (0.95 t ha⁻¹) as compared to the national average yield. The low productivity of the crop is attributed to diverse and incomprehensible restraints; abiotic, biotic, socioeconomic and those related to crop management. Among the biotic factors, diseases like wheat rusts (Puccinia spp.) are the main ones in the country (Ayele et al., 2008; Zegeye et al., 2001).

Yellow rust (Puccinia striiformis f.sp. tritici) and stem rust (Puccinia graminis f.sp tritici) are highly destructive diseases of wheat in worldwide. Previous literatures reported that under favorable conditions these diseases had the ability to destroy the entire wheat crops (Badebo, 2002; International Center for Agricultural Research in the Dry Areas [ICARDA], 2012; International Maize and Wheat Improvement Center [CIMMYT], 2005; Roelfs, 1985; Teklay et al., 2013). In comparison with the leaf rust (P. recondite f.sp. triticina) pathogen of wheat, the global distribution of yellow and stem rusts is more restricted to midland and highland and midland and lower
altitudes including Ethiopian and particularly in the study areas (ICARDA, 2012; CIMMYT, 2005; Wubishet et al., 2015). The recurrent occurrence of these diseases in the study area causes considerable yield losses. To prevent yield loss due to these diseases, farmers use different fungicides released for either wheat rusts or other crop diseases alone or in combination of fungicide with each other due to disease aggressiveness under field conditions.

According to the reports of Bureau of Agriculture in the respective districts, the dominant fungicide available for several years in wheat rust disease management was Tilt 250 EC, and the growers suggested that the rust diseases resist this fungicide and did not protect their fields from the diseases. The recurrent use of the same fungicide for several years under extensive wheat production might favor the development of resistance by the pathogens. Research reports supported that unwise use of fungicides had led to the development of resistance by the pathogen (Green et al., 1990; CIMMYT, 2005; Roelfs, 1985). However, the development of resistant varieties and the widespread uses of them under production presently in charge of yellow and stem rusts in worldwide. That means research works entirely relied on the development of resistant varieties and the widespread uses of them under wheat production system; however, resistant varieties became susceptible to rust diseases because of the low durability of the varieties.. This might probably be related to climate change and the continuous cultivation of wheat year after year.

The major approach for the management of these diseases would remain focused on the development of resistant varieties. As a result in Ethiopia, quite a lot of achievements were made toward the development of resistant varieties, and several varieties with various levels of rust resistance were released for production. However, most of them succumb to either yellow or stem rusts soon after their release due to either the introduction of exotic races or evolvement of new local races and changes in environmental factors (Wubishet & Chemed, 2016). For these reasons, the large-scale wheat producers in the country and particularly in southern parts of the country extensively use fungicides to control rusts (Ayele et al., 2008; Badebo, 2002; Hailu & Fininsa, 2009; CIMMYT, 2005). This circumstance might be the need of farmers to popularize and keep high-yielding varieties in the production for some years ones they adopt them. Yet, the low recognition of the farmers on wise use of fungicides for these particular rust management might aggravate the high epidemics of the diseases. For such kind of disease management through varietal mixture having different levels of reaction to the diseases and supplementing with newly released fungicide applications may have an advantage on suppressing disease development. In this regard, understanding of the epidemiology of plant diseases is necessary for devising trustworthy and efficient disease management approaches. The role of practical approaches of analysis of disease progress in evaluating disease management practices for various pathosystems has been summarized in a recent review (Jeger, 2004).

Yellow and stem rusts are the most widely studied diseases in worldwide and in Ethiopia as well though much of them would remain to be ascertained to optimize the management of the disease; however, the diseases still continue to be a major wheat production constraint. The observation made in the study areas indicated that the repeated used of a single fungicide for several years led to the need for alternative fungicides (Getachew & Biruk, 2018). The effects had acknowledged the use of a single fungicide by many researches. These reasons and other like the low recognition of the effect of variety supplemented with fungicide application by the farmers necessitated mounting of management option, where information on their management option through the integration of host resistance and fungicide applications is lacking. Many reports on the combination of varieties and fungicide application indicated that the performance of varieties perhaps varies with the fungicides used, which is probably due to the active ingredients in the product formulation and the pathogen itself to resist the active substances. A variety may react well with one or another fungicide. A good combination of variety and fungicide(s) will definitely be preferred than a variety that demands no or little fungicidal activity. Accordingly, these alternative management options have not been evaluated in the study area. With this background, the research was done with the objective of determining the effects of variety and fungicide application on yellow and stem rusts under natural field conditions and grain yield (GY) of bread wheat.
2. Materials and methods

2.1. Description of experimental areas
The experiment was carried out at Burji, Bonke and Chencha in southern Ethiopia during the 2018 cropping year. The areas were purposively chosen based on wheat production potentials and hot spot for the development of wheat rust epidemics. The sites experimented and their respective geographic locations are shown in Figure 1. The areas are far apart from each other with a distance of 146 km between Chencha and Bonke, 286 km between Bonke and Burji and 220 km between Chencha and Bugji along the accessible vehicle road. The sites were laid at an altitude of 2,302, 2,527 and 2,543 m.a.s.l at Burji, Bonke and Chencha, respectively. The areas are characterized by a bimodal rainfall pattern where short rainy season occurs during the months of March to June and the main rainy season with July up to November. Thus, the areas average annual rainfall and temperature for the last decade were 850 mm and 20.50°C, 980 mm and 16.27°C, and 1,170 mm and 15.50°C for Burji, Bonke and Chencha, respectively. The detailed descriptions of weather variables of the 2018 cropping year are presented in Table 1. In Bonke and Chencha, the soil is characterized by a strongly acidic pH with low organic contents which ranged from 0.25% to 1.05% and sandy-loam, whereas in Burji the soil is neutral in pH with high organic matter contents (6.82%) (Ministry of Agriculture and Natural Resources [MoANR] & Ethiopian Agricultural Transformation Agency [EATA], 2016).

2.2. Experimental materials and management procedure
Five wheat varieties (Shorima, Ogolcho, Wane, Hidasie and Kubsa) currently under production and differing in their resistance levels to yellow and stem rusts were used as a varietal component. Seeds of the varieties were obtained from Kulumsa Agricultural Research Centre, Ethiopian Institute of Agricultural Research, Ethiopia. Brief descriptions of the characteristic features of the tested wheat varieties are presented in Table 2. Fungicides, Tilt 250 EC, Natura 250 EW and Rex® Duo, were used as a fungicidal component. The detail descriptions of the fungicides used are presented in Table 3.

![Figure 1. Map showing Ethiopia and experimental districts for yellow and stem rust diseases in Southern Ethiopia.](image-url)
| District | Weather variable | January | February | March | April | May | June | July | August | September | October | November | December |
|----------|------------------|---------|----------|-------|-------|-----|------|------|--------|------------|---------|----------|----------|
| Burji    | Maximum (°C)     | 28.30   | 32.20    | 28.10 | 27.90 | 25.80 | 25.70 | 26.00 | 25.30   | 28.74      | 29.05   | 28.77    | 29.73    |
|          | Minimum (°C)     | 16.80   | 18.80    | 17.90 | 17.50 | 15.40 | 16.30 | 16.20 | 15.80   | 14.49      | 14.43   | 14.46    | 17.91    |
|          | Rainfall (mm)    | 22.80   | 56.70    | 126.6 | 323.70| 144.70| 46.70 | 116.40| 103.50  | 127.60     | 112.70  | 73.00    | 31.90    |
| Bonke    | Maximum (°C)     | 24.93   | 25.42    | 26.17 | 24.92 | 21.63 | 20.07 | 19.27 | 19.35   | 26.74      | 20.97   | 21.05    | 24.93    |
|          | Minimum (°C)     | 15.90   | 20.35    | 20.10 | 14.33 | 13.90 | 12.96 | 12.85 | 12.08   | 14.53      | 12.92   | 11.98    | 17.69    |
|          | Rainfall (mm)    | 3.30    | 22.20    | 64.00 | 226.20| 345.80| 61.50 | 102.20| 209.80  | 248.90     | 275.10  | 101.90   | 4.50     |
| Chencha  | Maximum (°C)     | 24.13   | 20.55    | 25.32 | 24.11 | 20.52 | 19.88 | 20.39 | 20.69   | 20.67      | 20.72   | 20.37    | 24.13    |
|          | Minimum (°C)     | 15.39   | 10.13    | 19.45 | 13.87 | 9.92  | 9.80  | 10.06 | 10.34   | 10.43      | 10.32   | 11.59    | 17.12    |
|          | Rainfall (mm)    | 3.30    | 44.40    | 66.60 | 226.20| 242.00| 24.80 | 57.40 | 150.40  | 79.40      | 74.20   | 101.90   | 4.50     |

Source: The meteorological data were obtained from National Meteorological Agency at Hawassa Branch in the year of 2018.
## Table 2. Characteristic features of bread wheat tested varieties for determining the intensity of yellow and stem rusts at Burji Bonke and Chencha in southern Ethiopia during the 2018 cropping season

| Wheat varieties | Pedigree | Year of release | Releasing center | Altitude (m) | Rainfall (mm) | Suitable agro-ecology | Maturity dates | GY (t/ha) | Reaction to rusts |
|-----------------|----------|-----------------|------------------|--------------|---------------|-----------------------|---------------|----------|------------------|
| Hidase           | ETBWS795 | 2012            | KARC             | 2200-2600    | 500-800       | Mid to highland       | 121           | 4.5 to 7.0 | R                |
| Shorima          | ETBWS5483| 2011            | KARC             | 1900-2600    | 600-900       | Mid to highland       | 125           | 4.4 to 6.3 | MR               |
| Wane             | ETBWS6130| 2016            | KARC             | 2100-2700    | 300-1000      | Mid to highland       | 125           | 5.0 to 6.0 | MR               |
| Ogolcho          | ETBWS5130| 2012            | KARC             | 1600-2100    | 400-500       | Low to midland        | 102           | 3.3 to 5.0 | MR               |
| Kubda            | HAW185   | 1995            | KARC             | 2000-2600    | >900          | Low to midland        | 105           | 3.0 to 5.0 | S                |

1\(^{\text{a}}\) Data were sourced and organized from Ministry of Agriculture (MoA, 2012), Worku et al. (2013), Ministry of Agriculture and Natural Resources (MoANR, 2016) and MoANR and EATA (2018) released from different research centers; Kulumsa and Holeta Agricultural Research Center, Ethiopia.

2\(^{\text{b}}\) GR = Grain yield at the time of released (t ha\(^{-1}\)).

3\(^{\text{c}}\) YR = Stripe rust; SR = stem rust; R = Resistant; MR = moderately resistant; MS = moderately susceptible; and S = Susceptible.

4\(^{\text{d}}\) Reaction to rusts: YR = stripe rust; SR = stem rust; R = Resistant; MR = moderately resistant; MS = moderately susceptible; and S = Susceptible.
Table 3. Descriptions of fungicide used for evaluation of their effects on yellow and stem rusts intensity on tested wheat varieties at Burji Bonke and Chencha in southern Ethiopia during the 2018 cropping season

| Fungicide (Trade name) | Year of registry | Active ingredient | Product formulation | Mode of action | Product rate (L/ha) | Amount of diluting water (L/ha) | Spray interval (in days) | Registrant                          |
|------------------------|------------------|-------------------|---------------------|----------------|---------------------|-------------------------------|-------------------------------|-----------------------------------|
| Tilt 250 EC            | 1995             | Propiconazole     | Emulsifiable concentrate | Systemic     | 0.5                 | 100-400                      | 15                           | Syngenta Agro-service Ag. Ethiopia |
| Rex® Dau               | 2010             | Epoxiconazole + Thiophanate-methyl | Emulsifiable wettable | Systemic     | 0.5                 | 200-400                      | 15                           | Bass Germany company               |
| Natura 250 EW          | 2013             | Tebuconazole      | Emulsifiable wettable | Systemic     | 0.5                 | 200-300                      | 15                           | Lines international trading PLC Ethiopia |

Source: Data were sourced and organized from Ministry of Agriculture (MoA, 2015) and product package booklet.
Seeds of each variety were sown at a rate of 100 kg ha\(^{-1}\) on a well-prepared seedbed. Seeds were sown manually in rows on 6 April 2018 at short rainy season (at Burji), and on 12 and 15 August at the main rainy season at Bonke and Chencha during 2018 cropping year, respectively. During planting, N and P\(_2\)O\(_5\) fertilizers were applied manually at the rates of 41 and 46 kg ha\(^{-1}\). Weeds were removed manually four times at all locations. The first fungicide spray was started at 32, 46 and 35 days after planting (DAP) at Burji, Bonke and Chencha, respectively. The first symptoms of yellow rust appeared on 24, 28 and 25 DAP, whereas stem rust was onset on 42, 46 and 37 DAP at Burji, Bonke and Chencha, respectively, during the growing periods. Foliar applications of the fungicides were performed with the company recommended rates (Table 3). Spraying was performed using a manual knapsack sprayer calibrated to deliver 500–700 L of water ha\(^{-1}\). A total of two consecutive sprays were practiced at the three locations.

### 2.3. Treatments and experimental design

There were a total of 20 treatment combinations: five wheat varieties x three fungicides with the unsprayed ones as a control for all varieties (Table 4). The design was a factorial arrangement in randomized complete block design with three replications, and the treatments were assigned randomly to experimental plots within a block. The size of the unit plot was 1.6 m x 2 m (3.20 m\(^2\)) consisting of eight rows with six harvestable rows spaced at 20 cm between rows. A spacing of 1.5 and 2.0 m was used to separate each plot and block, respectively. Fungicides were sprayed to run-off, and each plot was protected with polyethylene sheets, which was 2 m high on all sides of the plot to reduce interplot interferences. Unsprayed plots were left for each variety as controls to allow maximum development of rust epidemics.

### Table 4. Descriptions of the treatment combinations used for the field experiment at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season

| S/N | Treatments | Details of the treatment combinations | S/N | Treatments | Details of the treatment combinations |
|-----|------------|--------------------------------------|-----|------------|--------------------------------------|
| 1   | SHR + FU\(_0\) | Shorima + Fungicide Untreated plot | 11  | HID + TRD | Hidasie + Treated with Rex Dou |
| 2   | SHR + TT  | Shorima + Treated with Tilt          | 12  | HID + TN  | Hidasie + Treated with Natura         |
| 3   | SHR + TRD | Shorima + Treated with Rex Dou       | 13  | WAN + FU\(_0\) | Wane + Fungicide Untreated plot |
| 4   | SHR + TN  | Shorima + Treated with Natura        | 14  | WAN + TT  | Wane + Treated with Tilt             |
| 5   | OGL + FU\(_0\) | Ogolcho + Fungicide Untreated plot | 15  | WAN + TRD | Wane + Treated with Rex Dou          |
| 6   | OGL + TT  | Ogolcho + Treated with Tilt          | 16  | WAN + TN  | Wane + Treated with Natura           |
| 7   | OGL + TRD | Ogolcho + Treated with Rex Dou       | 17  | LCL + FU\(_0\) | Local + Fungicide Untreated plot |
| 8   | OGL + TN  | Ogolcho + Treated with Natura        | 18  | LCL + TT  | Local + Treated with Tilt            |
| 9   | HID + FU\(_0\) | Hidasie + Fungicide Untreated plot | 19  | LCL + TRD | Local + Treated with Rex Dou         |
| 10  | HID + TT  | Hidasie + Treated with Tilt          | 20  | LCL + TN  | Local + Treated with Natura          |

Seeds of each variety were sown at a rate of 100 kg ha\(^{-1}\) on a well-prepared seedbed. Seeds were sown manually in rows on 6 April 2018 at short rainy season (at Burji), and on 12 and 15 August at the main rainy season at Bonke and Chencha during 2018 cropping year, respectively. During planting, N and P\(_2\)O\(_5\) fertilizers were applied manually at the rates of 41 and 46 kg ha\(^{-1}\). Weeds were removed manually four times at all locations. The first fungicide spray was started at 32, 46 and 35 days after planting (DAP) at Burji, Bonke and Chencha, respectively. The first symptoms of yellow rust appeared on 24, 28 and 25 DAP, whereas stem rust was onset on 42, 46 and 37 DAP at Burji, Bonke and Chencha, respectively, during the growing periods. Foliar applications of the fungicides were performed with the company recommended rates (Table 3). Spraying was performed using a manual knapsack sprayer calibrated to deliver 500–700 L of water ha\(^{-1}\). A total of two consecutive sprays were practiced at the three locations.
2.4. Disease assessment

The severity of yellow and stem rust was assessed prior to each spray of fungicide. A total of six and five consecutive assessments were made for yellow and stem rust severity, respectively. Yellow and stem rust severity was assessed at 10-day interval from the time of symptom appearance to physiological maturity of the crop. Severity was scored visually from 15 pre-tagged plants for each disease using the modified Cobb’s scale described by Peterson et al. (1948). The mean yellow and stem rust terminal severity obtained from 15 plants of each plot was used for the analysis. The growth stage (GS) of the wheat was registered during the assessment in order to observe the beginning and progress of the diseases in relation to wheat phenology following the decimalized key developed by Zadoks et al. (1974). During disease assessment, spike infection of stem rust was recorded from 15 plants of each plot using 0 to 5 scale (Peterson et al., 1948), where 0 = no disease symptom on the spike, 1 = up to 20% of spike infection covered, 2 = up to 40% of spike infection covered, 3 = up to 60% of spike infection covered, 4 = up to 80% of spike infection covered, and 5 = 100% of the spike infected by stem rust for three consecutive assessments were made, and the mean spike severity was used for the analysis; however, spike infection of yellow rust did not happen during the growing period in all locations.

The integral model, i.e., area under the disease progress curve (AUDPC), the development of disease on a whole plant or part of the plant, was assessed for each disease at different DAP for each plot applying the following formula (Wilcoxson et al. 1975).

\[
\text{AUDPC} = \sum_{i=1}^{n-1} 0.5(X_i + X_{i+1})(t_{i+1} - t_i)
\]

where \(X_i\) = percentage of disease severity index (PSI) of disease at \(i^{th}\) assessment; \(t_i\) = time of the \(i^{th}\) assessment in days from the first assessment date and \(n\) = total number of disease assessments. The duration of disease assessment was not the same for each location, and as a result of this, its value was standardized, \(r\text{AUDPC}\), through dividing the value by the total duration \((t_n - t_1)\) of the epidemic periods following the procedure described by Campbell and Madden (1990). The epidemic periods were 60 and 50 days for yellow and stem rust severity, respectively.

Disease progress rate was determined by the repeated assessment of the percentage of leaf and stem area affected by yellow and stem rusts in each plot starting from the onset of the diseases. Logistic, \(\ln \left[\frac{Y}{1-Y}\right]\) (Van der Plank, 1963), and Gompertz, \(-\ln \left[-\ln(Y)\right]\) (Berger, 1981), models were compared for the goodness of fit in the estimation of disease progression from each treatment. Quick assessment of the comparison of two functions showed that the logistics model was superior as indicated by a higher coefficient of determination \((R^2)\). Campbell and Madden (1990) conveyed that the logistic model had the most appropriate model for temporal analysis of disease progress on account of its widespread application and goodness of fit for describing many epidemics. The transformed data of disease severity were regressed over time, and the apparent rates of disease increase were derived using the following formula.

\[
Y_t = \frac{1}{1 + \exp (-\ln \left[\frac{Y_o}{1-Y_o}\right] + r_L t)}
\]

where \(Y_t\): percentage of terminal severity at \(t^{th}\) assessment date; \(Y_o\): percentage of initial severity at \(t^{th}\) assessment date; \(t_i\): time of the \(i^{th}\) assessment in days from the first assessment date; and \(r_L\): the rate parameter determined by the production of inoculum by infected individuals/lesions per unit area of diseased tissue.

2.5. Yield parameter assessment

Yield parameters such as GY, thousand kernel weight (TKW) and dried biomass weight (DBW) were determined from each plot. These parameters for each treatment were recorded from the six central rows of each plot by avoiding the border rows so as to prevent their effects, and then converted to yield in terms of \(t\) ha\(^{-1}\), except for TKW which was measured in gram for each treatment. Thousand kernel
weight was measured from randomly sampled grains from the total grain harvested for each plot. The moisture content of 13% was recorded in the wheat grain harvested from the experiment.

2.6. Data analysis
Data on disease and yield parameters were subjected to analysis of variance appropriate for RCBD in the factorial experiment to determine the treatment effects. The three locations were considered as different environments because of the variation in not only weather conditions but also difference in planting time, short rainy season for Burji and main rainy season for Bonke and Chencha, during the study period. Consequently, the Bartlett’s Chi-square test was applied to test for homogeneity of the error variance. The Chi-square test for homogeneity of error variance to most of the parameters measured for the crop in the three locations was verified to the loss in the homogeneity of the data (Pr > χ²); as a result, the data were not combined for analysis; all data were, therefore, analyzed separately for each location. Fisher’s protected least significant difference (LSD) test at 5% was used to separate differences among the treatment means (Gomez & Gomez, 1984). Linear regression of the pooled data of AUDPC for yellow and stem rusts was used for predicting the GY loss in wheat production. All data analyses were conducted using the general linear model procedure of the SAS software version 9.3 (Statistical Analysis System Institute [SAS], 2014).

2.7. Partial budget and relative yield loss analysis
Based on the pooled data obtained from all locations, partial budget and relative yield loss analysis were applied following the procedure developed by International Maize and Wheat Improvement Center (CIMMYT, 1988) and Robert and James (1991), respectively. Partial budget analysis was done based on the cost of current fungicides, labor and market price of wheat grain. Gross benefit, the total variable cost, net benefit (NB) and marginal rate of return (MRR) are some of the attributes used in the partial budget analysis. Gross benefit was incurred as the products of market price and GY of wheat. Total variable cost bears on the sum of all variable costs of inputs (like fungicides, knapsack sprayer and labor (spraying and weeding)), whereas the NB is the difference between the gross benefit and the total variable costs. The MRR was obtained through the ratio of the difference in NB and total input costs. All costs and benefits were designed on a hectare basis in US dollars ($).

During the study, the unit price of Tilt 250 EC, Natura 250 EW and Rex® Dou was 36.06 USD L⁻¹, 45.43 USD kg⁻¹ and 49.04 USD kg⁻¹ during the 2018 cropping year, respectively. The cost of labor for field managements and fungicide applications was 2.82 USD man day⁻¹. Statistical analysis for the collected data was done prior to the economic analysis to compare the average yields between treatments. Statistically significant differences between treatment means were observed, and consequently, the economic analysis was performed using the partial budget analysis method. Information gained through personal communication with some traders elaborated that the mean unit price of GY of wheat per ton was 480 USD during the cropping year across the locations. The actual yield, grain yield obtained at the time of harvesting, was adjusted downward by 10% to speculate the differences between the experimental yield and farmers’ yield that could be expected from the same treatment. It was assumed that there was optimum crop population density, timely labor availability and better field management. On the other hand, relative percent yield loss due to yellow and stem rust was computed from each plot using the following formula.

Relative yield loss (%) = \( \frac{Y_{bt} - Y_b}{Y_{bt}} \times 100 \)

where \( Y_{bt} \) is the yield of maximum protected treatment and \( Y_b \) is the yield of lower treatments.

3. Results

3.1. Yellow and stem rust onset and severity
At Burji, Bonke and Chencha yellow and stem rust was incepted on the varieties of Kubsa, Hidase and Ogolcho, respectively. During the experiment, symptoms of yellow rust appeared at tillering GS
that ranged from 24 to 28 on Kubsa variety for the three locations, while the stem rust appeared on Hidase and Ogolcho varieties simultaneously during GS of 31 to 33 at Bonke and Chencha and GS of 37 at Burji. On the varieties Shorima and Wane, the diseases were observed for the first time at the GS ranging from 30 to 32 for yellow rust at the three locations and 39 to 42 for stem rust at Bonke and Chencha. GS of 46 for the same varieties, Shorima and Wane, was the time when stem rust occurred at Burji. Disease severity assessment was ceased when the crop was getting physiologically matured, which was connected with the GS of 74, 75 and 78 for yellow rust and 82, 77 and 86 for stem rust at Burji, Chencha and Bonke, respectively. To this end, the present study revealed that there were interaction effects of the main treatments, variety with fungicide application, on the diseases. The terminal severity of yellow rust (TSYR) and stem rust (TSSR) significantly (p < 0.001) varied among the varieties as well as the fungicide applications at all dates of assessment in the three locations (Table 5).

Terminal severities of yellow rust on the varieties of (Kubsa and Hidase) unsprayed and plots sprayed with Tilt 250 EC fungicide were significantly higher than those of the rest of varieties in the same lines at Chencha and Burji except for Bonke, in which the highest TSYR was recorded on the variety Hidase with unsprayed plots. Nevertheless, there was no significant difference, on TSYR, between the Natura 250 EW and Rex® Duo applied to all varieties evaluated within and across themselves at all locations. Hence, the highest TSYR was recorded on the varieties of Hidase (80% and 76.89%), Kubsa (80% and 69.33%), Ogolcho (36% and 35.56%), Wane (30.22% and 29.78%) and Shorima (29.78% and 26%) in unsprayed plots and Tilt 250 EC sprayed plots, respectively, than Bonke and Burji (Table 5). However, plots sprayed with Natura 250 EW and Rex® Duo received the lowest TSYR on all varieties evaluated at all locations (Table 5). Thus, the mean TSYR was lowered by 8.89%, 47.37%, 59.17% and 61.62% on Kubsa, Ogolcho, Wane and Shorima varieties, respectively, as compared to the Hidase variety, whereas regarding the fungicide application 7.21%, 40.28% and 43.58% TSYR was reduced by Tilt 250 EC, Natura 250 EW and Rex® Duo, respectively, when different varieties were used as compared to the unsprayed plots of each variety at all locations (Table 5).

On the other hand, all the varieties depicted a significant difference among themselves and the fungicides used as well in their TSSR at the three locations. The highest TSSR was recorded from the variety Kubsa on unsprayed plots (41.33%) and sprayed with Tilt 250 EC (41.78%) fungicide at Burji and unsprayed plot (76.89%) only at Bonke than the remaining varieties evaluated in the same locations. However, the highest TSSR (80%) was observed on the variety Hidase than the rest of the varieties evaluated at Chencha. Conversely, the lowest TSSR was found on plots sprayed with Natura 250 EW (0.0% and 3.33%) and Rex® Duo fungicides (0.0% and 0.0%) for the varieties Shorima and Wane, respectively, at Burji than Bonke and Chencha, where Natura 250 EW (18.79% and 17.11%) and Rex® Duo fungicides (11.75% and 15.33%) at Bonke and Natura 250 EW (25.78% and 23.11%) and Rex® Duo fungicides (16.89% and 20%) for the varieties Shorima and Wane, respectively (Table 5). Considering the integration of variety as well as fungicide application, the highest TSSR was noted from unsprayed and Tilt 250 EC sprayed plots than Natura 250 EW and Rex® Duo at the three locations. The TSSR was reduced by 5.25%, 10.30%, 51.72% and 54.14% on the varieties of Kubsa, Ogolcho, Wane and Shorima, respectively, as compared to Hidase variety, whereas the TSSR was reduced by 12.93%, 37.85% and 53.63% of TSSR on Tilt 250 EC, Natura 250 EW and Rex® Duo, respectively, when different varieties were used as compared to the unsprayed plots of each variety at all locations (Table 5).

3.2. Area under disease progress curve of yellow and stem rusts
Significant differences (p < 0.0001) in AUDPC for yellow and stem rusts were observed among the varieties as well as fungicide applications at Burji, Bonke and Chencha (Table 6). Mean AUDPC for yellow rust was highest at Chencha than at Burji and Bonke with 16.38%, 9.31% and 8.84%-day, respectively. Similarly, the highest (17.98%-day) mean AUDPC for stem rust was registered at Chencha followed by Bonke (16.11%-day) and Burji (5.41%-day). Accordingly, AUDPC for yellow rust at Burji and Bonke was lowered by 43.16% and 46.03% as compared to Chencha, respectively,
Table 5. Interaction effect of bread wheat variety and fungicide application on terminal severity of yellow and stem rust levels at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season

| Treatment | Terminal severity of yellow rust (%) | Terminal severity of stem rust (%) |
|-----------|-------------------------------------|----------------------------------|
|           | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| Wheat variety | Fungicide application | | | | | |
| Kubsa | Unsprayed | 52.00a | 44.22b | 80.00a | 41.33a | 76.89a | 74.22b |
| | Natura 250 EW | 24.44fg | 19.56eh | 36.89de | 25.56e | 19.78f-h | 46.22e |
| | Rex® Duo | 32.22d-f | 16.22gh | 36.89de | 29.11d | 21.33e-h | 31.11h |
| | Tilt 250 EC | 52.89ab | 23.56e-g | 69.33b | 41.78a | 46.22c | 56.89d |
| Hidase | Unsprayed | 59.56a | 64.44a | 80.00a | 36.00b | 75.11ab | 80.00a |
| | Natura 250 EW | 32.89d-f | 20.89e-h | 44.89c | 14.22h | 26.67de | 28.00ij |
| | Rex® Duo | 23.56fg | 20.89e-h | 44.89c | 14.22h | 26.67de | 28.00ij |
| | Tilt 250 EC | 53.78ab | 36.00b-d | 76.89a | 32.89c | 74.67ab | 72.89b |
| Ogolcho | Unsprayed | 36.00de | 37.33bc | 35.56e | 26.67de | 76.44ab | 65.78c |
| | Natura 250 EW | 28.00e-g | 21.33e-h | 32.89ef | 20.00ef | 21.33fg | 26.67de | 40.89f |
| | Rex® Duo | 23.11fg | 20.00e-h | 24.44g-i | 19.11g | 29.33cd | 34.67gh |
| | Tilt 250 EC | 32.44df | 23.56e-g | 36.00de | 24.00ef | 70.22b | 56.00d |
| Sharima | Unsprayed | 27.56e-g | 17.11f-h | 26.00f-h | 10.00i | 25.11df | 34.22h |
| | Natura 250 EW | 26.67e-g | 15.11gh | 20.00hi | 0.00k | 18.89f-h | 25.78jk |
| | Rex® Duo | 20.44g | 11.33h | 18.22i | 0.00k | 11.78i | 16.89m |
| | Tilt 250 EC | 30.67dg | 18.00f-h | 29.78e-g | 10.00i | 23.78df | 29.33ij |
| Wane | Unsprayed | 48.44bc | 28.44c-e | 30.22e-g | 5.00j | 23.56dg | 27.56i-k |
| | Natura 250 EW | 40.89cd | 15.11gh | 20.00hi | 3.33j | 17.11g-i | 23.11k |
| | Rex® Duo | 28.00e-g | 14.44gh | 20.00hi | 0.00k | 15.33hi | 20.00im |
| | Tilt 250 EC | 36.89de | 26.67df | 29.78e-g | 5.00j | 22.67e-g | 30.22h-j |
| VAR*FA | | *** | *** | *** | *** | *** | *** |
| Mean | | 35.52 | 24.71 | 39.54 | 18.23 | 36.33 | 41.64 |

(Continued)
Table 5. (Continued)

| Treatment | Terminal severity of yellow rust (%)<sup>1</sup> | Terminal severity of stem rust (%)<sup>1</sup> |
|-----------|-----------------------------------------------|-----------------------------------------------|
| Wheat variety | Fungicide application | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| LSD (5%) | | 10.26 | 10.26 | 7.24 | 2.70 | 6.61 | 4.70 |
| xCV (%) | | 17.50 | 25.17 | 11.09 | 8.99 | 11.03 | 6.85 |

Means followed by the same letters within each column are not significantly different. **VAR** = Variety; **FA** = Fungicide application; **VAR * FA** = Interaction effect of variety x fungicide application; ******* = Significantly different at **p < 0.001**; ******** = Significantly different at **p < 0.0001**; **CV** = Coefficient of variation (%); and **LSD** = Least significant difference at **p < 0.05** probability level.
Table 6. Standardized area under disease progress curve of yellow and stem rust as affected by a combination of wheat variety and different fungicide application at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season

| Treatment | AUDPC (%-day) for yellow rust\(^1\) | AUDPC (%-day) for stem rust\(^1\) |
|-----------|----------------------------------|----------------------------------|
| Wheat variety | Fungicide application | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| Kubsa | Unsprayed | 14.37a | 18.52b | 32.65a | 13.61a | 35.90a | 33.58a |
| | Natura 250 EW | 7.79ef | 6.55d-h | 16.47 cd | 6.13fg | 11.09d-g | 17.75fg |
| | Rex® Duo | 7.61 f | 5.00 f-h | 16.78 c | 7.18ef | 11.67d-f | 12.18jk |
| | Tilt 250 EC | 12.67b | 9.58d | 31.16ab | 13.12a | 34.22ab | 31.13bc |
| Hidase | Unsprayed | 14.34a | 26.44a | 33.07a | 11.38b | 34.84a | 32.23ab |
| | Natura 250 EW | 8.40def | 6.95d-h | 14.73 c-g | 5.06 g | 9.36 f-h | 19.55 f |
| | Rex® Duo | 7.37 f | 7.63d-g | 14.17 c-g | 3.28 h | 10.13e-g | 12.77jk |
| | Tilt 250 EC | 12.99ab | 13.91 c | 28.79b | 9.97 c | 21.67 c | 26.06d |
| Ogolcho | Unsprayed | 9.33 c-e | 13.61 c | 16.10 c-e | 9.42 c | 33.86ab | 29.35 c |
| | Natura 250 EW | 7.99ef | 7.09d-h | 14.02e-h | 7.70de | 12.58de | 17.06gh |
| | Rex® Duo | 7.09 f | 5.98e-h | 11.56i | 5.67 g | 13.58d | 14.51ij |
| | Tilt 250 EC | 8.43d-f | 8.57de | 15.23 c-f | 8.96 cd | 31.87b | 23.41e |
| Shorima | Unsprayed | 8.12ef | 6.55d-h | 11.83hi | 2.32hi | 10.29e-g | 15.23 hi |
| | Natura 250 EW | 7.34 f | 4.82gh | 8.07 j | 0.00 j | 7.00h-j | 10.03lm |
| | Rex® Duo | 7.03 f | 3.78 h | 7.51 j | 0.00 j | 4.61 j | 7.23 n |
| | Tilt 250 EC | 8.43d-f | 6.06e-h | 12.51 g-i | 2.35hi | 9.26 f-h | 13.29k |
| Wane | Unsprayed | 10.13 c | 7.63d-g | 13.33f-i | 1.28j | 9.31 f-h | 12.71jk |
| | Natura 250 EW | 9.30 cde | 4.92 f-h | 8.42 j | 0.00 j | 6.57ij | 9.45mn |
| | Rex® Duo | 7.56f | 4.55gh | 8.30 j | 0.00 j | 5.67 j | 8.49mn |
| | Tilt 250 EC | 9.86 cd | 8.66de | 12.83hi | 0.91 j | 8.73 g-i | 13.33i-k |
| VAR*FA | **** | **** | **** | **** | **** | **** |
| Mean | 9.31 | 8.84 | 16.38 | 5.41 | 16.11 | 17.98 |

\(^1\) AUDPC = Area Under Disease Progress Curve
| Treatment | AUDPC (%-day) for yellow rust | AUDPC (%-day) for stem rust |
|-----------|-----------------------------|-----------------------------|
| Wheat variety | Fungicide application | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| LSD (%) | 1.58 | 3.39 | 2.37 | 1.35 | 2.67 | 2.5 |
| CV (%) | 10.34 | 23.31 | 8.77 | 15.18 | 10.06 | 7.58 |

Means followed by the same letters within each column are not significantly different. * = Stands for letter started from and up to it; AUDPC = Standardize Area under disease progress curve; CUL = Cultivar; FA = Fungicide application; VAR * FA = Interaction effect of variety x fungicide application; **** = significantly different at $p < 0.0001$; CV = Coefficient of variation (%); and LSD = Least significant difference at $p < 0.05$ probability level.
whereas AUDPC for stem rust at Bonke and Burji was bated by 10.40% and 69.91% as compared to Chencha, respectively (Table 6).

At Burji and Chencha, the highest AUDPC for yellow rust was recorded on unsprayed plots of varieties of Kubsa (14.37% and 32.65%-day, respectively) and Hidase (14.34% and 33.07%-day, respectively) and plots sprayed with Tilt 250 EC with 12.67% and 12.99%-day, respectively, on Kubsa and 31.16% and 28.79%-day, respectively, on Hidase. At Bonke, the highest (24.44%-day) AUDPC for yellow rust was recorded on the variety Hidase with unsprayed plot than the other ones evaluated in the study. Conversely, the lowest AUDPC for yellow rust was recorded at all locations on the variety Shorima, which was in statistical parity with the values obtained on Wane, Ogolcho, Hidase and Kubsa varieties with plots sprayed with Natura 250 EW and Rex® Duo fungicides. AUDPC of yellow rust was reduced by 4.75%, 33.55%, 43.56% and 51.06% on the varieties of Kubsa, Ogolcho, Wane and Shorima as compared to Hidase variety, respectively, whereas AUDPC was reduced by 15.96%, 43.88% and 46.60% on fungicides of Tilt 250 EC, Natura 250 EW and Rex® Dou as compared to the unsprayed plots of each variety, respectively (Table 6).

On the other hand, the highest AUDPC for stem rust was recorded from unsprayed plots of Kubsa (13.16%, 33.38% and 35.90%-day) and Hidase (32.23% and 34.84%-day) varieties at Burji, Chencha and Bonke, except for Hidase cultivar in Burji, respectively. At Burji and Bonke, the variety Kubsa sprayed with Tilt 250 EC showed the highest AUDPC for stem rust with 13.12% and 34.22%-days than Natura 250 EW and Rex® Dou fungicides. Conversely, the lowest (0.0%-days) AUDPC of stem rust was recorded on the varieties of Shorima and Wane on plots sprayed with Natura 250 EW and Rex® Dou as compared to the varieties Kubsa, Hidase and Ogolcho at Burji and Bonke. AUDPC of stem rust was lowered by 8.73%, 13.82%, 59.01% and 64.16% on the varieties Ogolcho, Hidase, Wane and Shorima as compared to Kubsa, respectively, whereas AUDPC was reduced by 7.00%, 51.16% and 57.74% on fungicides of Tilt 250 EC, Natura 250 EW and Rex® Dou fungicides as compared to the unsprayed plots of each variety, respectively.

### 3.3. Disease progress rate of yellow and stem rusts

The rate of yellow and stem rust disease progress significantly differed (p < 0.0001) among the wheat cultivar and the fungicide applications at Burji, Bonke and Chencha (Table 7). At Chencha, there was highest yellow rust (0.0121 units day$^{-1}$) and stem rust (0.0127 units day$^{-1}$) disease progress rates among the variety and the fungicide applications as compared to Bonke and Burji. Conversely, Bonke exhibited the lowest rates of yellow rust (0.0049 units day$^{-1}$) and stem rust (0.0042 units day$^{-1}$) disease progress as compared to Chencha and Burji (Table 7). Thus, the highest yellow and stem rust disease progress rate was recorded at Chencha (46.36% and 43.64%) as compared to Bonkie (18.78% and 14.44%) and Burjdi (34.86% and 41.92%), respectively.

Unsprayed plots of all varieties along with fungicides as evaluated for yellow and stem rusts showed the highest disease progress rates as comparable to the sprayed ones across the locations. The rates of disease progress of yellow and stem rusts were slowed down by the use of fungicide applications, especially Natura 250 EW and Rex® Dou fungicides at 15-day interval on all varieties at the three locations. Among the varieties besides fungicide applications, comparing of all the treatment combinations considered, the highest disease progress rates of yellow rust 0.0470 and 0.0475 unit day$^{-1}$ were exhibited on the varieties Kubsa and Hidase, respectively, whereas those of stem rust 0.0530 unit day$^{-1}$ were demonstrated on the variety Hidase on unsprayed plots at Chencha as compared to Burji and Bonke. Hence, the rates of yellow and stem rust disease progress were faster on unsprayed plots of these varieties than the unsprayed plots of other varieties. The lowest disease progress rate of yellow and stem rust was chronicled from the plots of all varieties sprayed with Natura 250 EW and Rex® Dou at 15-day interval at the three locations. Even though the rate of stem rust disease progress was lowest at Bonke as
Table 7. Mean yellow and stem rust disease progress rate and spike infection as altered by the interaction of wheat variety and fungicide application at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season

| Treatment | DPR (unit day$^{-1}$) for Stripe rust | DPR (unit day$^{-1}$) for stem rust | Spike infection for stem rust (%) |
|-----------|-------------------------------------|-----------------------------------|----------------------------------|
| VAR       | Burji  | Bonke  | Chencha  | Burji  | Bonke  | Chencha  | Burji  | Bonke  | Chencha  |
| Kubosa    | 0.0180 | 0.0148 | 0.0176   | 0.0376 | 0.0138 | 0.0136   | 0.0470 | 0.0253 | 0.0470   |
| Natura 250 EW | 0.0084 | 0.0103 | 0.0103   | 0.0043 | 0.0103 | 0.0103   | 0.0043 | 0.0103 | 0.0043   |
| Reve® Duo | 0.0054 | 0.0084 | 0.0084   | 0.0014 | 0.0084 | 0.0084   | 0.0014 | 0.0084 | 0.0014   |
| Tilt 250 EC | 0.0034 | 0.0046 | 0.0046   | 0.0002 | 0.0046 | 0.0046   | 0.0002 | 0.0046 | 0.0002   |
| Hidbar    | 0.0032 | 0.0042 | 0.0042   | 0.0012 | 0.0042 | 0.0042   | 0.0012 | 0.0042 | 0.0012   |
| Ogodeho   | 0.0054 | 0.0074 | 0.0074   | 0.0034 | 0.0074 | 0.0074   | 0.0034 | 0.0074 | 0.0034   |
| Shorima   | 0.0032 | 0.0042 | 0.0042   | 0.0012 | 0.0042 | 0.0042   | 0.0012 | 0.0042 | 0.0012   |
| Wane      | 0.0054 | 0.0074 | 0.0074   | 0.0034 | 0.0074 | 0.0074   | 0.0034 | 0.0074 | 0.0034   |
| VAR*FA    | ****   | ****   | ****     | ****   | ****   | ****     | ****   | ****   | ****     |
| Mean      | 0.0091 | 0.0049 | 0.0158   | 0.0049 | 0.0158 | 0.0158   | 0.0121 | 0.0121 | 0.0121   |
| LSD (%)   | 0.0001 | 0.0001 | 0.0001   | 0.0001 | 0.0001 | 0.0001   | 0.0001 | 0.0001 | 0.0001   |
| CV (%)    | 24.72  | 46.33  | 30.10    | 39.10  | 35.95  | 33.18    | 31.96  | 31.96  | 27.10    |

Notes: Means followed by the same letters within each column are not significantly different. $1^\text{-}c$ = Stands for letter started from and up to it; DPR = Disease progress rate; CUL = Cultivar; FA = Fungicide application; VAR = Variety; VAR*FA = Interaction effect of variety x fungicide application; *** = Significantly different at $p < 0.0001$; **** = Significantly different at $p < 0.00001$; CV = Coefficient of variation (%); LSD = Least significant difference at $p < 0.05$ probability level.
comparable to the other ones, it was statistically par with each other on the unsprayed plots of the varieties Kubsa, Hidase and Ogolcho and the fungicide Tilt 250 EC used (Table 7).

Across the locations, the mean yellow rust disease progress rate on the varieties of Kubsa, Hidase, Ogolcho, Wane and Shorima was recorded as 0.0134, 0.0134, 0.0062, 0.0061 and 0.0045 unit day\(^{-1}\), respectively. Whereas the mean stem rust disease progress rate was demonstrated as 0.0117, 0.0172, 0.0130, 0.0038 and 0.0033 unit day\(^{-1}\) on the varieties Kubsa, Hidase, Ogolcho, Shorima and Wane, respectively, under crosswise evaluations. Regarding the fungicide application, the mean disease progress rates of yellow rust with 0.0176, 0.0123, 0.0051 and 0.0042 units day\(^{-1}\) and stem rust with 0.0145, 0.0100, 0.0055 and 0.0048 unit day\(^{-1}\) were recorded from unsprayed plots of Tilt 250 EC, Natura 250 EW and Rex® Dou, respectively, under crosswise assessments.

Disease progress rates of yellow rusts were reduced by 4.75%, 33.55%, 43.56% and 51.06% on the varieties Wane, Ogolcho and Shorima as compared to Kubsa and Hidase, respectively, whereas the disease progress rates were reduced by 30.34, 61.75 and 76.14% on the fungicides of Tilt 250 EC, Natura 250 EW and Rex® Dou as related to the unsprayed plots of each variety, respectively (Table 7).

3.4. Spike infection of stem rust disease
At Chencha, Burji and Bonke, stem rust spike infection appeared first on the varieties Kubsa, Hidase and Ogolcho, although the level of severities varied among the locations even with the varieties themselves within the environment. However, during the growing year Shorima and Wane varieties were not infected by stem rust. Unfortunately, spike infection of yellow rust was not observed on the Shorima and Wane varieties in the rest of the growing periods at all locations. At the three locations, it appeared on Kubsa, Hidase and Ogolcho at the end of the flowering GS which was corresponding with the GS of 67 up to 76 of the crop. At Chencha, the onset of spike infection was comparatively early as compared to Burji and Bonke. This might be due to variation in the environmental factors for the epidemic of the disease.

The interaction effect of variety and fungicide application demonstrated that significant (p < 0.0001) differences on the spike infection of stem rust were observed during the 2018 cropping season at all locations (Table 7). The highest mean spike infection was registered at Chencha (1.84%) followed by Bonke (1.82%) as compared to Burji. Likewise, the highest mean spike infection was obtained on unsprayed and Tilt 250 EC fungicide sprayed plots of the varieties Kubsa, Hidase and Ogolcho at the three locations, except for Kubsa variety on unsprayed and Tilt 250 EC fungicide sprayed plots at Burji. Contrariwise, Kubsa, Hidase and Ogolcho sprayed with fungicide, Rex® Dou, exhibited the lowest spike infection and were in statistical parity with the advantage obtained on Natura 250 EW fungicide across and within the locations. Crosswise evaluations showed that the mean spike infection values of 0.0000%, 0.0000%, 2.6697%, 2.9775% and 3.0463% were noted on the varieties Shorima, Wane, Ogolcho, Kubsa and Hidase, respectively. Whereas the mean spike infection values of 2.56%, 2.30%, 1.36% and 0.73% were recorded on the unsprayed, Tilt 250 EC, Natura 250 EW and Rex® Dou fungicides under crosswise appraisals, respectively. Spike infection was reduced by 100%, 100%, 2.26% and 12.36% on the varieties Shorima, Wane, Ogolcho and Kubsa as compared to Hidase variety, respectively, while the spike infection was reduced by 10.29%, 47.06% and 71.48% on the fungicides of Tilt 250 EC, Natura 250 EW and Rex® Dou as compared to the unsprayed plots of each cultivar, respectively (Table 7).

3.5. Effect of yellow and stem rusts on yield parameters
Harvesting of grain was undertaken on 134, 160 and 170 DAP at Burji, Chencha and Bonke, respectively. Results revealed that significant (p < 0.05) variation in yield parameters was observed among the
varieties as well as the fungicide applications under different environments. The interaction effect of the variety along with the fungicide application did not exhibit significance (p > 0.05) on the GY at Burji and DB Wat Chencho (Table 8). Crosswise evaluation of GY, TKW and DBM at Bonke (4.58 t ha⁻¹, 41.13 g and 6.13 t ha⁻¹) and Chencho (4.19 t ha⁻¹, 33.24 g and 5.43 t ha⁻¹) received highest advantage over Burji (3.78 t ha⁻¹, 28.66 g and 5.13 t ha⁻¹), respectively. The results of this study revealed that variation in the environmental factors in addition to variety and fungicide applications might affect the rust epidemics and yield performance of the crop. On the other hand, unsprayed plots of the varieties Kubsa (2.21 t ha⁻¹, 26.28 g and 2.82 t ha⁻¹), Hidase (2.13 t ha⁻¹, 24.22 g and 3.64 t ha⁻¹), Ogolcho (1.82 t ha⁻¹, 24.32 g and 4.23 t ha⁻¹), Wane (2.29 t ha⁻¹, 31.69 g and 3.75 t ha⁻¹) and Shorima (2.50 t ha⁻¹, 21.37 g and 3.89 t ha⁻¹) exhibited the lowest mean GY, TKW and DBW as compared to the sprayed plots under crosswise assessments, respectively (Table 8).

GY, TKW and DBW of Kubsa, Hidase, Ogolcho, Wane and Shorima were relatively higher and significantly varied among the varieties and fungicide applications. Plots sprayed with Rex® Dou and Natura 250 EW fungicides provided highest GYs of Kubsa (5.93 and 5.28 t ha⁻¹), Hidase (5.86 and 6.08 t ha⁻¹), Ogolcho (5.96 and 5.40 t ha⁻¹), Wane (5.65 and 5.55 t ha⁻¹) and Shorima (6.63 and 5.96 t ha⁻¹) as compared to unsprayed plots of all varieties under crosswise evaluations, respectively. But, comparing the fungicides with each other, the lowest GY was obtained from plots sprayed with Tilt 250 EC fungicide on the varieties of Kubsa (2.72 t ha⁻¹), Hidase (3.24 t ha⁻¹), Ogolcho (2.56 t ha⁻¹), Wane (2.62 t ha⁻¹) and Shorima (3.64 t ha⁻¹) as compared to Rex® Dou and Natura 250 fungicides across location assessments. Plots sprayed with Tilt 250 EC (31.85 g and 4.24 t ha⁻¹; 31.93 g and 4.14 t ha⁻¹; 28.09 g and 4.05 t ha⁻¹; 25.06 g and 5.54 t ha⁻¹; and 31.29 g and 3.52 t ha⁻¹), Natura 250 EW (32.92 g and 7.07 t ha⁻¹; 33.09 g and 7.57 t ha⁻¹; 30.19 g and 6.39 t ha⁻¹; 63.09 g and 7.48 t ha⁻¹; and 44.02 g and 6.95 t ha⁻¹) and Rex® Dou (33.60 g and 7.40 t ha⁻¹; 39.57 g and 7.32 t ha⁻¹; 31.21 g and 7.90 t ha⁻¹; 58.73 g and 7.95 t ha⁻¹; and 44.78 g and 6.92 t ha⁻¹) fungicides gave relatively higher TKWs and DBWs of Kubsa, Hidase, Ogolcho, Wane and Shorima, respectively, as compared to unsprayed plots of all varieties under crosswise assessments (Table 8).

3.6. Relationship of wheat yellow and stem rust epidemics with grain yields

Analysis of yield losses in every unit of disease amount was important since the aggressiveness and virulence of the pathogen in a given critical period had a great role to explain the relationship between the predictor and response variables. Linear regression analysis was performed using the pooled data of yellow and stem rust of AUDPC and GY for predicting the loss in wheat production (Figure 2). This is because AUDPC of linear regression is a better analytical model to indicate the relationship of yield loss with the disease effects than other models for these diseases. The higher yellow and stem rust of AUDPC indicates that the more vulnerable are the varieties and the lower the yield, that is the higher of AUDPC the more susceptible of the varieties to rusts, which resulted in low grain yields. The contribution of yellow and stem rusts AUDPC in GY reduction was 43.50% and 49.00% of the variation between them, respectively. Thus, as yellow and stem rust AUDPC increased, the yield decreased and goes toward zero asymptote, which indicated the converse relationships between AUDPC and GY of wheat. Similarly, the graph showed that for every one-unit increase in yellow and stem rust AUDPC values, there were 0.0226- and 0.1576-unit yield loss of wheat varieties, respectively. This indicated that the responsibility of the stem rust epidemic was higher than yellow rust in every unit of GY loss in wheat production. The closer the point to the line indicate the stronger their relationship between the disease and the yield in regarding yield loss The negative sign, in AUDPC, indicates the inverse relation of the disease and the yield and the observed levels of amount of diseases have a considerable adverse effect on GYof wheat varieties (Figure 2).

3.7. Partial budget analysis and relative yield loss

The partial budget analysis demonstrated that there was a significant variation in NB and MRR as seen among the tested varieties and fungicides (Table 9). The pooled results of the three locations...
Table 8. Grain yield, thousand kernel weight and dried biomass weight obtained by management of yellow and stem rust diseases through a combination of wheat variety as well as different fungicide applications at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season.

| Treatment | Grain yield (t ha\(^{-1}\)) | Thousand kernel weight (g) | Dry biomass weight (t ha\(^{-1}\)) |
|-----------|------------------------------|---------------------------|----------------------------------|
| VAR       | Burji | Bonke | Chencha | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| Kubsa Unsprayed | 1.39e | 2.31fg | 1.94fg | 20.95e | 32.17f-h | 25.73e-g | 2.90e | 3.34ij | 2.23h |
| Ntatura 250 EW | 5.74a-c | 5.46bc | 4.63e | 24.72e-h | 41.16de | 32.93 cd | 6.54b-d | 7.47b-d | 7.21b-d |
| Rex® Duo | 6.02ab | 5.93bc | 5.83b-d | 26.78ef | 41.13de | 32.90 cd | 6.20b-d | 7.68bc | 8.31a |
| Tilt 250 EC | 2.41e | 4.07de | 1.67g | 26.80ef | 37.97d-f | 30.78 c-e | 3.70e | 5.68ef | 3.34g |
| Hidase Unsprayed | 1.57e | 2.41fg | 2.41fg | 20.06hi | 29.60hi | 22.93gh | 2.83e | 4.07hi | 4.02fg |
| Ntatura 250 EW | 5.46bc | 5.83bc | 6.94a | 23.75e-h | 41.96 cd | 33.57 c | 7.50bc | 7.22 cd | 8.00ab |
| Rex® Duo | 5.19bc | 7.31a | 5.09de | 29.37de | 49.63bc | 39.71b | 7.62ab | 8.52ab | 5.81e |
| Tilt 250 EC | 2.78de | 4.17de | 2.78f | 34.72 cd | 33.92e-h | 27.14d-g | 3.79e | 5.31e-g | 3.31g |
| Ogolcho Unsprayed | 1.57e | 1.48 g | 2.41fg | 16.29 | 31.49f-h | 25.19e-g | 6.62e | 2.78j | 3.28g |
| Ntatura 250 EW | 5.46bc | 5.19 cd | 5.56cd | 24.06f-i | 36.95d-g | 29.56c-f | 6.45b-d | 6.42de | 6.30de |
| Rex® Duo | 4.26cd | 7.22a | 6.39a-c | 25.04e-h | 37.91d-f | 30.33 c-e | 6.20b-d | 9.41a | 8.10ab |
| Tilt 250 EC | 1.67e | 3.24ef | 2.78 f | 20.50hi | 35.43d-h | 28.34 c-g | 3.36e | 5.19 f-h | 3.60fg |
| Sharima Uncropped | 2.31e | 2.50fg | 2.69 f | 24.32e-h | 22.11i | 17.69 h | 3.77e | 4.17hi | 3.73fg |
| Ntatura 250 EW | 5.28bc | 6.57ab | 6.02bc | 54.93a | 74.61a | 59.69a | 6.64b-d | 8.12bc | 7.69a-c |
| Rex® Duo | 7.22a | 6.20a-c | 6.48ab | 49.24b | 66.82a | 60.12a | 8.43a | 7.59bc | 7.82ab |
| Tilt 250 EC | 4.26 cd | 3.89e | 2.78 f | 21.84 f-i | 29.64 | 23.71fg | 6.14b-d | 5.99ef | 4.49 f |
| Wane Uncropped | 1.67e | 2.50fg | 2.69 f | 27.36ef | 37.78d-f | 29.94 c-e | 3.30e | 4.26 g-i | 3.69 fg |
| Ntatura 250 EW | 4.44b-d | 6.48ab | 5.74b-d | 37.30c | 50.61b | 44.16b | 5.89cd | 8.15bc | 6.81cd |
| Rex® Duo | 4.44b-d | 6.20a-c | 6.30a-c | 38.64c | 55.20b | 40.49b | 5.62d | 7.59bc | 7.54a-c |
| Tilt 250 EC | 2.50e | 2.68f | 2.69f | 26.20e-g | 37.43d-g | 30.23 c-d | 3.52e | 3.73ij | 3.31g |

(Continued)
| Treatment | Grain yield (t ha\(^{-1}\)) | Thousand kernel weight (g) | Dry biomass weight (t ha\(^{-1}\)) |
|-----------|-----------------------------|---------------------------|----------------------------------|
| VAR       | FA                          | Burji         | Bonke      | Chencha | Burji | Bonke | Chencha | Burji | Bonke | Chencha | Burji | Bonke | Chencha |
| VAR*FA    | ns                          | *             | *          | ****    | ****  | ****  | ****    | ***   | ns    |
| Mean      | 3.78                        | 4.58          | 4.19       | 28.66   | 41.13 | 33.24 | 5.13     | 6.13  | 5.43  |
| LSD (5%)  | 1.69                        | 1.14          | 0.9        | 5.65    | 7.82  | 5.91  | 1.7      | 0.5   | 0.94  |
| CV (%)    | 27.22                       | 15.19         | 13.15      | 11.96   | 11.53 | 10.78 | 20.2     | 11.15 | 10.55 |

Means followed by the same letters within each column are not significantly different. \(^{1,2,3,4,5,6}\) = Stands for letter started from and up to it; VAR = Variety; FA = Fungicide application; VAR * FA = Interaction effect of variety x fungicide application; * = Significantly different at \(p < 0.05\); ** = Significantly different at \(p < 0.001\); *** = Significantly different at \(p < 0.0001\); ns = Not significant \((p > 0.05)\); CV = Coefficient of variation (%); and LSD = Least significant difference at \(p < 0.05\) probability level.
revealed that combination of wheat varieties with Rex® Dou and Natura 250 EW fungicide gave the highest NB with the varieties of Kubsa (1557.30 and 1307.75 $ ha\(^{-1}\)), Ogolcho (1568.98 and 1354.48 $ ha\(^{-1}\)), Wane (1448.25 and 1416.80 $ ha\(^{-1}\)) and Shorima (1833.82 and 1572.59 $ ha\(^{-1}\)), respectively. Likewise, a combination of wheat varieties with Rex® Dou and Natura 250 EW fungicides offered the highest MRR with the varieties Kubsa (17.53 and 5.28), Hidase (16.07 and 17.88), Ogolcho (17.95 and 16.11), Wane (14.42 and 14.67) and Shorima (17.95 and 15.53), respectively. Conversely, the lowest NB on the varieties of Kubsa (65.05 $ ha\(^{-1}\)), Hidase (162.42 $ ha\(^{-1}\)), Ogolcho (41.69 $ ha\(^{-1}\)), Wane (220.84 $ ha\(^{-1}\)) and Shorima (306.52 $ ha\(^{-1}\)) was computed from unsprayed plots. Comparing the fungicides with each other, Tilt 250 EC fungicide showed the lowest NB and MRR than Rex® Dou and Natura 250 EW fungicides for the corresponding wheat varieties (Table 9).

Relative GY losses due to yellow and stem rusts lowered among the plots sprayed with different fungicides on each wheat varieties and were considered in relative to the GY of highly protected plots (Table 9). The highest GY losses reached up to 69.46%, 68.30%, 64.97%, 62.35% and 59.65% on unsprayed plots of Ogolcho, Kubsa, Hidase, Wane and Shorima varieties, respectively. Relative GY losses computed from plots sprayed with Natura 250 EW fungicide gave better results after Rex® Dou than Tilt 250 EC fungicides and unsprayed ones, and it will serve as a second option when there is no availability of Rex® Dou in the market for the management of rust diseases in wheat (Table 9).

4. Discussion
At Burji, Bonke and Chencha, the onset of yellow and stem rusts was at tillering and early flowering in relation to the crop GS on the highly susceptible (Kubsa) and resistant (Hidase) and moderately resistant (Ogolcho) varieties, respectively. Peterson et al. (1948), Roelfs (1985) and Tadesse (2005) described yellow and stem rust as diseases of the tillering and reproductive phase of wheat, respectively. Comparing the locations, the onset of yellow and stem rusts was relatively late at Burji than Bonke and Chencha. However, the degrees of severities varied in crosswise. Burji is located at a relatively lower altitude than Bonke and Chencha. The variation in disease severity might be due to the environmental conditions for yellow and stem rusts epidemic development at low and high altitudes. This shows that currently yellow and stem rusts have stretched their adaptation to lower and warmer altitudes and at higher and cold altitudes, respectively, where they did not exist in the past. Previous reports confirmed that in recent years, new and high temperature-lenient, aggressive strains of yellow and stem rusts are moving into warmer and cold areas, respectively (Getachew & Biruk, 2018; Hovmoller et al., 2008; Milus et al., 2009; Wubishet & Chemeda, 2016). This might have been due to the capability of the pathogen through genetic modifications to adapt to wider areas as a result of climate change and other factors. Roelfs (1985)
Table 9. Partial budget analysis and relative yield loss assessment due to yellow and stem rust as affected by a combination of wheat variety and fungicide applications at Burji, Bonke and Chencha in southern Ethiopia during 2018 cropping season

| Treatment          | Grain yield (t ha\(^{-1}\)) | Adjusted yield (t ha\(^{-1}\)) 10% down | Total variable cost ($ ha\(^{-1}\)) | Gross benefit ($ ha\(^{-1}\)) | Net benefit ($ ha\(^{-1}\)) | Marginal rate of return (%) | Relative yield loss (%) |
|--------------------|-----------------------------|----------------------------------------|-----------------------------------|-------------------------------|-----------------------------|-----------------------------|------------------------|
| Wheat variety      | Fungicide applied           |                                        |                                   |                               |                             |                             |                        |
| Kubsa              | Unsprayed                   | 1.88                                   | 1.69                              | 667.15                        | 732.20                      | 65.05                       | 0.00                   | 68.30                  |
|                    | Ntatura 250 EW              | 5.28                                   | 4.75                              | 748.65                        | 2056.40                     | 1307.75                     | 15.25                  | 0.00                   |
|                    | Rex® Duo                    | 5.93                                   | 5.34                              | 752.25                        | 2309.55                     | 1557.30                     | 17.53                  | 10.96                  |
|                    | Tilt 250 EC                 | 2.72                                   | 2.45                              | 739.27                        | 1059.36                     | 320.08                      | 3.54                   | 54.13                  |
| Hidase             | Unsprayed                   | 2.13                                   | 1.92                              | 667.15                        | 829.57                      | 162.42                      | 0.00                   | 64.97                  |
|                    | Ntatura 250 EW              | 6.08                                   | 5.47                              | 748.65                        | 2367.97                     | 1619.32                     | 17.88                  | 3.62                   |
|                    | Rex® Duo                    | 5.86                                   | 5.27                              | 752.25                        | 2282.29                     | 1530.03                     | 16.07                  | 0.00                   |
|                    | Tilt 250 EC                 | 3.24                                   | 2.92                              | 739.27                        | 1261.88                     | 522.61                      | 4.99                   | 46.71                  |
| Ogolcho            | Unsprayed                   | 1.82                                   | 1.64                              | 667.15                        | 708.83                      | 41.69                       | 0.00                   | 69.46                  |
|                    | Ntatura 250 EW              | 5.40                                   | 4.86                              | 748.65                        | 2103.13                     | 1354.48                     | 16.11                  | 9.40                   |
|                    | Rex® Duo                    | 5.96                                   | 5.36                              | 752.25                        | 2321.23                     | 1568.98                     | 17.95                  | 0.00                   |
|                    | Tilt 250 EC                 | 2.56                                   | 2.30                              | 739.27                        | 997.04                      | 257.77                      | 3.00                   | 57.05                  |
| Shorima            | Unsprayed                   | 2.50                                   | 2.25                              | 667.15                        | 973.67                      | 306.52                      | 0.00                   | 62.35                  |
|                    | Ntatura 250 EW              | 5.96                                   | 5.36                              | 748.65                        | 2321.23                     | 1572.59                     | 15.53                  | 10.24                  |
|                    | Rex® Duo                    | 6.64                                   | 5.98                              | 752.25                        | 2586.07                     | 1833.82                     | 17.95                  | 0.00                   |
|                    | Tilt 250 EC                 | 3.64                                   | 3.28                              | 739.27                        | 1417.67                     | 678.40                      | 5.16                   | 45.18                  |
| Wane               | Unsprayed                   | 2.28                                   | 2.05                              | 667.15                        | 887.99                      | 220.84                      | 0.00                   | 59.65                  |
|                    | Ntatura 250 EW              | 5.56                                   | 5.00                              | 748.65                        | 2165.45                     | 1416.80                     | 14.67                  | 1.59                   |
|                    | Rex® Duo                    | 5.65                                   | 5.09                              | 752.25                        | 2200.50                     | 1448.25                     | 14.42                  | 0.00                   |
|                    | Tilt 250 EC                 | 2.62                                   | 2.36                              | 739.27                        | 1020.41                     | 281.14                      | 0.84                   | 53.63                  |

Mean unit price of grain yield per ton was 480 $ (at the exchange rate of 1(footpara)nbsp;= 27.73 ETB) at the time of selling during 2018 cropping seasons.
and Campbell and Madden (1990) reported that the appearance of the disease in a given environment where they do not exist before could be due to the new race of a given pathogen.

Infected leaves and stems began to be necrotic starting 3 weeks after the appearance of symptoms on those plots severely attacked by yellow and stem rusts, respectively. Jones (1998) and Ram et al. (2016) reported that infected plant parts gradually withered and died after the disease had occurred if it is not controlled by disease management options. The variety Hidase has been considered as resistant since 2012 until recent time and now it became susceptible to yellow and stem rusts in areas with heavy disease pressure. The results of the present study showed the severities, apparently disease tissues of leaf and stem, of yellow and stem rust as high as on unsprayed plots of the susceptible (Kubsa) and moderately (Ogolcho) and resistance (Hidase) varieties under different environments (Table 5). Similarly, the fungicide Tilt 250 EC, which was released for yellow and stem rust management during the year of 1995, currently the ability of this fungicide was lowered and lost its significance in rust disease management in wheat production. The likely or possible reasons for the loss of resistance to the rusts could be failure or incapability of the fungicide and/or pathogenic resistance due to the use of the fungicide for year after year for several years. As stated by Roelfs (1985), Campbell and Madden (1990), and Green et al. (1990) the loss of resistance by the plant and development of resistance by pathotype in a given pathogen had resulted from the breaking down of the resistance gene of the plant and development of new race or genetic modification by the pathogen as a result of risky uses of disease management options.

Regardless of the fungicide applications, yellow and stem rusts were less severe on the moderately resistant varieties (Shorima and Wane) as compared to the resistant (Hidase) and susceptible (Kubsa) varieties to each rust species at all locations. The less severe disease was mainly due to the inherent nature of the varieties to resist the rust epidemics, although the weather conditions at the three locations seemed to be conducive to the development of these diseases. A significant difference in the level of yellow and stem rust severities was observed on unsprayed plots at Bonke and Chencha, and this is more likely to be related to favorable environmental and the lower temperature conditions along with good distribution of precipitation during the growing periods. However, at Burji, the significance of these diseases was affected by seasonal variations, although the two rust diseases happened at low altitude and caused significant effects on the crop. Relatively minimum and maximum temperatures and higher precipitation were recorded during cropping periods starting from April. Leonard and Szabo (2005), Wanyera et al. (2006), Ransom and McMullen (2008) and Wubishet and Chemeda (2016) demonstrated that epidemic development of wheat rusts could be due to variation in virulence spectra of the pathogen and weather conditions for the stockpile of disease pressure.

The results of this study indicated that the use of variety in combination with fungicide application abridged yellow and stem rust severities, AUDPC, rate of disease progress and spike infection (only for stem rust) as compared to unsprayed plots. In short it tried to explain the new fungicide, Natura 250 EW and Rex® Dou, protects better than the other fungicide due to the responsible of active substances incorporated in the product formulation for rust management. This could be accredited to the growth of wheat variety having different levels of resistance to rust diseases supplemented with fungicide application in decreasing disease suppression that might hinder inoculum blowout and disease progress and creating favorable growing conditions for the crop. Integration of variety and fungicide application studies showed that lower amount of yellow and stem rusts could be related to significant effects favored by a combination of variety and fungicide on epidemic development (Campbell & Madden, 1990; Foster et al., 2017; Phillip & Nathan, 2018; Tadesse et al., 2010). Similarly, crosswise observations revealed that the yellow and stem rust epidemic development vary depending on the level of varietal resistance and the different fungicides used including the predominant environmental factors. The difference in the extent of yellow and stem rust severities at the three locations exhibited the effects of variety by fungicide application and including environmental factors on the disease development. As
indicated by Milus (1994), Campbell and Madden (1990), Tadesse et al. (2010), Willyerd et al. (2015) and Wubishet and Tamene (2016), the lowest rust severities in different environments could be the inherent behavior of the host and the supplemented fungicides, having responsible active substances in the formulation, for the management of rusts during the cropping season.

The AUDPC of yellow and stem rusts exhibited significant variation among the wheat varieties as well as the fungicide applications at the three locations. It was highest on unsprayed plots of the susceptible (kubsa) and moderately resistant (Ogolcho) and resistant (Hidase) varieties at all locations. Conversely, at the three locations, the lowest AUDPC for both diseases was obtained on the moderate-resistance varieties, Shorima and Wane varieties. The fungicides, Natura 250 EW and Rex® Dou, sprayed at the onset of the rusts for all varieties revealed significant effects on the development epidemics. These fungicides reduced AUDPC for yellow and stem rust epidemics much more below the unsprayed and Tilt 250 EC fungicide sprayed plots; they seem more effective and feasibly acceptable for rust managements. From the results of variety along with fungicide application, it is possible to figure out that Natura 250 EW and Rex® Duo spray at 15-day interval effectively reduced the magnitude of yellow and stem rust epidemics on each cultivar. Application of these fungicides might be a reason for its high efficacy and the low resistance of the pathogens. Therefore, it is worthwhile to use these fungicides alternatively and accordingly starting from the disease onset.

The present finding was supported by Milus (1994), Boshoff et al. (2003), Ransom and McMullen (2008), Tadesse et al. (2010), Wubishet and Tamene (2016) and Phillip and Nathan (2018) who reported that the highest value of AUDPC for yellow and stem rusts resulted from the highest disease development on plots that had no spray with any combinations of crop varieties and fungicide applications; the moderately resistant varieties had the lowest AUDPC for yellow and stem rust diseases when supplemented with fungicide application. Use of wheat varieties having different levels of resistance to rusts in combination with Natura 250 EW and Rex® Dou were proved to be the most cost-effective approach in reducing rust diseases development besides increasing production and productivity of wheat. Beard et al. (2004), Tadesse et al. (2010), Wubishet and Tamene (2016) and Phillip and Nathan (2018) suggested that to lower the subsequent disease progress on the plant, fungicides should be applied at the time of disease appearance in order to get effective results in disease pressure reductions with the intended management options.

The wheat varieties supplemented with a spray of fungicide showed reduced levels of yellow and stem rust rate of disease progression at the three locations. Similarly, the current results demonstrated that yellow and stem rusts rates of disease progress were different at the three locations, the highest rate of disease progress being at Chencha. Natura 250 EW and Rex® Dou fungicides ensured better control of yellow and stem rust development. However, the fungicide, Tilt 250 EC, exhibited a lower effect on the rates of disease progress as compared to the other fungicides. Failure or incapability of the active substance involved in the product formulation might be the major causes to loss its ability in protecting the pathogens and/or pathogenic resistance to the fungicide used. This observation is in line with the findings of Green et al. (1990) who stated that pathogens are more venerable to develop resistance ability with unwise and repeated use of agrochemicals for several years. Results of the present study evidently prove in reducing of rates of disease progress under the combination of wheat varieties having different levels of reaction to rusts with Natura 250 EW and Rex® Dou. Yellow and stem rust disease progress rates were more rapid on susceptible variety with no fungicide applied than other varieties complemented with fungicide applications. The present results are in agreement with the findings of previous works reported by several scholars who reported that rate of disease progress depends on the resistance level of host used during the growing period and the supplemented management options (Campbell & Madden, 1990; Cook et al., 1999; Mercer & Ruddock, 2005; Roelfs, 1985; Tadesse et al., 2010). Foster et al. (2017) and Phillip and Nathan (2018) also suggested that the
rate of disease epidemics was significantly reduced when the management of rusts was supplemented with fungicide applications.

GY, TKW and DBW were significantly altered by the wheat varieties and the different fungicides under integrated use in the study. Moderately resistant varieties (Shorima and Wane) furnished the highest GY, TKW and DBW as compared to the other wheat varieties, Ogolcho, Hidase and Kubsa, regardless of fungicide application. This difference might have resulted from the variation in genetic circumstantial of the varieties. The highest GY, TKW and DBW were obtained from all wheat varieties supplemented with Natura 250 EW and Rex® Dou fungicides at the three locations. Variation in the genetic background of the varieties as well as the fungicide applications might have resulted in the highest GY, TKW and DBW at the three locations. In agreement with this study, Tadesse et al. (2010), Wubishet and Tamene (2016) and Foster et al. (2017) found that integration of variety and fungicide application reduced disease suppression and increased the yield attributes of the crop. A similar result was also noted by Conceição et al. (2016) and Phillip and Nathan (2018) against wheat diseases that fungicide significantly reduced disease severity and increased yield parameters over the unsprayed plots. Possibly, the integration could enhance the health and well-being of the plants that undertake a normal physiological process, which might increase plant chances to withstand pathogen attack and support the plant defense systems.

In the present study, it was observed that the integration of variety and fungicide application exceedingly reduced diseases and increased crop parameters over the unsprayed ones. The pooled results of the three locations in the economic analysis revealed that the integration of Rex® Dou and Natura 250 EW fungicides with all evaluated varieties exhibited the highest NB and MRR over the unsprayed and Tilt 250 EC fungicide sprayed plots. The high NB and MRR in this study were due to the integration of wheat variety with supplementation of fungicide, which could be attributed to high yield. The low NB and MRR were accredited to low yield as a result of high disease pressures with ignorance of its management during the growing periods. To this effect, it was ostensible that the use of the abovementioned varieties in combination with Rex® Dou and Natura 250 EW fungicides could be suggested for the growers since the combinations were most profitable over the other fungicide, Tilt 250 EC. Similar results on the profitability of wheat rust management package were reported by Cook and King (1984), Foster et al. (2017) and Krishna et al. (2017). However, relatively lowest GY was found on unsprayed and Tilt 250 EC sprayed plots of all varieties than the other fungicides, Rex® Dou and Natura 250 EW.

The losses in GY could be attributed to the severe infection of yellow and stem rusts at full-grown stage of the crop, which progressively slayed the leaves and stems and affected the normal physiological function of the crop. Under severe disease pressure, wheat plants are almost devoid of grains due to retarded of the plant to carry out normal physiological functions and led to considerable yield losses. The medium levels of septoria leaf blotch (Septiria tritici) disease severity and other environmental factors might also be accountable for the GY losses in addition to yellow and stem rusts; their effects were fully elucidate by the present study and the confounding effect of these factors in the GY losses cannot be underestimated. Yield losses of up to 100% due to wheat rusts have been reported in different parts of the world (CIMMYT, 2005; Krishna et al., 2017; Leonard & Szabo, 2005; Tadesse et al., 2010).

The overall results of this study demonstrated that the extent of yellow and stem rusts was relatively higher on the unsprayed plots of all varieties and Tilt 250 EC fungicide sprayed plots, and progressively the disease was decreased and stabilized toward the end of the epidemic period using Rex® Dou and Natura 250 EW fungicides at the right time at the three locations. This could be comparatively explained by necrotic lesions on leaves and stems on plots severely attacked by yellow and stem rusts in all varieties evaluated especially resistant (Hidase), moderately resistant (Ogolcho) and susceptible (Kubsa) varieties. Plots of different wheat varieties sprayed with Natura 250 EW and Rex® Dou showed better results in reducing rust disease development. This
observation was in line with the findings of Tadesse et al. (2010), Wubishet and Tamene (2016) and Phillip and Nathan (2018) who reported that wheat varieties having different levels of resistance to rusts in combination with fungicide application had resulted in the lowest severities and stabilizing rust severities toward the end of growing periods on highly protected plots.

5. Conclusion
The experimental evidence of this research revealed that the use of variety supplemented with fungicide application provided a noticeable effect in the downplaying of yellow and stem rusts and in increasing yield attributes of wheat in the three locations. Up on releasing the variety Hidase was resistance to yellow and stem rusts; however, in the present study on unsprayed plots of it there was hinger severity. Now it is susceptible to both rusts. Cost-benefit analysis also revealed that combined use of variety and fungicide application provided the highest NB and MRR. Relatively better results in the management of the rusts were obtained from the use of varieties having different levels of resistance to rust diseases with Rex® Dou and Natura 250 EW right after the appearance of the disease symptoms. However, unsprayed plots of all varieties showed the highest rust severity and AUDPC and provided minimum yield and economic returns as compared to the sprayed ones. Thus, the use of varieties differing in levels of resistance to rust diseases in combination with Rex Dou and Natura was proved to be a better and cost-effective approach in reducing rust epidemics as well as increasing the production and productivity of wheat. In addition, instead of using Tilt 250 EC once again in the rust management, it is better to use Rex® Dou and Natura 250 EW since they managed the rusts significantly when they are used in combination with moderately resistant varieties (Shorima and Wane), even with susceptible varieties (Ogolcho, Hidase and Kubsa), giving maximum NB and minimizing the cost of production. Therefore, this could be suggested to the farmers in the study areas and elsewhere with similar agro-ecological conditions for efficient management of wheat rusts and optimization of the yield without compromising profit. Further studies have to be undertaken in other agro-ecologies for at least two consecutive years over locations for developing a solid recommendation on rust management options through a combination of variety and fungicide application to keep sustainable wheat production in the country.
South African Journal of Plant and Soil, 20(1), 11–17. doi: 10.1080/02571862.2003.10634898.

Campbell, C. L., & Madden, L. V. (1990). Temporal analysis of epidemics: Description and comparison of disease progress curves. In Introduction to plant disease epidemiology (pp. 532). ISBN 0471832367. John Wiley and Son.

Conceição, G., Rita, C., Ana, S. A., José, C., Nuno, P., João, C., Armindo, C., & Benvindo, M. (2016). Septoria leaf blotch and Yellow rust control by: Fungicide applica-
tion opportunity and genetic response of bread wheat varieties. Emirates Journal of Food and Agriculture, 28(7), 493–500. doi: 10.9755/efja.2015.04.345

Cook, R. J., Hims, M. J., & Vaughan, T. B. (1999). Effects of fungicide spray timing on winter wheat disease control. Plant Pathology, 48(1), 33–50. doi: 10.1046/j.1365-3059.1999.00319.x

Cook, R. J., & King, J. E. (1984). Loss caused by cereal diseases and the economics of fungical control, plant diseases: Infection, damage and loss. Blackwell.

CSA (Central Statistical Agency). (2018). Agricultural sample survey, 2017/2018 (Report on area and production of crops (Private peasant holdings, main season). Statistical Authority, Addis Ababa, Ethiopia. Statistical Bulletin No. 446. Volume 5. 60 pp.)

FAO, IFAD, UNICEF, WFP, & WHO. (2018). The state of food security and nutrition in the world 2018. (Building climate resilience for food security and nutrition) (pp.202). FAO. Licence: CC BY-NC-SA 3.0 IGO. ISBN 978-92-5-130571-3. https://creativecommons.org/licenses/by-nc-sa/3.0/igo.

Foster, A. J., Loliatto, R., Vandeveer, M., & De Wolf, E. D. (2017). Value of Fungicide Application in Wheat Production in Southwest Kansas. Kansas Agricultural Experiment Station Research Reports, 3(5), 8. https://doi.org/10.4148/2378-5977.7385

Getachew, G. M., & Biruk, K. M. (2018). Assessment on spatial distribution and their management options against wheat rust (Puccinia spp.) disease species in selected administrative zones of southern Ethiopia. International Journal of Research in Agriculture and Forestry, 5(3), 8–16.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research (2nd ed.). John Wiley and Sons, Inc.

Green, M. B., Le Baron, H. M., & Moberg, W. K. (1990). Managing resistance to agrochemicals: From fundamental research to practical strategies. American chemical society symposium series number 421. American Chemical Society.

Hailu, D., & Fininsa, C. (2009). relationship between yellow rust (puccinia striiformis) and common wheat (tritium aestivum) yield, in the highlands of bale, southeastern ethiopia. Archives of Phytopathology and Plant Protection, 42(6), 508–523. doi: 10.1080/03235400701191663

Hovmöller, M. S., Yahyaoui, A. H., Milus, E. A., & Justesen, A. F. (2008). Rapid global spread of two aggressive strains of a wheat rust fungus. Molecular Ecology, 17 (17), 3818–3826. https://doi.org/10.1111/j.1365-294X.2008.03886.x

International Center for Agricultural Research in the Dry Areas (ICARDA). (2012). Meeting the challenge of yellow rust. In C. Crops. Ed. Proceedings of the 2nd, 3rd and 4th Regional Conferences on Yellow Rust in the Central and West Asia and North Africa (CWANA), 22–26 March 2004 Tashkent, Uzbekistan, on 8–11 June 2006; and Antalya, Turkey, on 10–12 October 2009. ISBN: 92-9127-273-6 (pp. 422). https://doi.org/10.1094/PDIS-11-11-0999-PDN

International Maize and Wheat Improvement Center [CIMMYT]. (1998). Farm agronomic data to farmer recommendations: An economics training manual. Completely revised edition. CIMMYT. 968-6127-18-6.

International Maize and Wheat Improvement Center [CIMMYT]. (2005). Sounding the alarm on global stem rust: An assessment of race Ug99 in Kenya and Ethiopia and the potential for impact in neighboring regions and beyond (Expert Panel Report) (p. 26). International Center for Maize and Wheat Improvement.

Jeger, M. J. (2004). Analysis of disease progress as a basis for evaluating disease management practices. Annual Review of Phytopathology, 42, 61–82. https://doi.org/10.1146/annurev.phyto.42.040803.140427

Jones, D. G. (1998). The epidemiology of plant diseases. Kluwer Academic Publishers.

Krishna, D. J., Ghulam, U., Attiq, U. R., Muhammad, M. J., Javed, A., Makhdoom, H., Angelo, P., Ibni, A. K., & Amanullah, B. (2017). Wheat yield response to foliar fungicide application against leaf rust caused by Puccinia striiformis. Journal of Agricultural Science and Technology A, 7, 160–168. doi: 10.17265/2161-6256/2017.03.003

Leonard, K. J., & Szabo, L. J. (2005). Stem rust of small grains and grasses caused by Puccinia graminis. Molecular Plant Pathology, 6(2), 99–111. https://doi.org/10.1111/j.1364-3703.2005.00273.x

Mercer, P. C., & Ruddock, A. (2005). Disease management of winter wheat with reduced doses of fungicides in Northern Ireland. Crop Protection, 24(3), 221–228. doi: 10.1016/j.cropro.2004.07.009

Milus, E. A. (1994). Effect of foliar fungicides on disease control, yield and test weight of soft red winter wheat. Crop Protection, 13, 291–295. doi: 10.1016/0261-2194(94)90018-3

Milus, E. A., Kristensen, K., & Hovmoller, M. (2009). Evidence of increased aggressiveness in a recent wide spread strain of Puccinia striiformis f.sp. tritici causing Yellow rust of wheat. Phytopathology, 99(1), 89–94. https://doi.org/10.1094/PHYTO-99-1-00899

MoA (Ministry of Agriculture). (2012). Animal and plant health regulatory directorate crop variety register. Issue No. 15. Ministry of Agriculture.

MoA (Ministry of Agriculture). (2015). Plant health regulatory directorate. List of registered pesticides as of October, 2015.

MoANR (Ministry of Agriculture and Natural Resources). (2016). Plant variety release, protection and seed quality control directorate. Crop Variety Register, (19), 7–18. Addis Ababa, Ethiopia: Ministry of Agriculture.

MoANR (Ministry of Agriculture and Natural Resources) & EATA (Ethiopian Agricultural Transformation Agency). (2016). Soil fertility status and fertilizer recommenda-
tion Atlas of the southern nations, nationalities and peoples’ regional state, Ethiopia. ATA.

MoANR (Ministry of Agriculture and Natural Resources) & EATA (Ethiopian Agricultural Transformation Agency). (2018). Crop production and development package. In Amharic Version (pp. 215). Ministry of Agriculture.

Peterson, R. F., Campbell, A. B., & Hannah, A. E. (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian Journal of Research, 26, 496–500. doi: 10.1139/cj48c-033

Phillip, N. S., & Nathan, M. (2018). Evaluation of foliar fungicide programs in mid-Atlantic winter wheat production systems. Crop Protection, 13, 103–110. https://doi.org/10.1016/j.cropro.2017.09.012
Ram, C. S., Kumarse, N., Amir, A., Zafar, Z., & Anwar, U. J. (2016). Reduction of Winter Wheat Yield Losses Caused by Yellow Rust through Fungicide Management. Journal of Phytopathology, 164, 671–677. doi: 10.1111/jpp.12909

Ransom, J. K., & McMullen, M. P. (2008). Yield and disease control on hard winter wheat varieties with foliar fungicides. Agronomy Journal, 100(4), 1130–1137. doi: 10.2134/agronj2007.0397

Robert, G. D., & James, H. T. (1991). A biometrical approach. In Principles of statistics (2nd ed.) (pp. 633). McGraw-Hill College. ISBN-10: 0070610282; ISBN-13: 978-0070610286.

Roelfs, A. P. (1985). Chapter 13, Epidemiology in North America. In Roelfs, A.P. & Bushnell, W.R. (Eds), The cereal rusts, Vol. II: Diseases, distribution, epidemiology and control (pp. 403–434). Academic Press. SAS (Statistical Analysis System) Institute. (2014). SAS/STATA user’s guide for personal computers, version 9.3. SAS Institute Inc.

Tadesse, K. (2005). Temporal development of stem rust (Puccinia graminis f.sp. tritici) and its effect on grain yield and protein content of bread wheat in Bale, Ethiopia [M.Sc. Thesis]. Haramaya University.

Tadesse, K., Ayelew, A., & Badebo, A. (2010). Effect of fungicide on the development of stem rust and yield of wheat varieties in highlands of Ethiopia. African Crop Science Journal, 18(1), 23–33. doi: 10.4314/acsj.v18i1.54194

Teklay, A., Getaneh, W., Woubit, D., Adhiena, M., & Yemane, N. (2013). Distribution and Seasonal Variation in Occurrence of Wheat Yellow Rust in Tigray, Ethiopia. Direct Research Journal of Agriculture and Food Science, 1(2), 11–17. Retrieved from http://directresearchpublisher.org/drjafs

USDA (United State Department of agriculture). (2018, November) Foreign agricultural service: World agricultural production global analysis (World agricultural supply and demand report). 31. Circular series WAP 11-18, DC 20250-1051. Foreign Agricultural Service/USDA.

van der Plank, J. E. (1963). Plant diseases: Epidemics and control. Academic Press.

Wanyera, R., Kinyua, M. G., Jin, Y., & Singh, R. P. (2006). The spread of stem rust caused by Puccinia graminis f. sp. tritici, with virulence on Sr31 in wheat in Eastern Africa. Plant Disease, 90(1), 113. https://doi.org/10.1094/PD-90-0113A

Wilcoxson, R.D., Skovmand, B., & Atif, A.H. (1975). Evaluation of wheat cultivars for ability to retard development of stem rust. Annals of Applied Biology, 80, 275–2181.

Willyerd, K. T., Bradley, C. A., Chapara, V., Conley, S. P., Esker, P. D., Madden, L. V., Wise, K. A., & Paul, P. A. (2015). Revisiting fungicide-based management guidelines for leaf blotch diseases in soft red winter wheat. Plant Disease, 99(10), 1434–1444. https://doi.org/10.1094/PD-02-15-0218-RE

Worku, D., Ayele, B., & Tamene, A. (2013). Evaluation of ethiopian commercial wheat cultivars for resistance to stem rust of wheat race ‘UG99’. International Journal of Agronomy and Plant Production, 4(1), 15–24.

Wubishet, A., & Chemeda, F. (2016). Effects of environment on wheat varieties’ Yellow Rust resistance, yield and yield related traits in South-Eastern Ethiopia. Plant, 4(3), 14–22. https://doi.org/10.11648/j.plant.20160403.11

Wubishet, A., Chemeda, F., & Bekele, H. (2015). Effects of environment on epidemics of yellow rust (Puccinia striiformis West.) of bread wheat (Triticum aestivum L.) in Bale highlands, South-Eastern Ethiopia.. Global Journal of Pests, Diseases and Crop Protection, 3(2), 096–107. Retrieved from http://www.globalscienceresearchjournals.org/

Wubishet, A., & Tamene, M. (2016). Verification and evaluation of fungicides efficacy against wheat rust diseases on bread wheat (Triticum aestivum L.) in the Highlands of Bale, Southeastern Ethiopia. International Journal of Research Studies in Agricultural Sciences, 2(9), 35–40. doi: 10.20431/2454-6224.0209005

Zadoks, J. C., Chang, T. T., & Kanza, C. F. (1974). A decimal code for the growth stage of cereals. Weed Research, 14, 415–421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x

Zegeye, T., Teye, G., Tanner, D., Verkuilj, H., Agidie, A., & Mwangi, W. (2001). Adoption of improved bread wheat varieties and inorganic fertilizer by small scale farmers. In Y. Densa & Farta districts of Northern Ethiopia (Ed.), (pp. 3–5). Ethiopian Agricultural Research Organization [EARO] and CIMMYT.
