

Relation Between Rust (Uromyces viciae-fabae) and Faba Bean (Vicia Faba) Yield Loss in Bale Highlands, South Eastern Ethiopia

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Abstract
In Ethiopia, Uromyces viciae-fabae is one of the most destructive biotic constraints for faba bean production. Information on the management and yield losses are inadequate in the Bale highlands where the crop is largely produced. The objective of this study was to manage faba bean rust through host resistance and fungicides, and determine the extent of yield losses. Field experiments were conducted at Madda Walabu University (MWU) and Harewa research stations. Four fungicides (mancozeb, fungozeb, nativo and diprocon) were used against four varieties having different level of resistance arranged in a randomized complete block design in a factorial combination with three replications. Data were collected on disease severity and yield components. Fungozeb sprayed at 2.5 kg a.i./ha proved the best management option in all varieties at both locations. Fungozeb foliar sprays reduced relative seed yield loss compared with their respective unsprayed checks. Generally, relative yield loss up to 56% at Madda Walabu University and up to 34% at Harewa from local unsprayed plots was recorded. Linear regression of the estimates indicated that -0.015, -0.051, -0.048 and -0.061 t/ha yield loss were predicted on walki, shallo, hachalu and local, respectively for every % days increase of area under disease progress curve (AUDPC) at MWU. Similarly, -0.123 t/ha on walki, -0.142 t/ha on shallo, -0.137 t/ha on hachalu and -0.151 t/ha on local variety yield loss was predicted for every %-days increase of AUDPC at Harewa. Significance differences were recorded in pods per plant and days to maturity. The unsprayed plots had shorter days to maturity as compared to plots sprayed at both locations on all genotypes. In conclusion, integration of walki and hachalu with fungozeb sprays was found to be effective management option. Moreover, extensive studies are recommended for evaluation of management options at different locations with similar agro-ecologies to enhance high quality faba bean production in Ethiopia.
Keywords: AUDPC; Fungicides; Rust; Severity; Vicia faba; Yield loss

1. Introduction

Faba bean (*Vicia faba* L.) is the first among pulse crops cultivated in Ethiopia with nearly 0.43 million hectares of lands, accounting for about 27.76% of the total pulse area, with annual production of 0.88 million tones, contributing about 31.2% of total pulse production (CSA, 2017). Diseases are the most important biotic factors causing faba bean yield reduction. The most important yield limiting diseases are rust (*Uromyces viciae-fabae*), chocolate spot (*Botrytis fabae*), black rot (*Fusarium solani*), aschochyta blight (*Aschochyta fabae*), faba bean necrotic yellow virus (FBNYV), and recently faba bean gall (*Olpidium viciae*) (Dereje and Tesfaye, 1994, Yitayih and Azmeraw, 2017). Among these, rust is the most important disease in different parts of the world, wherever faba bean is grown. Most of the time rust epidemics begin late in the season, when pod filling has started and yield losses usually range from 5 to 20% (Sillero *et. al*., 2000). However, when the infection starts early in the season, severe epidemics can occur and yield losses can be as high as 70% (Rashid and Bernier, 1991; Torres *et al*., 2006). Rust is widely distributed in Ethiopia and causes yield losses up to 27% (Dereje and Tesfaye, 1994; Shifa *et al*., 2011; Terefe *et al*., 2016). Yield loss could be even higher when in mixed infection with chocolate spot disease. They may also cause total crop failure under severe epidemic conditions (Torres *et al*., 2006). The disease is favored by high humidity, cloudy and warm weather conditions (Hawthorne *et. al.*, 2004). *Uromyces viciae-fabae* produces numerous, small, orange-brown pustules, each surrounded by a light yellow halo that develops on the leaves. On stem, rust pustules are larger and longer than those found on the leaves. Isolated rust pustules may also appear on the pods, which can reduce seed weight. Severe infection may cause premature defoliation, resulting in reduced seed size (Richardson, 2008).

Different control methods have been proposed against rust, including cultural practices, the use of chemicals and resistant varieties. Prevention of rust may be difficult because its spores can be carried long distances by wind to infect crops far away from the initial source of inoculum. Cultural practices, such as adjusting plant density, nitrogen fertilization or crop mixtures can significantly influence rust infection (Fernandez-Apricio *et. al.,* 2011). However, use of resistant varieties is recognized as the most desirable, efficient and economical strategy as management option. In commercial production, fungicides may be used in the absence of resistant or tolerant varieties. Still, a rational disease management using chemical should be based on a precise knowledge of the relationship between disease severity and yield loss in case of rust (Zadoks, 1985).

Foliar sprays of mancozeb, chlorothalonil and copper hydroxide have been recommended against rust in Australia (Hawthorne *et. al.*, 2004). Yeoman *et.al. (*1987) also used a range of fungicides to control rust for two years on springsown field beans in UK. Hassen *et.al.* (2010) reported that the use of Mancozeb and triadimefon best control rust.

Currently, Faba bean production in Ethiopia is threatened by rust because local cultivars grown by farmers are highly susceptible to rust and resistant varieties are not yet available to satisfy the need of the producers (Hassen *et. al.,* 2010). Optimum combination of sustainable controls cannot be determined without empirical yield loss estimates. Loss estimates provide information for disease forecasting and making management decisions. Thus, the relation between disease and yield loss in different agroecologies needs to be established. However, information is not available on the relationship between yield loss and rust disease in the country. Therefore, the objectives of this research were to (i) quantify the amount of loss in yield incurred due to rust on faba bean varieties, and (ii) assess the relationship between rust and yield loss of faba bean in the Bale Highlands.

Materials and Methods

Treatments, Experimental Design and Management

Two field experiments were conducted at the Madda Walabu University Research Station (MWU) and Harewa Research Station during the main cropping season of 2017. Four improved faba bean varieties currently under production and differing in their resistance level to rust were used. The varieties were: Walki, hachalu, shallo and local which were under cultivation in Ethiopia. Four fungicides: Mancozeb 80WP, fungozeb 80WP, diprocon 30EC and nativo SC300 were sprayed at doses of 2.5 kg a.i / ha, 2.5 kg a.i / ha, 0.75 L a.i / ha and 0.45 L a.i / ha, respectively. Mancozeb 80WP and fungozeb 80WP were sprayed every 7 days (5 sprays at MWU, 4 sprays at Harewa). Diprocon 30EC and nativo SC300 were sprayed every 14 days (3 sprays at MWU, 2 sprays at Harewa). A control plot was left unsprayed. During fungicide sprays, plastic sheet was used to separate the plot being sprayed from the adjacent plots to prevent inter-plot interference. The fungicides were sprayed using a manual knapsack sprayer. A randomized complete block design in factorial arrangement was used in three replications at both locations. The spacing was 1.5 m between blocks, 0.6 m between plots, 0.4 m between rows and 0.1 m between plants. Plots were fertilized with diammonium phosphate (DAP) at the rate of 100 kg per hectare. Mechanical and hand weeding was done when required. Rust was allowed to develop naturally on each cultivar without any artificial inoculation.

Disease severity assessment

The severity of rust was assessed 8 times at MWU and 4 times at Harewa at weekly intervals starting from the first appearance of the disease symptoms in the experimental plots. Disease severity was recorded from 10 randomly selected and tagged plants in the central two rows of each plot separately, for the three layers of the canopy (top, middle and bottom). Severity was rated using a 1–9 scale, where 1 indicates no visible symptom and 9 represents disease covering greater than 80% of leaf area (ICARDA, 1986). Disease severity scores were converted into percentage severity index (PSI) for analysis (Wheeler, 1969).

$$\mathrm{PSI} = \frac{\text{Sum of numerical ratings } \times 100}{\text{No of plants scored } \times \text{Maximum score on scale}}$$

Means of canopy layers were determined per plant and then mean per plot was determined for data analysis.
Area under disease progress curve (AUDPC) was worked out using the formula (Campbell and Madden, 1990):

$$\mathrm{AUDPC} = \sum_{i=1}^{n-1}[0.5(x_{i+1} + x_i)(t_{i+1} - t_i)]$$

where n is total number of assessment made, t_i is time of the i^{th} assessment in days from the first assessment date, x_i is percentage of disease severity at i^{th} assessment.

Yield Components

Data of yield components were recorded for each plot. The yield components include plant height, hundred seed weight, and pods per plant and seeds per pod on 10 randomly taken pre-tagged plants in each plot. Hundred seed weight of faba bean were harvested from middle two rows of each plot. Data on days to maturity was also recorded from each plot. Percentage yield loss was calculated using the formula:

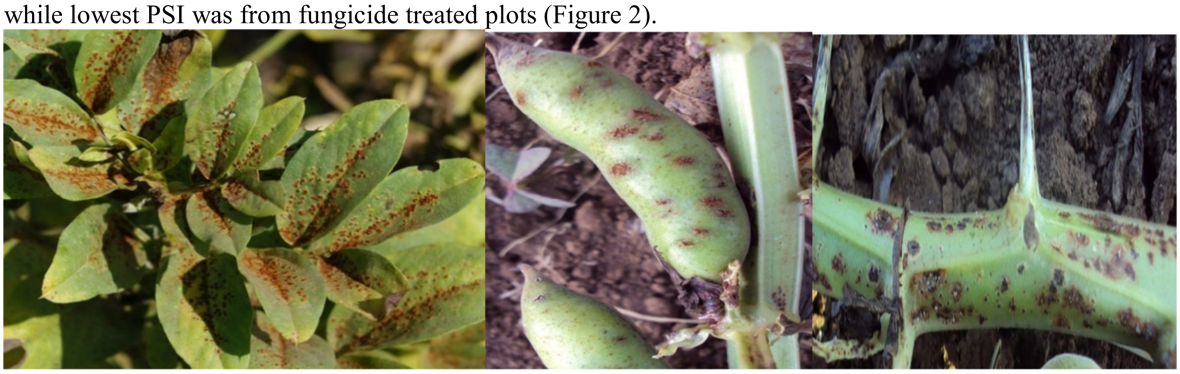
$$L = \frac{(YP - YT) \times 100}{YP}$$

where L = Percent yield loss, YP = mean of the respective parameter on protected plots (plots with maximum protection) and YT = mean of the respective parameter in unprotected plots (i.e. unsprayed plots or sprayed plots with varying level of disease).

Data analysis
Yield component data from each variety and fungicide treatments were examined. The two locations data were considered as different environments because of the significant variation in weather conditions during the study period. In addition to that homogeneity of variance was conducted and the two locations were heterogeneous. As a result, data were not combined for analysis. Data of PSI at terminal assessment, yield components were subjected to analysis of variance (ANOVA) to determine treatment effects. Data analysis was performed using SAS procedure GLM (SAS Institute, 2008). Least significance difference was used for mean separation (LSD) when necessary. Linear regression analysis was conducted by plotting yield data for individual varieties against AUDPC. Regression analysis was performed to determine intercept (b_0), regression slope (b_1) and coefficient of determination (R^2). Coefficient of determination (R^2) estimated the proportion of the variation explained by the regression.

RESULTS

Percentage severity index (PSI) of rust
Rust of faba bean was observed on the experimental plots of local variety after flowering at both locations (Figure 1). The mean PSI of rust disease was different on plots treated with different fungicides at both locations. At MWU the highest rust mean PSI was on local unsprayed, whereas the lowest was from plots treated with fungicides. At Harewa there was similar trend that the highest rust PSI recorded from naturally infected plots, while lowest PSI was from fungicide treated plots (Figure 2).



A B C

Figure 1. Symptoms of faba bean rust on leaf (A), pods (B) and stems (C)

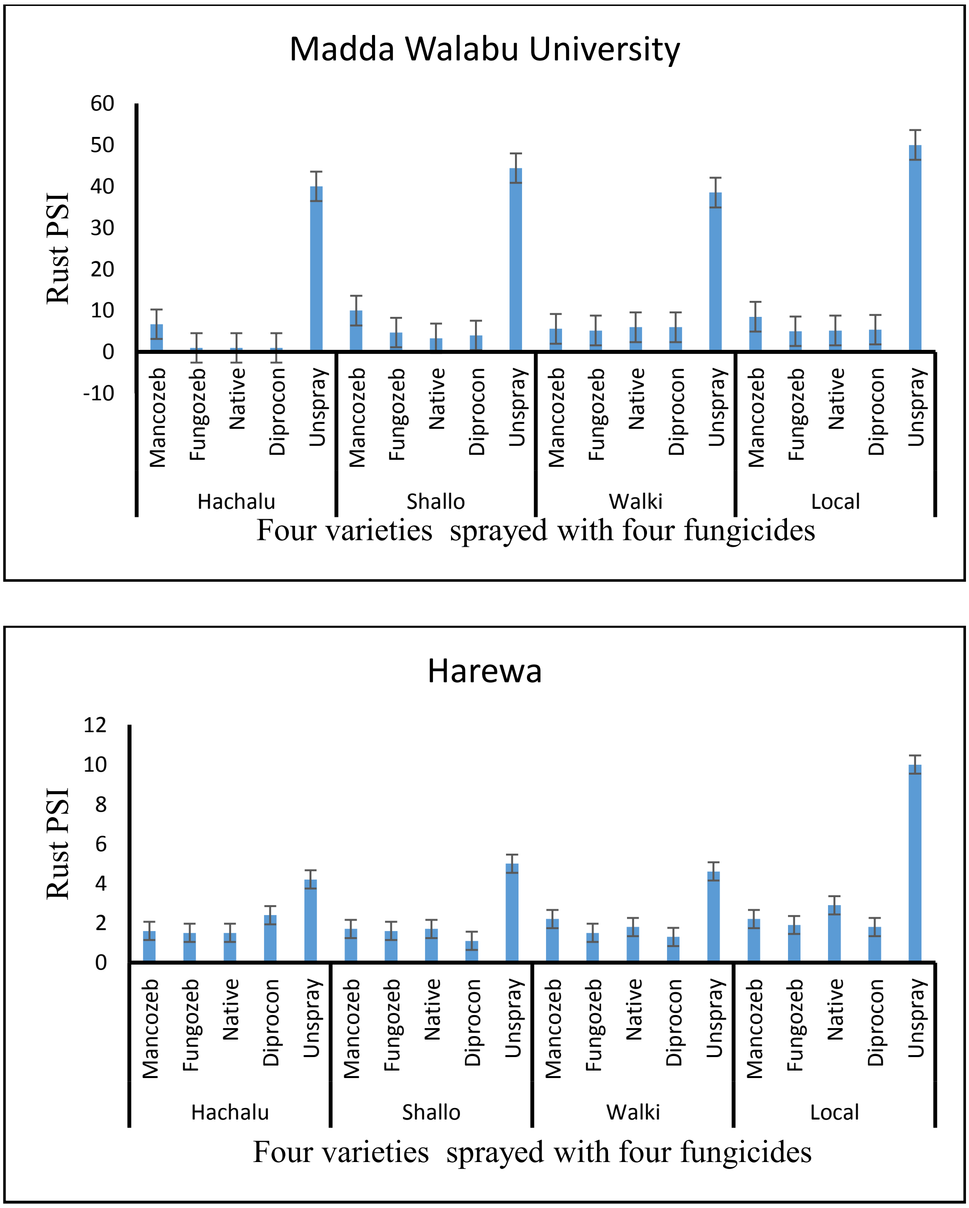


Figure 2. Effect of rust on faba bean varieties treated with different fungicides at Madda Walabu University and Harewa research stations during 2017 main cropping season

Yield Components

Significant variation ($p \leq 0.05$) was obtained in all yield components among different foliar sprays at both locations. Fungicide sprayed plots had higher number of pods per plant, seeds per pod, hundred seed weight and more days to maturity than unsprayed control in all varieties at both locations (Tables 1 and 2).

At MWU the highest hundred seed weight was recorded on walki variety from plots treated with fungozeb (65.33g) followed by mancozeb (60.33g) (Table 1). Hundred seed weight ranged from 51.67 to 64.67g for hachlu variety and from 43.3 to 56g for local variety. While at Harewa the highest hundred seed weight (58.9g) was recorded from hachalu treated with fungozeb and the lowest hundred seed weight was recorded from local unsprayed plot (34.67g) (Table 2).

Higher pods per plant (20) were recorded in variety walki at MWU from plots treated with fungozeb, but the number of pods per plant was not significantly different from plots treated with mancozeb (19). The number of pod per plant ranged from 12 to 16 at MWU and 7 to11 at Harewa on local variety. Number of seeds per pod (3.4) was also higher in walki variety in plots treated with fungozeb which was significantly different from other fungicide treated plots (Table 12). Rust significantly ($P \leq 0.05$) decreased the number of days to maturity (Tables 1 and 2). Varieties treated with fungozeb and mancozeb have long days to maturity than nativo and diprocon fungicides. The unsprayed plots had relatively shorter days to maturity that ranged from 99 to 144 days at MWU and 113 to 138 days at Harewa.

Table 1. Varieties treated with fungicides and agronomic parameters at Madda Walabu in 2017 main cropping season.

Variety	Fungicide	100-seed weight (g)	Days to maturity	Number of pods per plant	Number of seeds per pod
Hachalu	Mancozeb	62.00	132.67	16.10	3.03
	Fungozeb	64.67	134.67	16.73	3.00
	Nativo	58.67	131.67	14.67	3.00
	Diprocon	53.33	130.67	15.40	2.96
	Unspray	51.67	129.67	13.63	2.96
	Mean	58.07	129.70	15.31	2.99
	LSD(0.05)	4.78	1.75	2.45	0.35
	CV (%)	4.38	0.72	8.48	6.28
Shallo	Mancozeb	58.00	127.33	16.70	2.96
	Fungozeb	59.00	128.33	17.13	3.13
	Nativo	51.33	126.33	14.83	3.00
	Diprocon	54.00	127.00	14.90	2.96
	Unspray	46.33	123.33	14.56	2.93
	Mean	53.70	124.30	15.63	3.01
	LSD(0.05)	8.46	2.53	5.02	0.23
	CV (%)	8.36	1.08	17.06	4.11
Walki	Mancozeb	60.33	141.67	18.56	3.13
	Fungozeb	65.33	143.67	20.10	3.36
	Nativo	59.00	139.67	17.46	3.03
	Diprocon	58.33	138.67	16.26	3.06
	Unspray	53.00	136.67	15.70	3.00
	Mean	10.40	58.80	17.62	3.07
	LSD(0.05)	12.15	2.12	1.69	0.16
	CV (%)	10.97	0.81	5.09	2.73
Local	Mancozeb	52.33	102.33	14.80	3.23
	Fungozeb	56.00	103.33	15.53	3.16
	Nativo	51.00	101.33	14.30	3.13
	Diprocon	50.33	100.33	13.50	2.80
	Unspray	43.33	99.33	12.03	2.60
	Mean	18.70	50.60	14.04	3.03
	LSD(0.05)	5.98	2.12	2.40	0.38
	CV (%)	6.28	1.15	9.08	6.65

CV, coefficient variation; LSD, least significant differences

Table 2. Varieties treated with fungicides and agronomic parameters at Harewa in 2017 main cropping season

Variety	Fungicide	100-seed weight (g)	Days to maturity	Number of pods per plant	Number of seeds per pod
Hachalu	Mancozeb	55.33	136.67	12.62	3.03
	Fungozeb	58.90	138.33	14.53	3.00
	Nativo	47.00	128.67	12.02	2.60
	Diprocon	49.33	126.67	10.04	2.67
	Unspray	43.33	123.67	9.52	2.56
	Mean	50.84	130.00	11.70	2.78
	LSD(0.05)	3.61	5.59	2.19	0.44
	CV (%)	3.77	2.28	9.93	8.31
Shallo	Mancozeb	50.67	134.33	12.03	2.90
	Fungozeb	52.67	135.33	12.26	2.83
	Nativo	42.33	131.00	9.95	2.60
	Diprocon	44.00	128.33	9.25	2.17
	Unspray	41.06	123.67	8.33	2.27
	Mean	46.15	130.53	10.42	2.55
	LSD(0.05)	5.61	3.53	1.02	0.48
	CV (%)	6.46	1.44	5.18	9.97
Walki	Mancozeb	50.00	137.00	12.20	2.90
	Fungozeb	53.67	137.33	12.33	2.90
	Nativo	44.00	133.66	10.00	2.80
	Diprocon	47.00	131.00	9.67	2.63
	Unspray	39.53	129.33	9.40	2.56
	Mean	46.84	133.67	10.66	2.76
	LSD(0.05)	7.82	7.30	2.41	0.43
	CV (%)	8.86	2.90	12.00	8.27
Local	Mancozeb	47.00	126.67	10.15	2.63
	Fungozeb	48.00	133.67	11.17	2.76
	Nativo	40.33	124.67	10.02	2.53
	Diprocon	37.33	125.35	9.36	2.33
	Unspray	34.67	113.67	7.13	1.96
	Mean	41.46	124.80	9.56	2.45
	LSD(0.05)	4.49	4.30	1.90	0.41
	CV (%)	5.75	1.83	10.69	8.81

CV, coefficient variation; LSD, least significant differences

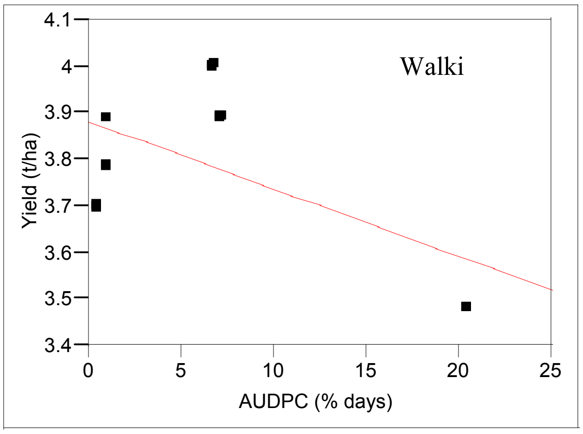
Relation of rust to faba bean seed yield and yield components

The maximum yield loss of 56.08% at MWU and 33.72% at Harewa was recoded from local unsprayed variety. Next to fungozeb treated plot, the minimum yield loss of 0.39% at MWU and 0.19% at Harewa was recorded when hachalu sprayed with mancozeb (Table 3).

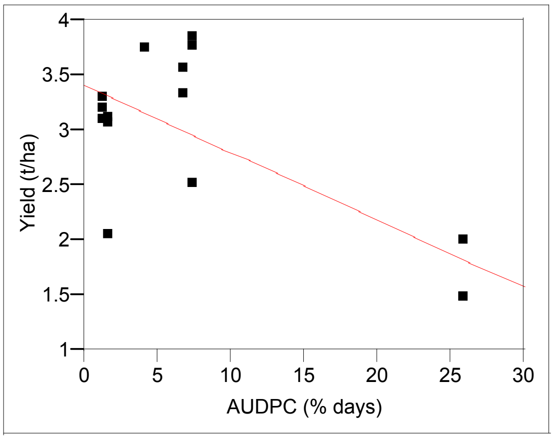
Table 3. Relative yield loss faba bean varieties treated with different fungicides at Madda Walabu (MWU) and Harewa research stations during 2017 main cropping season.

		Relative yield loss (%)	
Variety	Fungicide	MWU	Harewa
Hachalu	Mancozeb	0.39	0.19
	Fungozeb	0.00	0.00
	Nativo	7.03	12.58
	Diprocon	7.16	0.90
	Unspray	26.53	26.22
Shallo	Mancozeb	5.28	5.06
	Fungozeb	0.00	0.00
	Nativo	17.63	14.89
	Diprocon	16.95	12.05
	Unspray	49.98	31.54
Walki	Mancozeb	2.72	0.32
	Fungozeb	0.00	0.00
	Nativo	4.55	4.80
	Diprocon	7.57	9.91
	Unspray	13.01	30.66
Local	Mancozeb	3.31	3.17
	Fungozeb	0.00	0.00
	Nativo	25.19	18.01
	Diprocon	2.28	6.45
	Unspray	56.08	33.72

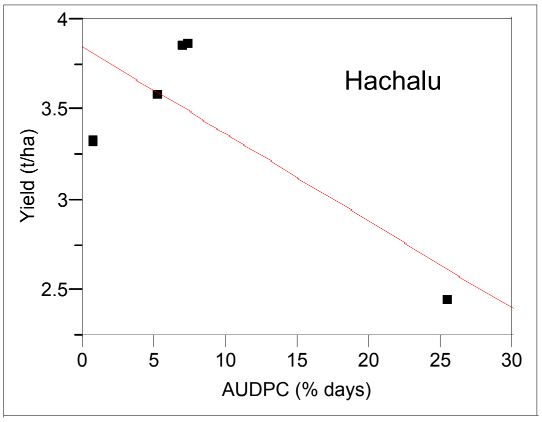
The linear regression of AUDPC better described the relationships between faba bean yield and disease severity compared to percent severity index. The estimate showed that for each unit increase in percent of rust AUDPC, there was a seed yield losses. The estimated slope of the regression line obtained indicated that the increment of the diseases progress. Based on coefficient of determination (R^2) value, the equations explained the variation in seed yield due to rust severity. The estimated equation showed there was a seed yield reduction for each unit increase in percent of rust AUDPC. At MWU the relationship described by the model accounted for 33.9% to 61.5% of the variance (Figure 3). The estimated slope of the regression line for rust obtained at MWU on walki, shallo, hachalu and local were $b_{1=}$-0.015, -0.051, -0.048 and -0.061 respectively. The estimates indicated that -0.015, -0.051, -0.048 and -0.061 t/ha yield losses were predicted on walki, shallo, hachalu and local variety, respectively for every %-days increase of AUDPC. At Harewa, the estimated slopes were b_1=-0.123, -0.142, -0.137 and -0.151 on walki, shallo, hachalu and local, respectively. The estimates indicated that -0.123 t/ha on walki, -0.142 t/ha on shallo, -0.137 t/ha on hachalu and -0.151 t/ha on local variety yield loss were predicted for every %-days increase of AUDPC at Harewa (Figure 4).



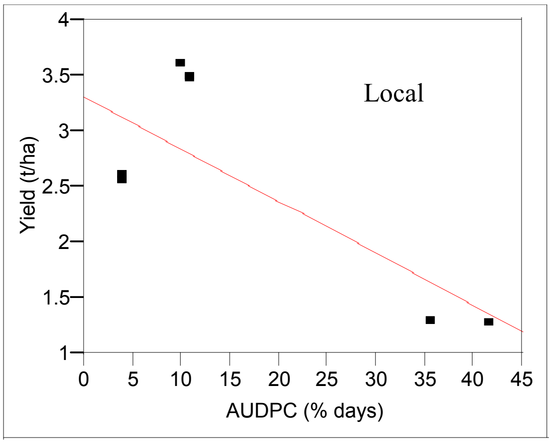
$Y = 3.881 - 0.015x$; $R^2=0.339$



$Y= 3.407 - 0.051x$; $R^2=0.511$

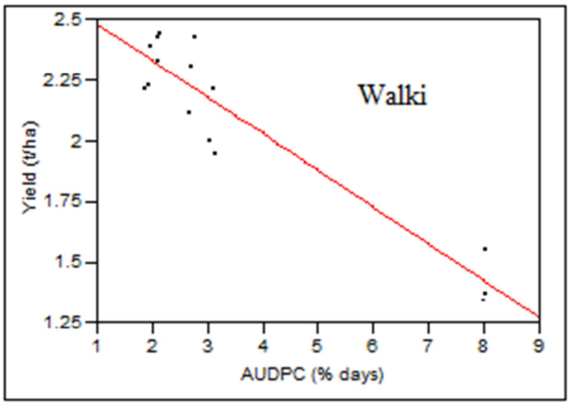


$Y = 3.848 - 0.048x$; $R^2=0.615$

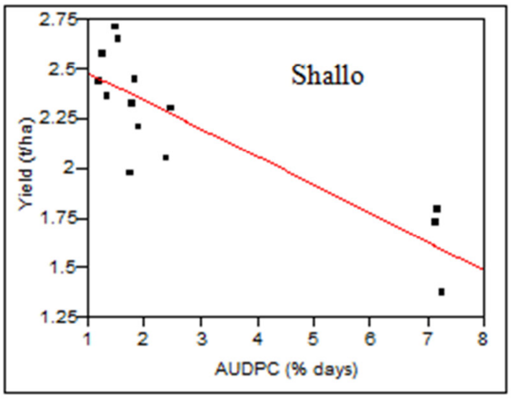


$Y= 3.305 - 0.061x$; $R^2=0.503$

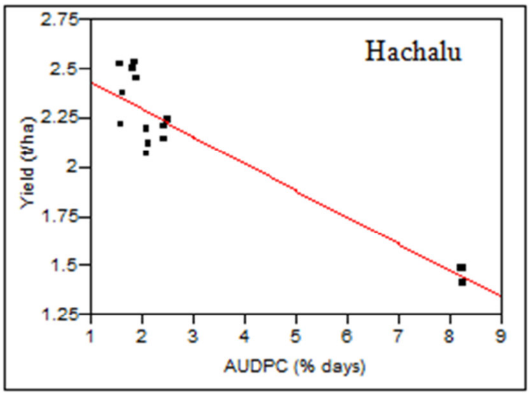
Figure 3. Linear regression relating AUDPC of faba bean rust with grain yield (t/ha) on four individual cultivars treated with fungicides at Madda Walabu University in 2017



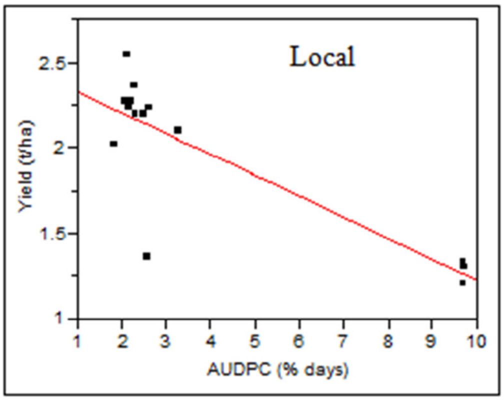
Y = 2.630 - 0.123x; R^2=0.881



Y= 2.625 - 0.142x; R^2=0.741



Y = 2.568- 0.137x; R^2=0. 0.879



Y= 2.452 - 0.151x; R^2=0.698

Figure 4. Linear regression relating AUDPC of faba bean Rust with grain yield (t/ha) on individual cultivars treated with fungicides at Harewa in 2017

4. Discussion

The number of pods per plant, the number of seeds per pod and seed weight are the most important components of yield in faba bean. The economic value of any type of disease resistance could be determined from increased yields and/or quality that result from a reduced amount of disease on resistant genotypes. Sache and Zadoks (1994) reported that generally yield components decreased with increasing disease severity. The variations in these yield components at the two locations might be due to difference in environmental conditions and disease pressure.

In this study, spraying contact fungicides (fungozeb and mancozeb) at seven day interval markedly reduced rust severity compared to nativo and diprocon sprayed plots at both locations. The results of this study are consistent with research conducted by Marcellos *et al*. (1995) on the influence of foliar fungicides by using mancozeb which showed that a significant reduction of rust severity and increased seed yield of faba bean through control of *U. viciae-fabae*. Variation in rust severity between locations might be due to differences in environmental factors, inoculum load and time of infection. Plant diseases reduce crop yields and therefore, their management is important. The basic requirement is to identify and establish a relation between the cause (plant disease) and the effect (yield loss). Estimates of yield losses were made on the basis of field experiments at MWU and Harewa, in which the disease was controlled by fungicides. In general, minmum seed yield loss was obtained when fungozeb was applied followed by mancozeb. In earlier reports, it was indicated that an early application of mancozeb and tebuconazole showed decreased rust severity (Marcellos *et al*., 1995). Rashid and Bernier (1991) showed that the yield increase from rust control was due to higher hundred seed weight, which was also observed in the present work. The results of this study are consistent with those obtained elsewhere which demonstrated that foliar applications of fungicides prevent yield loss due to rust (Yeomans *et al.,* 1987; Rashid and Bernier, 1991; Marcellos *et al*., 1995). When the infection starts early in the season severe epidemics can occur and yield losses as high as 70% have been reported (Rashid and Bernier, 1991).

Marcellos *et al*. (1995) reported that a reduction in hundred seed weight was associated with treatments in which yield was reduced. Increase in seed weight over the control varied with different foliar spray fungicides used for control of faba bean rust. Our findings also support this fact. At both locations, yield increase was due to increase in hundred seed weight and pods per plant in fungicide treated plots when compared with unsprayed plots. Yeoman *et al.* (1987) also reported that yield increases were mainly attributed to increasing weight of individual grains when non-systemic fungicides were used. The present study has indicated that the main cropping season in the Bale highlands is highly conducive for rust of faba bean rust epidemics to occur and cause high yield loss in faba bean production. The results imply the importance of using resistant varieties and applying fungicides on cultivars at the time of disease onset in order to minimize the effect of disease on faba bean production. Faba bean rust affected days to maturity, forcing early maturing of the plant. This kind of disease relation has been reported by Samuel *et al*. (2008) due to chocolate spot of faba bean. In this case, the plots treated with fungozeb and mancozeb extended the days to maturity. The delay in days to maturity means more time for photosynthesis, which might have increased seed yield.

Linear regression of the AUDPC was used for predicting the yield loss in faba bean, because AUDPC linear regression better indicated the relationship of yield loss and the disease than the severity linear regression. On the other hand, disease progress curves are highly sensitive to fluctuations in epidemiological factors during disease development so they are not good predictors of the relationship of yield and disease severity. The AUDPC accounts for all these factors (Chaube and Pundhir, 2005) as the crop yield loss depends upon severity as well as on duration of the disease. This relation was used by Samuel *et al*. (2008) to investigate the relationship between yield loss and chocolate spot in sole and mixed cropping systems under Ethiopian conditions.

Competing Interests
The authors declare that they have no competing interests.

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