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Management of Common Bean Rust (*Uromyces appendiculatus*) through Host Resistance and Fungicide Sprays in Hirna District, Eastern Ethiopia

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Abstract

Common bean rust (*Uromyces appendiculatus*) is an important disease affecting common bean (*Phaseolus vulgaris* L.) production in the world. In Ethiopia, this is the most destructive disease constraining common bean production. Field experiments were carried out at Hirna Research Sub-Station of Haramaya University in the 2010 main cropping season to elucidate reaction of released common bean varieties to rust infection and to study the effect of integrated use of host resistance and fungicide foliar sprays on incidence of the disease and its control. For the evaluation of common bean varieties to rust disease the experiment was laid out in randomized complete block design with three replications and 15 varieties and the experiment was laid out as a randomized complete block design in factorial arrangement with three replications for the management part. In the fungicide spray, three contact (i.e., Chlorothalonil, Mancozeb and Copper hydroxide) and one systemic (Triadimefon) fungicides were tested on a susceptible (Mexican-142) and a moderately resistant (Awash-1) varieties. The research results obtained indicated that the evaluated common bean varieties varied significantly in severity, area under disease progress curve, disease progress rate and grain yield. Three reaction groups of common bean varieties were identified, viz. susceptible, moderately resistant and resistant. The resistant varieties produced the highest grain yield. At Hirna the varieties, Kufanzik, Haramaya, Melkadima, Gofta, Chore and Awash Melka were found to be resistant to the disease. These varieties were also high yielders. However, in case seeds of resistant varieties are inadequate to cover the major growing areas, farmers can use the moderately resistant varieties with fungicide sprays wherever the disease is a pervasive and pressing problem. In the management study, lower rust incidence, severity, area under progress curve and slower disease progress rate occurred on the moderately resistant variety sprayed with Triadimefon than on the susceptible variety with Triadimefon and/or with other fungicides (Mancozeb, Copper hydroxide and Chlorothalonil). The integrated use of moderately resistant variety (Awash-1) with Triadimefon proved to be the best management option producing the highest (2306.25 kg ha^{-1}) grain yield. Triadimefon foliar spray reduced relative grain yield loss by 10.84% on the moderately resistant variety Awash-1 compared to the susceptible variety Mexican-142. In conclusion, integrated use of Awash-1 with Triadimefon spray was found to be the most effective bean rust management option.

Keywords: Common bean rust; Fungicide; Incidence; Integrated; Phaseolus vulgaris; Resistance; Severity; Uromyces appendiculatus; Variety

Introduction

The economic significance of common bean (*Phaseolus vulgaris* L.) is quite considerable in Ethiopia since it represents one of the major food and cash crops. It is often grown as a cash crop by smallholder farmers and used as a major food legume in many parts of the country [1]. The area devoted to common bean production in Ethiopia was 245,722 hectares with a total production of 211,380 t and the average yield was 0.86 t ha^{-1} [2]. Dry bean production under farmers' conditions is in the range of 0.06 to 0.70 t ha^{-1}. Under good management conditions, however, beans can produce up to 2.5 to 3.0 t ha^{-1} in Ethiopia [3]. Common bean is mainly grown in eastern, southern, south western and the Rift Valley areas of Ethiopia [4,5]. Suitable altitude for common bean growth ranges from 1200 to 2000 meters above sea level in the country [6,7]. Common bean has the advantage of early maturity and low moisture requirement, making it a dependable alternate crop when staple food crops such as sorghum and maize fail during the period of early drought. This is especially true in Hararghe region where early drought and erratic rainfall are common phenomena.

Insect pests and diseases are major biotic constraints to common bean production in Africa [8]. Rust [*Uromyces appendiculatus* (Pers.) Unger], anthracnose [*Colletotrichum lindemuthianum* (Sacc.) *Magnas*], common bacterial blight (*Xanthomonas campestris* pv. phaseoli Smith Dowson), angular leaf spot (*Phaeoisariopsis griseola* (Sacc.Ferr), web blight [*Rhizoctonia solani* pv. phaseoli (Mart) Sacc.], bean common mosaic virus and golden mosaic virus are the major diseases identified to cause yield reduction in Ethiopia [9]. Bean rust [*Uromyces appendiculatus* var. appendiculatus (Syn. U. phaseoli)] is one of the major diseases of common bean in the humid, moderately humid, and semi-arid irrigated production areas worldwide. The bean rust pathogen consistently causes bean yield losses reaching up to 100% under severe epidemics [10,11]. Bean rust is often more severe in tropical and sub-tropical regions than in the temperate areas of Europe and North America [12].

In the Ethiopian bean production system, common bean rust is an important constraint. The disease has a wide geographical distribution.

During favourable seasons, it can completely wipe out susceptible common bean varieties [13]. Although the impact of bean rust on attainable bean yield varies with cultivar, location, and year, under conditions of early disease onset, yield loss could be as high as 85% for susceptible cultivars [14]. It was also reported that a total seed yield loss ranging from 2 to 15% and 14 to 21% occurred at Melkasa and Debre Zeit, respectively [15].

Management of bean rust relied primarily on three strategies: application of fungicides, host resistance, and various cultural practices, i.e., crop husbandry techniques. Cultural practices were once thought to have only a small effect on rust disease severity, but they played a significant role when combined with other methods in an integrated disease management system. Chemical control has been a mainstay in intensive common bean production areas where bean growers manage their crops for maximum yield and quality. Numerous fungicides, including Chlorothalonil, Tebuconazole, Propiconazole and some dithiocarbamates (like Mancozeb, Maneb) are effective in controlling rust, but proper timing of fungicide application, which is essential to improve economic return, requires good disease monitoring and a weather forecasting system. Common bean variety mixtures, host resistance and chemical seed treatment were reported to increase the efficacy of the system for reducing common bean rust. The effects of such an integrated scheme to reduce bean rust disease are needed to be assessed in the Hararghe condition [5]. Therefore, this study was undertaken with the objectives of elucidating response of common bean varieties to bean rust under natural infection and to evaluate the efficacy of integrating foliar fungicide sprays with varietal resistance in controlling the disease.

Materials and Methods

The study consisted of two activities, namely evaluation of common bean varieties for reaction to rust and integrated management of common bean rust through host resistance and fungicide sprays. The field experiments were conducted at Hirna research site during the 2010/11 main cropping season.

Evaluation of common bean varieties for reaction to rust

Description of the study area: The field experiment was conducted at Hirna Research sub-station of Haramaya University in West Hararghe Zone of eastern Ethiopia during the 2010 main cropping season. Hirna is located at 41°4' E, 9°12'N at an altitude of 1870 meters above sea level. The area is characterized by a bimodal rainfall pattern, during March to April (Belg season) and July to end of September (Meher season). The site receives a mean minimum rainfall of 990 and maximum rainfall of 1010 mm, with an average temperature of 24°C [16]. The soil is Vertisol.

Description of plant material: The planting materials were obtained from Melkasa Agricultural Research center and Haramaya University.

No	Variety	Year of release	Days of maturity	Yield on station (t ha^{-1})	Seed size	Reaction type to rust	Suitable area
1	**Awash Melka**	1998	95-100	2.2-3.2	Small	R	All over the country
2	**Awash-1**	1990	95-100	2.0-2.4	Small	MR	Central Rift Valley
3	**Ayenew**	1997	90-95	2.2-2.4	Medium	MR	Eastern and western Hararghe zones
4	**Chercher**	2006	98	2.2-2.8	Small	MR	Hararg hehighlands and similar areas
5	**Chore**	2006	87-109	2.3	Small	R	All bean growing areas
6	**Dinknesh**	2006	92	2.5-3.2	Medium	S	Central rift valley and similar areas
7	**Dursitu**	2008	100-105	2.0-3.5	Medium	MR	Eastern and western Hararghezones (Fedis, Kombolcha, Haramaya, Kersa, Meta, Hirna)
8	**GobeRasha**	1998	90-95	2.2-2.5	Large	MR	Jimma and similar areas in southwestern Ethiopia
9	**Gofta**	1997	95	2.2-2.4	Large	R	Eastern and western Hararghe zones
10	**Haramaya**	2006	100	2.0-3.2	Medium	R	Eastern Hararghe zone and similar areas
11	**Kufanzik**	2008	90-95	2.5-4.0	Medium	R	Eastern and western Hararghe zones (Fedis, Kombolcha, Haramaya, Kersa, Meta, Hirna)
12	**Melka Dima**	2006	91	1.8 - 2.3	Medium	R	Central rift valley and similar areas
13	**Mexican-142**	1972	96	1.6 - 2.0	Small	S	Across all locations

14	**Red Wolaita**	1997	77	2.2	Small	MR	Across all environment
15	**Roba-1**	1990	75	2.1	Small	MR	All bean growing areas

Table 1: Description of the common bean varieties evaluated for their reaction against bean rust under field conditions at Hirna during 2010 main cropping season. Note: S, susceptible; MR, moderately resistant; R, resistant. Source: (MoARD) [17].

Treatments and experimental design: The treatments consisted of 15 released common bean varieties, including a susceptible check, Mexican-142 (Table 1). The experiment was laid out as a randomized complete block design (RCBD) and replicated three times per treatment. These varieties were planted in four rows per plot in which 40 plants were maintained in each row. The space between plots was 0.6 m while the space between blocks was 1.5 m. Plot size was 1.6 m × 4.1 m (6.56 m^2) in which the row-to-row distance was 40 cm and the plant-to-plant distance was 10 cm apart.

Experimental procedure: Planting was done on 20 July 2010 by drilling two seeds per hole, which were later thinned to one plant per hole. All agronomic practices were applied in accordance with the existing recommendations for the area.

Data collection and measurement: Disease assessment: Data were collected from 20 randomly pre-tagged plants in the two central rows. Disease incidence and severity were recorded from the pre-tagged 20 plants in the middle two rows of each plot every seven days starting from the first appearance of the disease symptoms. Three assessments were done during the evaluation period for disease incidence. The assessment was repeated five times for studying disease severity.

Disease severity was recorded by estimating the percentage of leaf area diseased using the CIAT [18] 1-9 disease scoring scale, where 1=no visible rust pustules and 9=presence of large and very large pustules with chlorotic halos covering more than 25% of the foliar area and causing severe premature defoliation [19]. Disease severity scores were then converted into percentage severity index (PSI) for the analysis of variance (ANOVA) using the formula used by Wheeler [20] as shown below.

$$PSI = \frac{Snr}{Npr \times Msc} \times 100 \qquad (1)$$

Where: Snr=Sum of numerical rating; Npr=No of plants scored (rated); Msc=Maximum score on scale.

Data on the following parameters were collected: Days to 50% emergence: The time period from planting to 50% emergence was recorded to compare phenology of common bean varieties.

Disease incidence: This was assessed by counting the number of plants showing symptoms of bean rust from 20 pre-tagged two central rows of each plot and then data were converted into percentage.

Disease severity: Percent tissue area affected by the disease was assessed on 20 pre-tagged plants in the two central rows of each plot. Data were recorded using the CIAT 1-9 disease scoring scale [19]. The Severity was expressed as percent severity index (PSI) computed based on 1-9 disease scale.

Area under disease progress curve (AUDPC): was calculated for each plot using the formula of Shanner and Finney [21].

$$AUDPC = \sum_{i=1}^{n-1} 0.5\left[\left(X_i + X_i + 1\right)\left(t_i + 1 - t_i\right)\right] (2)$$

Where: x_i=the cumulative disease severity expressed as a proportion at the i^{th} observation, t_i=time of the i^{th} assessment in days, and n=the total number of observations.

Stand count at harvest: Numbers of plants in the two central rows were counted at harvest.

Plant height (cm) at harvest: This was measured by taking plant height from the ground level to the tip of the canopy in centimeter at harvest.

Number of pods per plant: Number of pods per plant was recorded from 20 pre-tagged plants at harvest.

Number of seeds per pod: Number of seeds per pod was recorded from 20 pre-tagged plants by taking 5 pods from each plant and averaged.

Yield (kg per plot): This was recorded from the net harvested plots and converted into kg ha^{-1}.

Data analysis: The data on disease incidence and severity were subjected to ANOVA to determine treatment effects. AUDPC values were used for analysis of variance to compare amounts of disease among different treatments. AUDPC was expressed in percent-days because severity was expressed in percent and time (t) in days [20]. Disease incidence and percentage disease severity data from each assessment were analyzed. Correlation analysis was used to determine the relationship among yield, percent severity index, and AUDPC across the treatments. AUDPC, yield and yield component data were subjected to ANOVA to determine treatment effect. All the disease reaction for each common bean variety was evaluated by averaging the disease incidence and the disease severity values from the individual plant. Least significant difference (LSD) value was used to separate the treatment means. All data analyses were conducted using the SAS Statistical Version 9.0 Software [22].

Integrated management of common bean rust

This experiment was also conducted at Hirna in the 2010 main cropping season using two common bean varieties, i.e., one susceptible (Mexican-142) and the other moderately resistant (Awash-1) with four fungicide foliar sprays.

Treatment and experimental design: The treatments consisted of two factors, namely common bean varieties and foliar fungicide sprays. Factorial combinations of the two varieties and four foliar sprays of fungicides (Chlorothalonil, Copper hydroxide, Mancozeb and Triadimefon) in ten treatment combinations were used. The experiment was laid out in a randomized complete block design (RCBD) and replicated three times per treatment. Treatments were assigned to each plot randomly. The spacing between plants, rows, plots and blocks were laid out with the same procedures as in Section 2.1.2.

Planting was done on 20 July 2010 by drilling two seeds per hole. Then after seedling emerge 2-3 leaves thinning was performed to avoid competition. Chlorothalonil (at the rate of 3.5 l ha^{-1} of Odeon 82.5 WDG), Copper hydroxide (at the rate of 2.5 kg ha^{-1} of Kocide 101 WP), Mancozeb (at the rate of 2.5 kg ha^{-1} of Pencozeb 80 WP) and Triadimefon (at the rate of 500 ml ha^{-1} of Byleton 25 WP) were sprayed every ten days [23]. Spraying started on the first detection of the appearance of the disease symptoms 58 days after planting (DAP). Control plots were sprayed with water only. During fungicide spraying, plastic sheets were used to separate the plot being sprayed from adjacent plots to prevent inter-plot interference due to spray drift.

Disease assessment: Disease incidence and severity were recorded every seven days starting from the first appearance of the disease symptoms on 20 randomly pre-tagged plants in the middle two rows of each plot. Three assessments were done during the evaluation period for disease incidence and three for disease severity.

Data analysis: Data were analyzed in the same way as described in Section 2.1.4. In addition, relative yield loss was calculated using the following formula [24].

$L=[(YP-Yt)/YP] \times 100$ (3)

Where: Yt=yield from control plot; L=relative percentage yield loss; YP=yield from the maximum protected plot

Results and Discussion

Evaluation of common bean varieties for reaction to bean rust

Disease incidence: Rust appeared first on the varieties Dinknesh, Mexican-142 and Awash-1 58 days after sowing, but it appeared on all other varieties during the last assessment (72 days after sowing). There was no significant variation in the final incidence of rust among all the common bean varieties evaluated, and the incidence on all varieties was 100%. However, incidences from the first three assessments showed significant ($P \leq 0.001$) variation (Table 2). The highest (100%) initial incidence was observed on the common bean variety Dinknesh, followed by the variety Awash-1 (99.06%) and Mexican-142 (99.01%). The disease incidences observed on the aforementioned three varieties were in statistical parity, but differed significantly from the disease incidences recorded for all other varieties. The lowest disease incidences were recorded for the varieties Haramaya and Kufanzik (Table 2), indicating the relative resistance of these varieties to the disease.

Disease severity: The severity of rust on the common bean varieties differed significantly ($P \leq 0.001$) (Table 2). The mean percent severity index ranged from 12.53 to 78.69% (Table 2). The highest severity (78.69%) was recorded for the variety Dinknesh followed by that of Mexican-142(74.89%).

Large pustules with chlorotic halos were observed on leaves of Dinknesh and Mexican-142, with some of the leaves of these varieties showing premature defoliation. Similarly, small pustules were commonly noted on leaves on the varieties Awash-1, Red Wolaita, Chercher, Ayenew, Roba-1, Dursitu, and Goberasha, while small scattered pustules were observed on leaves of Awash Melka, Chore, Haramaya, Gofta, Melkadima, and Kufanzik.

Disease progress rate: The disease developed at significantly different rates on the common bean varieties evaluated (Table 2). The highest (0.175 unit per day) disease progress rate occurred for Dinknesh, which was significantly different from the rate of disease development on the other common bean varieties, followed by Mexican-142 (0.138 units per day). The lowest (0.008 units per day) rate of disease development occurred for Kufanzik, followed by Haramaya and Melkadima (Table 2). The disease progress rates of the other ranged between the aforementioned highest and lowest ranges. Compared to the check and the accompanying group of common bean varieties, bean rust developed at relatively lower rates and the final disease severity levels were lower in the group with lowest disease development rates, indicating that the varieties in this group were less susceptible to rust than the varieties in the first and second groups.

On the other hand, even though the rate of disease development on the common bean variety Red Wolaita was higher than that of Ayenew, the final disease severity on this variety was less than Roba-1 (only 48.88%). Similarly, the rate of disease development on the variety Awash Melka was higher than Goberasha, but the final disease severity (19.95%) on Awash Melka was less than that of Goberasha (41.86%). This observation indicates that final disease level does not depend on the disease progress rate only. It is a well-known fact that in plant disease epidemiology other factor, such as availability of host tissue [25] and temperature, moisture and crop plant resistance level [26] affect final disease level.

Area under disease progress curve: The area under disease progress curve (AUDPC) is a very convenient summary of plant disease epidemics that incorporates into initial intensity, the rate parameter, and the duration of the epidemic which determines final disease intensity [27]. Hence the effects of disease resistance on disease progress on crops can be evaluated using AUDPC Boiteux [28]. Also AUDPC is used as a criterion of resistance against early blight in potato by comparing AUDPC values of many genotypes with that of a resistant potato variety. Likewise, the AUDPC was used to summarize the epidemics in the different varieties evaluated during this experiment. Significant ($p \leq 0.001$) differences were observed among the varieties (Table 2). Variety Dinknesh reached the highest AUDPC (531.16% days), which did not significantly vary from Mexican-142. The variety Mexican-142 exhibited the second highest (506.30% days) AUDPC, followed by Awash-1 (485.40% days).The variety Kufanzik had the lowest (87.37%-days) AUDPC values that showed no significant differences from Haramaya, Melkadima, Gofta, Chore and Awash Melka. These six varieties also had the lowest severity and showed a consistently and markedly low disease progress rates, indicating that they were less susceptible to the disease relative to the other varieties.

Variety	DI (65 DAP)	Final PSI (%)	AUDPC (% days)	Disease progress rate	Rust Scale	Reaction type
Awash Melka	55.11	19.95	136.82	0.065	3.37	R
Awash-1	99.06	70.48	485.4	0.113	5.8	MR

Ayenew	71.78	50.93	291.8	0.088	5.63	MR
Chercher	75	56.91	392.88	0.098	5.53	MR
Chore	58.45	17.21	108.71	0.028	3.3	R
Dinknesh	100	78.69	531.16	0.175	7.96	S
Dursitu	60.04	42.47	355.48	0.044	5.5	MR
Goberasha	60	41.86	338.17	0.035	5.5	MR
Gofta	55	15.96	120.03	0.024	3.3	R
Haramaya	45.15	12.88	87.45	0.019	3.2	R
Kufanzik	45.04	12.53	87.37	0.008	3.2	R
Melkadima	51.63	15.62	107.53	0.021	3.3	R
Mexican-142	99.01	74.89	506.3	0.138	7.86	S
Red Wolaita	77.85	65.03	439.37	0.112	5.73	MR
Roba-1	65.68	48.88	291.55	0.036	5.53	MR
CV (%)	5.14	12.78	12.98	11.94		
LSD (0.05)	5.84	8.89	61.95	0.02		

Table 2: Mean DI, PSI, AUDPC, diseases progress rate and reaction groups of common bean varieties evaluated for reactions against rust under field condition at Hirna during the 2010/11 main cropping season. Note: DI, disease incidence; S, susceptible; DAP, days after planting; MR, moderately resistant; R, resistant; PSI, percent severity index, AUDPC, area under disease progress curve.

Yield and yield components of common bean: Significant variations in some yield components and yield were observed among the common bean varieties (Table 3).

Variety	**Yield and Yield components**			
	NPPP	**NSPP**	**PHAH (cm)**	**Y (kg ha^{-1})**
Mexican-142	12.5	4.06	30.31	1661.59
Awash Melka	19.11	5.51	41.86	2425.81
Awash-1	14.69	4.67	34.45	1808.94
Ayenew	16.92	4.99	37.81	1827.74
Chercher	16.57	5.07	37.73	1839.43
Chore	19	5.15	41.86	1900.41
Dinknesh	14.07	4.36	35.81	1778.46
Dursitu	18.24	5.62	39.16	2490.85
Goberasha	18.72	5.73	39.9	2489.33
Gofta	19.2	5.86	42.33	2491.87
Haramaya	19.82	6.09	42.51	2870.93
Kufanzik	19.97	6.02	42.51	2835.37
Melkadima	19.72	5.91	42.5	2500
Red Wolaita	15.31	4.86	36.81	1820.63
Roba-1	17.92	5.3	38.1	1931.91
CV (%)	1.37	5.64	3.06	1.05
LSD (0.05)	2.9	0.49	1.99	38.28

Table 3: Yield and other agronomic characteristics of common bean varieties evaluated for reaction against rust under natural conditions at Hirna during the 2010 main cropping season. NPPP, Number of pods per plant; Y, Yield; NSPP, Number of seeds per pod; PHAH, Plant height at harvest; cm, centimeter.

Association of yield and disease parameters: The associations of yield and disease parameters, which included final percent severity, AUDPC and disease progress rate were evaluated using correlation analyses. Research results revealed that yield and percent severity of rust were significantly and negatively correlated (r=-0.77) (Table 4). There was a positive association between disease progress rate and percent severity (r=0.53).

Yield and AUDPC were also negatively correlated at a slightly higher level (r=-0.84) than that of the association of yield and severity indicating that lower AUDPC implies higher yield. Also, the association between disease progress rate and yield showed significant and negative correlation (r=-0.56). A very strong positive correlation (r=0.99) was observed between percent severity of rust on common bean varieties and AUDPC, which indicated that varieties that were severely infected showed higher AUDPC values. This is evidence that the use of AUDPC values as a criterion to classify the varieties into reaction groups was justifiable.

Parameters	AUDPC	PSI	Disease progress rate	Scale	Yield
AUDPC	-				
PSI	0.99***	-			
Disease progress rate	0.83***	0.53**	-		
Scale	0.84***	0.84***	0.71***	-	
Yield	-0.84***	-0.77***	-0.56***	-0.66***	

Table 4: Correlation coefficients (r) between yield and disease parameters of common bean varieties evaluated for their reactions against bean rust under natural conditions at Hirna during 2010 main cropping season. Note: ***, Correlation is very highly significant; **, Correlation is highly significant.

Integrated management of common bean rust

Disease incidence: Rust incidence data recorded one week after fungicide application showed a significant (P ≤ 0.01) difference between the two varieties at 65 DAP (Table 5). Mean disease incidence reached 95.96% for Mexican-142 and 92.29% for Awash-1 at 65 DAP (Table 5). There was a significant variation among foliar spray fungicides at 65 DAP (Table 5).

For the variety Mexican-142, the mean disease incidence ranged from 89.16% for Triadimefon treated plots to 100% in unsprayed plots. Similarly, for the variety Awash-1, mean disease incidence ranged from 84.64% on Triadimefon treated plots to 100% on unsprayed plots (Table 4).

Significant (P ≤ 0.001) interaction was observed for variety and foliar spray in reducing the disease incidence at 65 DAP (Table 5). Disease incidence decreased in moderately resistant variety with Triadimefon compared to susceptible variety with Triadimefon treatment (Table 5).

Disease severity: There was a significant difference between the varieties on all days of disease severity assessments except the first assessment. The difference between the two varieties during the first assessment might have occurred from the genetic differences between the varieties, but one week after application of fungicides variations were observed. Mean PSI was higher for the susceptible variety (Mexican-142) than for the moderate resistant variety (Awash-1) (Table 5).

Fungicide sprays reduced PSI significantly at all dates of assessment except the first assessment. On plots sprayed with Triadimefon at ten days interval, rust severity decreased to trace levels on moderate resistance variety Awash-1 compared to the susceptible variety Mexican-142. Plots sprayed with Mancozeb at ten days interval also significantly reduced rust severity one week after application. On the other hand, spraying Triadimefon and Mancozeb at ten days interval had markedly reduced rust severity compared to Chlorothalonil, Copper hydroxide and unsprayed treatment on both varieties.

According to Singh et al. [29], Triadimefon gave good control of rust on French bean in India. It reduced the severity of French bean rust by 55%. Singh and Bahat [30] reported a reduction in pea rust intensity by about 36% in response to the application of Triadimefon. However, the result obtained from this current experiment indicated that spraying of Triadimefon at the rate of 500 ml ha^{-1} reduced the disease severity by 44.78% for the variety Mexican-142 and by 46.49% for Awash-1. This may indicate that the application of the chemical for the control of rust was more effective on moderately resistant varieties than the susceptible one.

The interaction effects showed a significant difference among treatments at 58, 65, 72, 79 and 86 DAP in reducing PSI, except the first assessment (Table 5). The disease incidence and severity were significantly different among the common bean varieties and higher for the susceptible than he moderately resistant ones. Disease incidence and severity were lower for Awash-1 with Triadimefon compared to Mexican with Triadimefon and/or the rest fungicides.

Disease progress rate: The overall mean disease progress rate of all the plots was 0.0402 units per day .The progress rates in plots of individual treatments, however, varied highly and significantly (p ≤ 0.01) between the two varieties. The highest (0.133 units per day) progress rate was observed on Mexican-142 unsprayed plots and on Awash-1 (0.112 units per day). These progress rates were significantly different from all the other plots treated with different fungicides. Compared to the lowest (0.007 units per day) progress rate observed on plots treated with Triadimefon on Mexican-142 and on Awash-1 (0.005 units per day), it was higher by 5.26% on Mexican-142 and 4.46% on Awash-1 than on the control plots, indicating that rust progressed at a higher rate in the untreated (control) plots.

The disease progress rate of fungicide-treated plots of common bean varieties showed very highly significant (p ≤ 0.001) differences among themselves and there was a highly significant (p ≤ 0.01) difference between the two common bean varieties. The relatively lower disease progress rates were observed on Awash-1 and Mexican-142 variety plots treated with Triadimefon and this situation indicated that the chemical treatment was effective in slowing down the disease progress.

The interaction effect of variety × fungicides showed significant (p ≤ 0.05) difference in disease progress rate (Table 5). Disease progress rate was reduced by 71.42% on Awash-1 when treated with Triadimefon compared to that of Mexican-142 treated with Triadimefon. Generally, variation in common bean rust progress rate was due to the resistance level possessed by the varieties and the different fungicide sprays used. Shanner and Finney [21] also pointed out the value of the disease progress rate in predicting the effect of various disease control practices. The results of this study demonstrated that Triadimefon application on Awash-1 had significant effects on reducing the common bean rust development compared to the response of Mexican-142.

Area under disease progress curve: Area under disease progress curve (AUDPC) is a valid descriptor of an epidemic under the hypothesis that injury to a host plant is proportional to the amount and duration of the disease [31]. Information on disease progress is important for interpretation of epidemics and development of effective disease control measures.

Significant ($p \leq 0.001$) differences were observed in the magnitude of the area under the disease progress curve (AUDPC) among the fungicides and highly significant differences were observed among varieties and variety × fungicide interaction (Table 5). The highest AUDPC values were recorded from the control plots sprayed with water only in both varieties. These values were significantly different from all the other values obtained from fungicide treatments. The lowest AUDPC values were observed on plots treated with Triadimefon in both varieties (233.54% days on Mexican-142 and 228.80% days on Awash-1) (Table 5). Compared to the control plots, Awash-1 and Mexican-142 common bean plots treated with Triadimefon had 46.29 and 47.29% less AUDPC values, respectively, suggesting that they were much less affected. The magnitude of AUDPC was reduced on Awash-1 with Triadimefon compared to Mexican-142 with Triadimefon and/or the rest fungicides. The highly significant difference in AUDPC values among nearly all the fungicides and varieties indicated that they had varying impacts on rust development on common bean.

Variety	Fungicide	DI (65 DAP)	PSI (86 DAP)	AUDPC	Disease progress rate
Mexican-142	Control	100	74.68	504.44	0.133
	Mancozeb	95.11	36.96	256.39	0.021
	Triadimefon	89.16	33.44	233.54	0.007
	Copper hydroxide	98.83	48.54	336.23	0.041
	Chlorothalonil	96.7	42.92	298.72	0.029
Awash-1	Control	100	70.42	483.79	0.112
	Mancozeb	90.11	36.89	257.47	0.009
	Triadimefon	84.64	32.74	228.8	0.005
	Copper hydroxide	95.28	46.44	322.77	0.027
	Chlorothalonil	91.42	42.19	293.8	0.018
CV (%)		1.28	2.14	2.08	16.25
LSD (0.05)		1.71	2.08	1.71	0.012

Table 5: Effect of common bean varieties and different fungicide sprays on rust incidence, percent severity index (PSI), AUDPC and disease progress rate at Hirna during the 2010 main cropping season. Note: DAP, days after planting.

Yield and Yield Components of Common Bean: Interaction effect of variety and fungicide showed significant ($P<0.001$) difference in plant height at harvest and number of seeds per pod ($P<0.01$) but there was no significant difference in pods per plant. Numbers of seeds per pod were also higher in plots treated with Triadimefon on Awash-1 compared to Mexican-142. In general plant height at harvest, numbers of pods per plant and number of seeds per pod were higher on moderately resistant variety Awash-1 with Triadimefon compared to the susceptible variety Mexican-142 (Table 6). This is due to resistance to the disease and other genetic characteristics of the varieties. On both varieties, yield increase was due to increase in number of seeds per pod and plant height at harvest in fungicide treated plots when compared to untreated plots.

Variety	Yield and yield components				
	Fungicides	**NPPP**	**NSPP**	**PHAH (cm)**	**Y (kg/ha)**
Mexican-142	Triadimefon	18.27	5.29	36.56	2056.25
	Mancozeb	17.11	5.13	34.53	2018.75
	Chlorothalonil	15.33	5.01	34.03	1887.5
	Copper hydroxide	14.57	4.96	32.41	1853.95
	Control	12.46	4.01	27.43	1606.25
Awash-1	Triadimefon	18.6	5.95	39.79	2306.25
	Mancozeb	18.02	5.56	36.52	2268.75
	Chlorothalonil	16.23	5.24	35.53	2025
	Copper hydroxide	15.66	4.97	34.54	1987.5
	Control	14.05	4.19	32.21	1808.33
CV (%)		2.4	1.9	1.12	0.41
LSD(0.05)		0.29	0.16	0.66	13.89

Table 6: Effects of fungicide × variety evaluated for control of rust on yield and yield components of common bean at Hirna during the 2010 main cropping season. Note: NPPP, Number of pods per plant; NSPP, Number of seeds per pod; PHAH, Plant height at harvest; cm, centimeter; Y, Yield.

Relative Grain Yield Loss: Reliable estimates of the impact of a disease on yield are a prerequisite to the establishment of any crop protection strategy [32]. Yield losses were computed relative to the average yield of plots with the maximum protection against the disease (highest yield and lowest disease severity), i.e., the plots treated with Triadimefon. Yield losses differed among plots treated with the different fungicides (Table 7).

Varieties	Fungicide	Y (kg ha^{-1})	RYL (%)
Mexican-142	Triadimefon	2056.25	0
	Mancozeb	2018.75	1.82
	Chlorothalonil	1887.5	8.2
	Copper hydroxide	1853.96	9.84
	Control	1606.25	21.88
Awash-1	Triadimefon	2306.25	0
	Mancozeb	2268.75	1.63
	Chlorothalonil	2025	12.2
	Copper hydroxide	1987.5	13.82
	Control	1808.33	21.59

Table 7: Yield on two varieties and corresponding losses due to rust under different foliar sprays during the 2010 main cropping season. Note: RYL, relative yield loss; Y, yield per kilogram.

This amount of yield loss was slightly greater than the 16.9% yield loss on Mexican-142 reported from two years loss assessment studies on rust at Ambo under natural infection [33]. Although the impact of bean rust on attainable bean yield varies with cultivar, location and year, under conditions of early disease onset yield loss could be as high as 85% for susceptible cultivars [14].

In Ethiopia, it was reported that a total seed yield loss of 2 to 15% and 14 to 21% occurred at Melkasa and Debra Zeit, respectively [15]. Yield loss was higher in the present study (Table 7) than the one reported from the aforementioned places in Ethiopia. The present study indicated that in Hirna the main cropping season was highly conducive for rust of common bean epidemics to occur and cause high yield loss in common bean production. The results of this study indicate the importance of using resistant varieties and applying fungicides on varieties at the time of disease onset to minimize the effect of the disease on common bean production.

Association of PSI, AUDPC and Disease Progress Rate with Common Bean Crop Yield at Hirna in the 2010 Main Cropping Season: Disease severity values assessed on plots treated with different fungicide treatments had significant (P<0.001) and negative correlation (r=- 0.92) and (r=-0.81) with yield on Mexican-142 and Awash-1 variety, respectively (Table 8).

AUDPC and disease progress rate also had significant (P<0.001) on both varieties and negative association with yield. Disease severities, AUDPC and progress rates in general had higher negative correlations with yield. This indicates that the observed levels of the disease had a considerable adverse effect on yield of the crop.

On the other hand, the correlations observed between disease parameters (severity, AUDPC and progress rate) were positive. The correlation coefficient (r=0.99) between severity and AUDPC was significant (P<0.001), whereas the correlation coefficient (r = 0.96) between severity and progress rate and (r=0.97) on variety Mexican-142 and Awsh-1 respectively was significant (P<0.001) (Table 8).

Variety		AUDPC	progress rate	Final PSI	Yield
Mexican-142	AUDPC	-			
	progress rate	0.96***	-		
	Final PSI	0.99***	0.96***	-	
	Yield	-0.98***	-0.92***	-0.98***	-
Awash-1	AUDPC	-			
	progress rate	0.96***	-		
	Final PSI	0.99***	0.97***	-	
	Yield	-0.91***	-0.81**	-0.90***	-

Table 8: Correlation coefficients (r) between AUDPC, PSI, disease progress rate and crop yields in fungicide trial for the management of common bean rust at Hirna 2010 main cropping season. Note: ***, very highly significant; **, highly significant.

Conclusions

The results of this study have demonstrated that common bean varieties grown by smallholder farmers in Ethiopia significantly vary in resistance to yield as well as in response to different fungicides in terms of controlling the disease. Based on the research results, the evaluated common bean varieties were classified into susceptible (S), moderately resistant (MR) and resistant (R) reaction types or groups. Accordingly, among the varieties Kufanzik, Haramaya, Melkadima, Gofta, Chore and Awashmelka were found to be resistant. Awash-1, Dursitu, Goberasha, Red Wolaita, Ayenew, Roba-1 and Chercher were classified as moderately resistant types. The highest yield was generally obtained from the resistant common bean varieties. Dinknesh and Mexican 142 were found to be susceptible.

Foliar sprays with Triadimefon at the rate of 500 ml ha^{-1} applied four times starting right after the appearance or onset of the disease and continued at ten days interval managed the disease better than the other fungicides. More extensive studies are suggested to evaluate new fungicides, additional common bean varieties and their genetic characteristics and to work out more effective management strategies against the bean rust under different ecological conditions to enhance high quality and sustainable common bean production in Ethiopia.

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References

1. Habtu Assefa (1994) Epidemiology of bean rust in Ethiopia. PhD thesis, Wogageningen Agricultural University, p: 172.

2. CSA (Central Statistical Authority) (2005) Agricultural sample survey 2005/2006. Report on forecasting of area and production of major crops. Statistical Bulletin No 171, Addis Ababa, Ethiopia.
3. Abebe A (1987) Haricot bean (Phaseolus vulgaris L.) varieties performance and recommended methods of production. In: proceedings of the 19th crop improvement conference, Addis Ababa, Ethiopia, pp: 229-251.
4. Habtu A, Sache I, Zadoks JC (1996) A survey of cropping practices and foliar disease of common bean in Ethiopia. Crop Prot 15: 179-186.
5. Fininsa C, Yuen J (2001) Association of bean rust and common bacterial blight epidemics with cropping systems in Hararghe highlands, eastern Ethiopia. Int J of Pest Managem 47: 211-219.
6. Ohlander LJR (1980) Research on haricot bean (Phaseolus vulgaris L.) production in Ethiopia 1972-1976. Swedish University on Agricultural Sciences, Uppsala, p: 288.
7. Habtu A, Bosch F, Zadoks JC (1995) Focus expansion of bean rust in cultivar mixture. Plant Pathol 44: 503-509.
8. Allen DJ, Dessert M, Trutmann P, Vass J (1989) Common beans in Africa and their constraints. In: Schwartz HF, Pastor C (eds.). Common bean production constraints in the tropics, 2nd edition. CIAT, California, Colombia, p: 128.
9. Habtu A (1987) Haricot bean diseases and their importance in Ethiopia. Ethiopian Journal of Agriculture Science 9: 55-56.
10. Howland AK, Mc Cartney JC (1966) East Africa bean rust studies. East Africa Agri and Forestry J 32: 55-66.
11. Ballatyne BJ (1978) The genetic basis of resistance to rust caused by Uromycesappendiculatus in beans. PhD Thesis, University of Sydney, Australia, p: 262.
12. Ballantyne BJ (1974) Resistance to rust in beans Annu Rep. Bean Improv Coop 45: 120-124.
13. Tsedeke A (1985) A review of crop protection research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium. IAR, Addis Ababa, Ethiopia, p: 681.
14. Habtu A (1997) Analyzing crop loss in bean rust pathosystem I Disease progress, crop growth and yield loss. Pest Managem J of Ethiopia 1: 9-18.
15. Habtu A (1986) Effects of seed treated and foliar sprays against foliar disease of faba bean. In: Proceedings of the 10th Annual Meeting of the Ethiopian Phytopathological Committee, Addis Ababa, Ethiopia. pp: 89-100.
16. ALARC (Alemaya Agricultural Research Center) (1997) Proceedings of the 13th Annual Research and Extension Review Meeting.
17. MoARD (Ministry of Agriculture and Rural Development) (2009) Crop development Department. Crop Variety Registration, Addis Ababa, Ethiopia.
18. Van Schoonhoven A, Pastor Corrales MA (1987) Standard system for the evaluation of bean germplasm. CIAT, Cali, Colombia, p: 54.
19. Van Schoonhoven A, Pastor Corrales MA (1987) Rust. In: Standard system for the evaluation of bean germplasm. CIAT, Cali, Colombia, p: 24-27.
20. Wheeler JB (1969) An introduction to plant diseases. Wiley, London, p: 347.
21. Shanner E, Finney RE (1977) The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67: 1051-1056.
22. SAS Institute Inc., 2002. SAS/ Stat Guide for Personal Computers, Version 9.0 edition. SAS Institute Inc., Carry, NC.
23. Bujulu L, Lotasarwaki J (1986) The effect of fungicides and foliar fertilizers on bean rust. East Africa Agri and Forestry Jour 12: 112-121.
24. Robert D, James HT (1991) A biometry approach. Principle of Statistics. 2nd edition. New York, USA.
25. Campbell CL, Madden LV (1990) Introduction to Plant Disease Epidemiology. John Wiley and Sons, New York, p: 532.
26. Madden LV, Hughes G, Van den Bosch F (2008) The Study of Plant Disease Epidemics. The American Phytopathological Society. St Paul, Minnesota, USA, p: 421.
27. Jones DG (1998) The Epidemiology of Plant Diseases. Journal of Agri Sci 9: 55-66.
28. Boiteux LS (1995) Search for early blight field resistance not associated with vegetative late maturity in tetraploid potato germplasms. Euphytica 83: 63-70.
29. Singh SJ, Soki SS, Grewal RK (1981) Relative efficiency of fungi-toxicants against pea rust. Indian Phytopathol 34: 272-275.
30. Singh AK, Bahat NM (2002) Control of French bean through fungicides and a neem based formulation. Indian Phytopathol 55: 241-243.
31. Campbell CL (1998) Disease progress in time: modelling and data analysis. In: Jones DG (Ed.). The Epidemiology of Plant Disease. Kluwer Academic Publishers, London, p: 181-206.
32. Zadoks JC, Schein RD (1979) Epidemiology and plant disease management. Oxford University Press. New York, USA, p: 427.
33. Habtu A (1990) Bean rust: Its importance, epidemiology and control in the Eastern Africa bean production system. In: Smithson JB (Ed.). Proc Workshop Bean Research in Eastern Africa. Nairobi, Kenya, pp: 43-62.