Short Communication

Association of Faba Bean Rust (*Uromyces viciae-fabae*) with Environmental Factors and Cultural Practices in the Hararghe Highlands, Eastern Ethiopia

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Abstract: Disease survey was conducted in Hararghe highlands of Ethiopia during the 2009 cropping season to determine the incidence and severity of faba bean rust (*Uromyces viciae-fabae*) in major growing districts of Hararghe highlands, and its association with environmental factors and cultural practices. A total of 90 faba bean fields were surveyed in six districts. Sample plants were systematically selected in an "X" fashion. In each field, 10 plants were sampled for disease assessment. During the survey, altitude, type of cropping system, weed management practices, crop growth stage, previous crop in the field and sowing date were recorded. Significant differences among locations were indicated with respect to altitude, sowing date, crop growth stage and field management practices. The mean incidence of the disease varied from 44.6% in Bedeno to 98% in Tullo, while severity of the disease varied from 12.7% in Bedeno to 65% in Gorogutu and Kurfachale districts. Logistic regression analysis for the association of rust incidence and severity with environmental factors and cultural practices as independent variables showed rust incidence below 80% had a high probability of association with Deder district, areas with altitude above 2450 m.a.s.l. and when faba bean was planted after July 25. Rust incidence above 80% had a high probability of association with Gorogutu, Kurfachale, Tullo districts; altitudes below 2450 masl, and when faba bean was planted from the end of June up to July 25. Similarly, disease severity below 40% had a high probability of association with Bedeno district, flowering growth stage, altitude above 2450 m.a.s.l., and when weeds were managed properly. Disease severity greater than 40% had a high probability of association with Gorogutu, Kurfachale, Tullo, Deder and Metta districts, altitudes below 2450 m.a.s.l., podding and late podding growth stages, and where poor weed management was practiced. The survey revealed high occurrence and distribution of faba bean rust in the study area and the need for effective and feasible management options to be developed.

Keywords: Disease Incidence; Disease Severity; Faba Bean Rust; *Uromyces viciae-fabae;* Weed Management

1. Introduction

Faba bean (*Vicia faba* L.), occupies nearly 3.2 million hectares with production of 2.6 million metric tons worldwide in 2003 (Torres *et al.,* 2006). It is the first in area coverage (459,000 ha) among the legumes with production of 0.58 million metric tons in Ethiopia. It is cultivated on 23,061 hectares of land in Hararghe highlands (CSA, 2007). It is a multi-purpose crop that plays an important role in the socio-economic life of farming communities (Agegnehu and Fessehaie, 2006). Faba bean has an important place in the Ethiopian national diet and is consumed in various forms (Keneni and Jarso, 2002). The contribution of faba bean in improving soil fertility is well documented (Asfaw *et al.*, 1994). It is a cool season pulse crop grown in the highlands (1800-3000 masl) of Ethiopia, where the need for chilling temperature is satisfied. It grows well with optimal temperature of 15-20°C and mean annual rainfall of 700-1000 mm (ICARDA, 2006).

In spite of its huge importance, the productivity of faba bean in Ethiopia remains far below the crop's potential (> 3 t/ha). The major constraints that limit the realization of full yield potential of faba bean and cause instability in yield in different parts of the world are both abiotic and biotic constraints (Agegnehu *et al.*, 2006). Among the biotic constraints, fungal diseases are the major factors affecting production and productivity as well as the quality of faba bean in different parts of Ethiopia. Among the fungal diseases, rust caused by *Uromyces viciae-fabae* is the most important one worldwide including Ethiopia (Saxena, 1991). Normally, rust epidemics begin late in the season, when pod filling has started and yield losses usually range from 5 to 20%. 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). Faba bean rust is widely distributed in Ethiopia (Dereje and Tesfaye, 1994) and causes yield losses of 27%.

The disease is favored by high humidity, cloudy and warm weather conditions. *Uromyces viciae-fabae* produces numerous, small, orange-brown pustules, each surrounded by a light yellow halo that develops on the leaves. On the stem, rust pustules are larger and longer than those found on the leaves (Hanounik and Bisri, 1991). 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. Urediospores of *U. viciae-fabae* germinate well in a temperature that ranges 5-26 ^{O}C, with fastest germination at 20 ^{O}C (Joseph and Hering, 1997).

Different control methods have been proposed against rust, including cultural practices, the use of chemicals and resistant varieties. Cultural practices, such as adjusting plant density, nitrogen fertilization or crop mixtures can significantly influence rust infection (Fernandez-Apricio *et*

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al., 2006). However, use of resistant varieties is recognized as the most desirable, efficient and economical management option (Bond *et al.,* 1994). Disease management using chemicals 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). In Ethiopia, Hassen *et al*. (2010) showed that severity and rate of rust progression were significantly influenced by use of resistant varieties and fungicides. He indicated treatment of faba bean with mancozeb at the rate of 1.6 a. i. kg ha^{-1} resulted in significant reductions in rust severity and produced the highest yield. Faba bean in Ethiopia, especially in the Hararghe highlands where such information is totally lacking.

Understanding the association of disease intensity and different management practices will help to identify the most important variables and focus efforts in developing an integrated and sustainable rust management package for faba bean production (Rusuka *et al*., 1997). Survey data are useful to gain insight into the occurrence, distribution and relative importance of diseases (Rusuka *et al*., 1997). Even if the crop has diverse uses, very little survey work has been done for rust of faba bean.

Therefore, this study was conducted with objectives to determine (i) the incidence and severity of faba bean rust in major growing districts of Hararghe highlands, and (ii) its association with environmental factors and cultural practices.

2. Materials and Methods

2.1. Survey Area

Disease survey was conducted to assess the incidence, severity and prevalence of faba bean rust in six districts of Hararghe highlands located at latitude of 09^0 11'-09^0 21' N and longitude 041^0 01'-041^0 48' E during the 2009 main growing season. Rugged topography and mountainous landscapes characterize the Hararghe highlands (Table 1). The region has a bimodal rainfall distribution and is a typical sub-humid, high altitude agro-climatic zone. The short rainy season (*Arfassaa*) extends from April to June and accounts for about 25% of the annual rainfall, whereas the long rainy season (*Gaanna*) extends from July to October and accounts for about 45% (Belay *et al*., 1998).

The survey was conducted in Deder, Metta, Bedeno, Kurfachale, Gorogutu, and Tullo districts of Hararghe highlands. Deder, Metta, Bedeno, Kurfachale, and Gorogutu highlands are in eastern, while Tullo district is in western Hararghe Zone of the Oromia Regional State. A total of 90 fields were assessed for disease incidence and severity from October 22 to 28, 2009.

Table 1. Characteristic features of surveyed faba bean fields in six districts of Hararghe highlands, Ethiopia.

District	altitude (masl)	Temperature range (^{o}C)
Bedeno	2540 - 2602	8 - 24
Deder	2414 - 2779	10 - 23
Gorogutu	2303 - 2534	6 - 24
Kurfachale	2135 - 2441	5 - 20
Metta	2413 - 2510	3 - 22
Tullo	2420 - 2673	1 - 29

Source: National Meteorological Services Agency, Jijiga Branch (NMSAJB, 2009).

2.2. Sampling and the Sample Unit

Fields were sampled at intervals of 5-10 km along roads and distance between fields depending on the topography and the relative importance of faba bean cultivation within each district. Sample plants were systematically selected by making a specified number of equally spaced paces by moving through the field in an "X" fashion. Having made the pre-set number of paces (according to the size of the field), the nearest plant to the right foot was first sampled. In each field, 10 plants were sampled for disease assessment. A sub sample of twelve leaves per plant and four leaves per canopy layers (upper, middle and lower) were selected from the main stem, yielding a total of 120 leaves per field. Mean of canopy layers was determined per plant and then averaged per field for data analysis. All sample fields belonged to small, private farmers. Each field was visited once.

2.3. Crop and Disease Assessment

During the survey, altitude (m), type of cropping pattern (row versus broadcast planting), weed management practices, crop growth stage, previous crop in the field and sowing date were recorded for each sampled field to determine their relationship with the disease incidence and severity. Growers were asked information on cultural practices (time of sowing, faba bean varieties grown, previous crop, and disease control practices) employed. Altitude was recorded using a GPS.

Severity was rated using the 1-9 disease scoring scale (ICARDA, 1986), where 1 indicates no visible symptom and 9 represents disease covering more than 80% of the foliar tissue. Disease severity scores were converted into percentage severity index (PSI) for analysis (Wheeler, 1969).

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

2.4. Data Analysis

Disease incidence and severity data were classified into distinct groups of binomial qualitative data. Class boundaries were chosen so that groups contained approximately equal totals. Thus, $\leq$ 80 and > 80 were chosen for rust incidence and $\leq$ 40 and > 40 for rust severity, yielding binary dependent variables. Categorized independent variables that were used in the analysis are presented (Table 2). Contingency tables of disease intensity and the independent variables were built to represent the bivariate distribution of fields according to two classifications (e.g. district by rust incidence). An entry in a cell of a contingency table represents the frequency of fields falling into that cell (Table 3). Several contingency tables were combined into a single matrix.

The association of faba bean rust intensities with independent variables was analysed using logistic regression as described by Yuen *et al.* (1996) with the SAS Procedure GENMOD (SAS Institute Inc., 2008). The logistic regression model allows to evaluate the importance of multiple independent variables that affect the response variable. In plant pathology, the model has been used to study the effect of different variables on Sclerotinia stem rot forecasting (Twengstrom *et al.*, 1998). Logistic regression calculates the probability of a given binary outcome (response) as a function of the independent variables (McCullagh and Nelder, 1989). If the probability of the outcome is denoted as (*P*), the logistic regression model assumes that the logarithm of the odds of *P* (*P*/(*1-P*)), which equals logit (*P*), is a linear function of the independent variables (Yuen *et al.*, 1996). In this case, the binary outcome was the probability that faba bean rust incidence exceeds 80% and severity exceeds 40% in a given faba bean field. The GENMOD procedure gives parameter estimates and the standard error of the parameter estimates. Exponentiating the parameter estimate yields the odds ratio, which is interpreted here as the relative risks (Yuen *et al.*, 1996).

The importance of the independent variables was evaluated in three ways. First, the association of an independent variable alone with disease incidence or severity was tested. This consists of testing the deviance reduction attributed to a variable when it was first entered into the model. Second, the association of an independent variable with disease incidence or severity was tested when entered last into the model with all other independent variables. Third, variables with high association to disease intensity when entered first and last into a model were added to a reduced multiple variable model. A complete analysis of deviance table was generated for the final reduced multiple variable model, where deviance reduction (DR) was calculated for each variable as it was added to the reduced model.

The deviance (-2 x log likelihood) was used to compare single and multiple variable models. The difference between the two models, known as a likelihood ratio test (LRT), was used to examine the importance of the variable and was tested against a χ^2 value (McCullagh and Nelder, 1989) where the number of degrees of freedom in the χ^2 value corresponded to the difference in degrees of freedom between the two models.

3. Results

3.1. Disease Incidence and Severity

Rust was prevalent in all the faba bean fields surveyed. The districts varied in occurrence of rust and severity. Among the faba bean fields surveyed in six districts, the least mean incidence (44.6%) and mean disease severity (12.7%) were recorded in Bedeno district and the highest mean disease incidence (98%) in Tullo district and the highest mean severity (65%) was recorded in Gorogutu and Kurfachale districts (Table 4). The finding of the survey indicated that late planting (after July 25) resulted in less rust incidence and severity. The lowest mean (57%) faba bean rust incidence and mean severity (18.8%) were noted on faba bean crops sown after July 25.

Farmers planted faba bean as sole crop as well as intercropped with maize, wheat, barley, sorghum and field pea. Out of the total surveyed faba bean fields, 54.4% fields were intercropped with these crops and rust was also less as compared with sole faba bean fields. Faba bean fields were at three different growth stages: 20% at flowering, 27.78% at podding and 52.2% at late podding stage during the survey (Table 3). Maximum incidence and severity were recorded in fields where faba bean was at late podding stage. Faba bean fields cultivated at an altitude below 2450 masl, fields having sole faba bean and fields having poor weed management score showed the highest incidence and severity of rust as compared to their respective other variable classes (Table 4). Most of the fields surveyed (57.78%) were planted on fields where barley crop was previously grown (Table 3). The highest and lowest mean rust incidence was recorded in fields previously sown with sorghum (96%) and wheat (73.5%).

Table 2. Categorization of variables used in analysis for a survey of faba bean rust disease in six districts (n = 90) of Hararghe highlands, Ethiopia.

Variable	Variable class	No. of fields	Variable	Variable class	No. of fields
District	Metta	15	Weed management[a]	Good	32
	Gorogutu	15		Intermediate	30
	Deder	15		Poor	28
	Tullo	15	Previous crop	Barley	52
	Kurfachale	15		Wheat	10
	Bedeno	15		Maize	16
Cropping System	Sole	41		Sorghum	5
	Mixed	49		Field Pea	7
Altitude	≤ 2450	35	Rust	≤ 40	42
	> 2450	55		> 40	48
Growth Stage	Flowering	18	Incidence	≤ 80	44
	Podding	25		> 80	46
	Late pod filling	47			
Sowing Date	June-July 25	65			
	> July25	25			

[a]*Good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation.*

Table 3. Independent variable by disease contingency table for logistic regression analysis of faba bean rust survey during the 2009 cropping seasons from Hararghe highlands, Ethiopia.

		Disease intensity (%)			
		Incidence		PSI	
Independent variable	Variable class	≤ 80	> 80	≤ 40	> 40
District	Metta	10	5	12	3
	Gorogutu	5	10	0	15
	Deder	11	4	11	4
	Tullo	1	14	2	13
	Kurfachale	2	13	2	13
	Bedeno	15	0	15	0
Cropping system	Sole	18	23	13	28
	Mixed	26	23	29	20
Altitude	≤ 2450	3	32	5	30
	> 2450	41	14	37	18
Growth stage	Flowering	18	0	18	0
	Podding	15	10	14	11
	Late pod filling	11	36	10	37
Sowing date	June-July 25	19	46	18	47
	> July	25	0	24	1
Weed management[a]	Good	21	11	21	11
	Intermediate	15	15	16	14
	Poor	8	20	5	23
Previous crop	Barley	25	27	20	32
	Wheat	6	4	5	5
	Maize	8	8	12	4
	Sorghum	1	4	2	3
	Field Pea	4	3	3	4

[a]*Good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation*. *PSI = Percent severity index*.

3.2. Association of Faba Bean Rust with Environmental Factors and Cultural Practices

The association of all independent variables with rust incidence is presented in Table 5. All the independent variables, except district, altitude and sowing date, were not significantly associated with rust incidence when entered first into a logistic regression model. However, district lost significance, while growth stage gained importance when entered last into the model with addition of other variables.

Altitude (χ^2 = 14.03, 17.96) and sowing date (χ^2 = 10.05, 6.96) were the most significant and important variables associated both when entered into the model first and last. A group of three variables: district, altitude and sowing date significance were tested in a reduced multiple variable model. Analysis of deviance for these variables added one by one to the reduced model showed the importance of each variable and variable class (Table 6). The parameter estimates resulting from the reduced regression model and their standard error are presented (Table 6). Low rust incidence had a high probability of association with Deder district, altitude above 2450 m.a.s.l. and when crop sown after July 25. High rust incidence had a high probability of association to Kurfachale, Gorogutu and Tullo districts. In Kurfachale and Gorogutu districts there was about four and three times greater probability, respectively, that rust incidence would exceed 80%.

Four variables: districts, altitude, growth stage and weed management were highly associated with rust severity when entered as single variable into the model. Altitude lost significance while previous crop and growth stage gained importance when entered last into the model with addition of other variables. District and weed management were the most highly associated with severity when entered as a single variable and last with other variables into the model (Table 5). The significance of district, altitude, growth stage and weed management was tested by adding these variables one by one to a reduced model. Analysis of deviance for the variables, parameter estimates and their standard errors is given in Table 7. Rust severity (≤ 40%) had a high probability of association with Bedeno district and an altitude of (> 2450 masl), flowering growth stage and in field with good and intermediate weed management system. Gorogutu, Kurfachale, Tullo and Deder districts and late podding growth stage had a high probability of association with high rust severity. There were about 226 and 2 times greater probabilities that rust severity would exceed (> 40%) in the Gorogutu district as compared to Metta and in late podding to podding, respectively.

Table 4. Mean incidence and percent severity index (PSI) of faba bean rust for different independent variables in 2009 cropping season in Hararghe highlands, Ethiopia.

		Incidence				PSI			
Variable	Variable Class	Min	Max	mean	SD	Min	Max	Mean	SD
District	Meta	65	100	83.2	13.0	24.7	55.0	36.4	8.1
	Gorogutu	60	100	91.3	13.6	40.9	100.0	65.2	15.7
	Deder	66	100	82.6	11.6	11.1	89.0	33.8	19.4
	Bedeno	15	80	44.6	22.7	11.1	18.1	12.7	2.0
	Kurfachale	75	100	97.0	8.0	26.9	80.3	65.2	16.2
	Tullo	80	100	98.0	5.6	33.2	80.7	62.3	14.9
Sowing date	June-July25	60	100	92.6	11.8	11.1	100.0	56.4	19.3
	After July25	15	80	57.0	23.6	11.1	45.2	18.8	9.6
Altitude	≤ 2450	70	100	97.7	6.9	24.1	89.0	62.7	16.5
	> 2450	15	100	73.2	23.8	11.1	100.0	35.2	22.2
Cropping system	Sole	25	100	87.3	16.5	11.1	100.0	53.0	22.4
	Mixed	15	100	79.0	26.0	11.1	80.7	39.9	24.1
Growth stage	Flowering	15	80	62.5	22.2	11.1	37.9	18.5	7.9
	Podding	15	100	76.2	26.2	11.1	80.3	39.1	20.3
	Late podding	60	100	94.1	11.0	11.1	100.0	60.1	18.9
Weed management	Good	15	100	75.2	25.4	11.1	100.0	36.2	26.1
	Intermediate	15	100	83.4	22.0	11.1	80.7	43.8	21.1
	Poor	32	100	90.9	16.3	11.8	89.0	59.4	18.6
Previous crop	Barley	20	100	84.4	20.8	11.1	80.8	46.8	23.5
	Wheat	15	100	73.5	28.8	11.1	80.7	43.7	22.3
	Maize	30	100	83.4	20.3	11.1	89.0	38.6	23.0
	Sorghum	80	100	96.0	8.9	33.3	80.7	58.5	23.4
	Field Pea	15	100	73.7	32.5	11.1	100.0	50.2	34.4

Min. = Minimum value; Max. = Maximum value; SD = Standard deviation; PSI = Percent severity index.

Table 5. Independent variables used in logistic regression modeling of faba bean rust incidence and severity and likelihood ratio test (LRT) for seven variables entered first and last into a model.

		Rust incidence LRT				Rust Severity LRT			
		Type 1 analysis		Type 3 analysis		Type 1 analysis		Type 3 analysis	
Independent variable	df	DR	$Pr > \chi^2$	DR	$Pr > \chi^2$	DR	$Pr > \chi^2$	DR	$Pr > \chi^2$
District	5	48.9	<0.0001	7.22	0.205	66.2	0.0001	29.77	0.0001
Previous crop	4	3.99	0.407	7.89	0.096	3.59	0.465	10.38	0.035
Cropping system	1	0.28	0.597	2.83	0.093	0.00	1.00	0.01	0.936
Altitude	1	14.03	0.0002	17.96	<0.0001	10.1	0.001	3.27	0.07
Sowing date	1	10.05	0.002	6.96	0.0082	1.89	0.169	0.48	0.49
Growth stage	2	4.41	0.11	6.44	0.04	5.24	0.073	7.18	0.028
Weed management	2	2.94	0.23	2.94	0.23	10.9	0.004	10.91	0.004

Type 1 analysis, variable entered first; Type 3 analysis, variable entered last; df = Degrees of freedom; DR = Deviance reduction; Pr = Probability of a value χ^2 exceeding the deviance reduction.

4. Discussion

During the survey period, faba bean rust was found widely distributed in all districts with ranging degree of incidence and severity. In Tullo, Gorogutu and Kurfachale districts the severity was greater by 2–5% than Metta, Deder and Bedeno districts. It is believed that the existence of favorable temperatures that ranged from 5-24^{0}C during the growing period led to increased spore germination and rust epidemic development in most of the districts (Table 1). Rust is favored by warm temperatures (17-22^{0}C) and cloudy weather conditions (Stoddard *et al.,* 2010). Rust infection can occur following six hours of leaf wetness, so does not require extended wet periods (Hawthorne *et al.,* 2004). Unfortunately, it was difficult to find rainfall data of the districts that could better explain the association. Altitude alone and when combined with other cultural practices had a significant effect on the development of rust. Both disease incidence and severity were relatively higher below 2450 m.a.s.l. This suggests that the relatively humid and warm climate is more favorable for the disease development (Dereje and Tesfaye, 1994).

The farmers grow local cultivars of faba bean year after year in Hararghe highlands and faba production is constrained by rust because local cultivars grown by farmers are highly susceptible and resistant varieties are not yet available to satisfy the need of the producers (Hassen *et al.,* 2010). In cooler production regions, the uredospores are important means of survival between cropping seasons. Secondary spread is by means of uredospores, which can readily germinate on plant surfaces under humid conditions and dispersed by wind (Stoddard *et al.,* 2010).

Mean rust severity was 56% in fields sown between June-July 25, while it was 19% in fields planted after July 25. Hawthorne *et al.* (2004) indicated that early sowing faba bean may result in a bulky crop, which creates an environment most conducive to rust disease but later sowings reduce the disease risk in Australia. High mean disease incidence and severity were found to increase with advancement in growth stage under favorable conditions. This might be due to the defoliation or aging of the already infected leaves of the plant at this stage. It was also not easy to measure the time between flowering, podding and late-podding growth stages because the survey was conducted on one occasion within a season and the type of cropping practices and many other factors also influence the development of the disease.

Throughout the survey it was observed that there were a higher number of rust-infected plants within fields when faba bean was planted as sole compared with fields intercropped with other crops like field pea, barley, wheat, maize, and sorghum (Table 4). There was no significant difference when this factor was considered independently and combined with other factors (Table 5). Sharaiha *et al.* (1989) also reported reduced (29%) rust incidence in maize-faba bean intercropped plots under the Jordan Valley conditions. Faba bean rust incidence and severity were more in non-weeded fields than weeded or weed free fields. Some farmers did not see the need to weed their faba bean fields because they also used the weeds as animal feed. This led to a situation in which farmers tolerated high weed densities within their faba bean crop. Cultivation of faba bean in the presence of high weed populations is known to highly reduce the yield of the crop and favour the development of disease epidemics (Agegnehu and Fessehaie, 2006). In fields with dense weed populations, there was competition for space, moisture and soil nutrients as a result of which the faba bean plants were less vigorous and prone to the disease. Sahile *et al.* (2008) reported that high weed density in non-weeded fields increased chocolate spot disease of faba bean. Besides, the presence of a high weed population in a field increases the humidity within the crop canopy (microclimate) which is more favorable for *U. viciae-fabae* infection and the development of rust epidemics (Fernandez-Aparicio *et al.*, 2006).

The survey data analysed using logistic regression analysis indicated environmental and cultural variables that were associated with faba bean rust incidence and severity either singly or in combination. The regression model quantified the relative importance of the variables indicating how much the disease was increased or decreased as a function of the independent variables singly or in combination. The present study identified districts, altitude, growth stage, sowing date and weed management as important variables that influenced faba bean rust epidemic. The results of this study suggests the importance of research on weed management and other related cultural practices to supplement effective rust management options in the surveyed areas and elsewhere with similar agro-ecological settings. Moreover, extensive and consistent survey is recommended to know the intensity of the disease in similar agro-ecology of the country where the crop is widely grown.

Table 6. Analysis of deviance, natural logarithms of odds ratio and standard error of added variables in a reduced model analyzing faba bean rust incidence[a].

Added variable[b]	Residual deviance	df	LRT		Variable class	Estimate[c]	SE[d]	Odds ratio[e]
			DR	Pr > $\chi 2$				
Intercept	124.72	0				1.87	1.16	6.49
District	75.83	5	48.9	0.0001	Deder	-0.57	1.12	0.57
					Bedeno	0.22	2.26	1.25
					Gorogutu	1.02	0.82	2.77
					Tullo	0.59	1.51	1.80
					Kurfachale	1.36	1.15	3.90
					Metta	0*	0*	1
Altitude	61.76	1	14.07	0.0002	$\leq$ 2450	0*	0*	1
					> 2450	-2.52	1.04	0.08
Sowing date	55.27	1	6.49	0.011	June-July25	0*	0*	1
					> July25	-2.88	1.71	0.06

[a]*df, degrees of freedom; LRT, likelihood ratio test; DR, deviance reduction; Pr, probability of a* χ^2 *value exceeding the deviance reduction; *, reference group;* [b]*Variables are added into the model in order of presentation in table;* [c]*Estimates are from the model with all independent variables added;* [d]*Standard error of the estimate;* [e]*Exponentiating the estimates.*

Table 7. Analysis of deviance, natural logarithms of odds ratio and standard error of added variables in a reduced model analyzing faba bean rust severity[a].

Added variable[b]	Residual deviance	df	LRT		Variable class	Estimate[c]	SE[d]	Odds ratio[e]
			DR	Pr>χ2				
Intercept	124.37	0				0.443	1.16	1.56
District	58.13	5	66.2	0.0001	Dedder	0.66	1.16	1.93
					Bedeno	-0.27	1.61	0.76
					Gorogutu	5.42	1.63	225.88
					Tullo	1.83	1.80	6.23
					Kurfachale	3.30	1.42	27.11
					Metta	0*	0*	1
Altitude	51.44	1	6.68	0.009	$\leq$ 2450	0*	0*	1
					> 2450	-1.52	1.16	0.22
Growth stage	44.16	2	7.29	0.026	Flowering	-0.23	1.56	0.79
					Podding	0*	0*	1
					Late podding	0.70	0.96	2.01
WMT[f]	37.11	2	7.05	0.029	Good	-2.64	1.13	0.07
					Intermediate	-1.27	0.92	0.28
					Poor	0*	0*	1

*[a]df, degrees of freedom; LRT, likelihood ratio test; DR, deviance reduction; Pr, probability of a χ^2 value exceeding the deviance reduction; *, reference group; [b]Variables are added into the model in order of presentation in table; [c]Estimates are from the model with all independent variables added; [d]Standard error of the estimate; [e]Exponentiating the estimates; [f]WMT, weed management: good weeding, any weed is weeded; intermediate weeding, few weeds are present; poor, no weeding and high weed infestation.*

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