Scientific Research Publishing

Open Journal of Ecology, 2022, 12, 391-406
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

# Assessment of Factors Influencing Chocolate Spot (*Botrytis fabae*) Disease Epidemics of Faba Bean (*Vicia faba* L.) at Tach Gayint District in North Western Ethiopia

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**How to cite this paper:** Abera, M. and Semagn, M. (2022) Assessment of Factors Influencing Chocolate Spot (*Botrytis fabae*) Disease Epidemics of Faba Bean (*Vicia faba* L.) at Tach Gayint District in North Western Ethiopia. *Open Journal of Ecology*, **12**, 391-406.
https://doi.org/10.4236/oje.2022.127023

**Received:** March 25, 2022
**Accepted:** May 9, 2022
**Published:** July 5, 2022



## Abstract

Faba bean (*Vicia faba* L.) is one of the oldest domesticated food legumes that have been cultivated for at least 5000 years. It is a multi-purpose crop that plays an important role in the socio-economic life of farming communities in Ethiopia. Chocolate spot disease, caused by Botrytis fabae is one of the yield limiting factors of this crop resulting in yield losses up to 68% in Ethiopia. A field survey was conducted in Tach Gayint district South Gondar Administrative Zone during the 2020/2021 main cropping season to assess the importance of the chocolate spot disease of faba bean. A total of 60 faba bean farmer fields were assessed in six (6) Kebele Administrations and most farmer fields were affected by chocolate spots. But the status of disease incidence and severity was varied. Significant differences among locations were observed due to altitude, soil type, planting density, date of planting, crop growth stages and farm history of the fields. Independent variables like Altitude, farm history, crop growth stage, date of planting and planting density were significantly associated with both disease incidence and severity when entered first and last into a model. The finding indicates that the lowest plant density and late planting of the crop reduce the incidence and severity of the disease.

## Keywords

Chocolate Spot, Incidence, Severity, Faba Bean

## 1. Introduction

### Background and Justification

Faba bean (*Vicia faba* L.) is one of the oldest domesticated food legumes that

have been cultivated for at least 5000 years [1]. Globally 4,840,090 tons of faba bean were produced on 2,463,966 hectares of land and from this; China (1,803,019 tons), Ethiopia (930,633 tons), Australia (373,605 tons), United Kingdom (302,468 tons) and Germany (188,800 tons) are the top five faba bean producers in 2017 [2]. Moreover, the mean yield of faba bean is 1964.3 kg/ha globally and 1995.52 kg/ha in Ethiopia. It is a multi-purpose crop that plays an important role in the socio-economic life of farming communities in Ethiopia [3]. This crop is grown in the highlands (1800 - 3000 m.a.s.l) of the country which receives an annual rainfall of 700 - 1000 mm where the need for cold temperature is met [4] [5]. The crop occupies the largest area in Ethiopia, among other pulses [6] [7]. Amhara and Oromia are the major faba bean-producing regions in Ethiopia. It is mainly produced in the Gondar, Gojam, Wollo, Wollega, Shoa and Gamo-Gofa regions of Ethiopia [6] [8].

Despite the wide cultivation of the crop, its average yield is quite low in Ethiopia and the productivity is far below its potential because of numerous biotic and abiotic factors [9] [10] [11]. The production of faba bean is about 2.1 tons/ha compared with the production potential ranging from 2.3 to 3.9 tons/ha in Ethiopia [12].

Among biotic factors for the reduction of faba bean crop yield, chocolate spot disease is the major problem in our country and it is more serious in the Amhara region [10] [11]. The region has the largest faba bean production area (42.98%) compared with other regions [6]. Ethiopian Institute of Agricultural Research and ICARDA shows that the distribution and seasonal incidence of a chocolate spot on faba bean are increasing in Amhara Region including South Gondar [4]. [13] reported that chocolate spot disease is the main constraint of faba bean production in Tach Gayint. Many types of researches are done for the management of this disease in the country including in some parts of the South Gondar Zone. However, it has not been studied so far in the Tach Gayint district even though this area is one of the major faba bean producing places which accounts for 56.7% of production area coverage [14]. Due to these farmers are challenged with the compatible management strategy in the area. Currently, there is an urgent need to improve faba bean yield since the crop remains an important crop in the study area. The objective of this study was to assess the factors influencing the incidence and severity of faba bean chocolate spot disease status in the study area.

## 2. Materials and Methods

### 2.1. Description of the Study Area

A field survey was conducted in the South Gondar administrative Zone, Tach Gayint district during the 2020/2021 cropping season. Tach Gayint District lies at altitude ranges from 1500 - 3000 m.a.s.l. The district currently encompasses 17 *Kebele* Administrations (*KAs*) with one urban *Kebele* Administration [15]. The map of the study area is indicated in **Figure 1**.

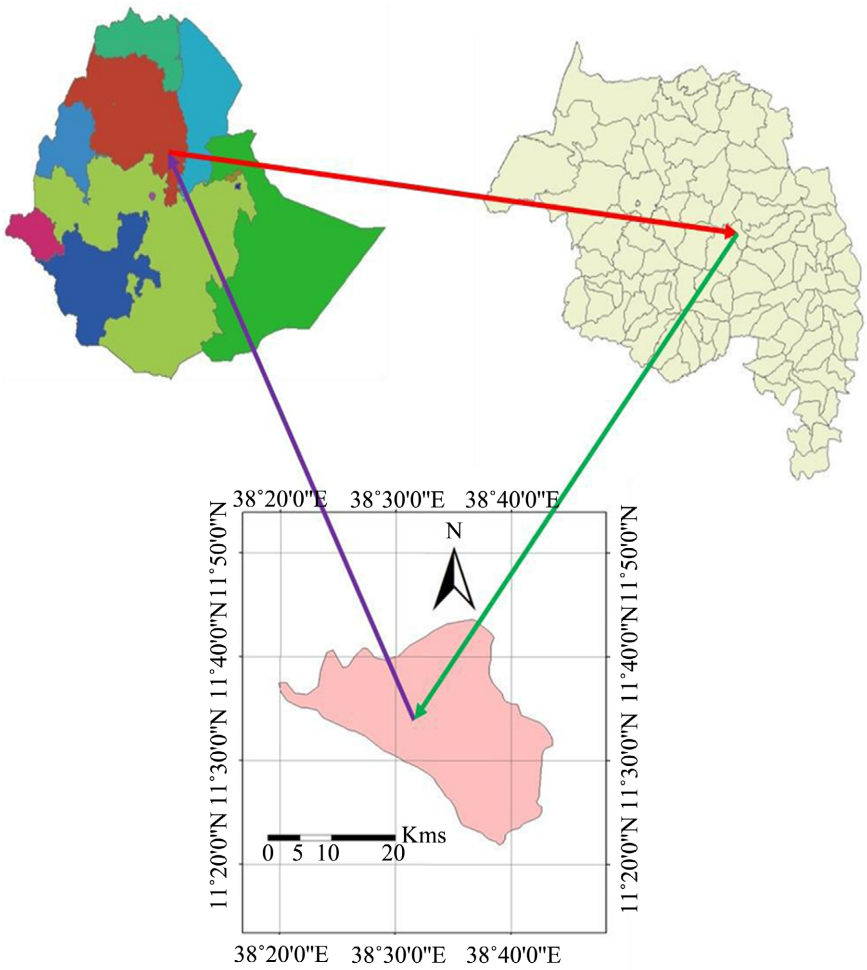


**Figure 1.** Map of the study area. Source: Ethio GIS data base system (June, 2020).

The mean minimum and maximum temperature range from 10˚C to 27˚C and the mean minimum and maximum rainfall ranges from 900 - 1000 mm per annum. There are three agro climatic zones in the district namely, *Kola* [low land] (23.5%) altitude range from 1500 to 1800 m.a.s.l., *Woina-Dega* [mid-altitude] (63.5%) altitude ranges from 1800 to 2400 m.a.s.l and *Dega* [high land] (13%) altitude ranges from 2400 to 3000 m.a.s.l.. The major soil types are clay loam and loamy sand [15].

Major crops grown in the areas are wheat (*Triticum aestivum L.*), faba bean (*Vicia faba*), barley (*Hordeum vulgare* L.), potato (*Solanum tubersom* L.), *teff* (*Eragrostis tef* L) and haricot bean (*Phaseolus vulgare*). [14] reported that the district is one of major faba bean producing places and which accounts for 56.7% of the production area owing to its high altitude.

## 2.2. Field Sampling Procedures

In district six (6) *Kebele* Administrations were purposively selected based on faba bean production status. In each *Kebele* Administration ten (10) faba bean growing farmer fields were selected randomly. Totally 60 farmer fields were as-

sessed. In each sample field, quadrate (1 m × 1 m) was thrown by moving diagonally across each field from one end to the other in an "X" pattern [10] [16]. In each sample field, nine quadrants (1 m × 1 m) were sampled diagonally.

Faba bean fields were at three growth stages during the survey flowering, pre-podding and podding stage. The whole plants within the Quadrant were assessed for disease incidence and 10 plants for disease severity from each quadrate and averages were taken for each field.

Each field was visited (surveyed) once. Disease incidence (the number of diseased plants, expressed as a percentage of the total number of plants assessed) of faba bean chocolate spot was assessed by visual examination and counting of stands with disease symptoms on the leaves of faba bean plants. The data on Disease severity: Percentage of infected leaf area was determined as the percentage of the total leaf surface covered with chocolate spot lesions based on the scale [17] [18] [19].

## 2.3. Data Collection

Disease parameters like disease severity and incidence were considered using the formula indicated below (**Table 1**). The severity of chocolate spot disease was recorded using the scale 0 - 9 [17] [18] [19]:

$$\text{Disease incidence} = \frac{\text{No.of diseased plants}}{\text{total plants observed}} \times 100$$

$$\text{Disease severity} = \frac{\text{Area disease coverage}}{\text{Total area observed}} \times 100$$

The severity grades were converted into percentage severity index (PSI) for ease of analysis according to the formula by [20].

$$\text{PSI} = \frac{\text{Sum of numerical rating}}{\text{No. of plant scored} \times \text{max max score on scale}} \times 100$$

During the field survey, altitude, field history (preceding crops), varieties of faba bean, planting date, fertilization, planting density, planting method, growth stage, soil types and fungicide management were assessed to determine the relationship with chocolate spot disease incidence and severity.

## 2.4. Statistical Data Analysis

The collected survey data were subjected to descriptive statistical analysis on data

**Table 1.** Percent of infection and scale for recording severity of chocolate spot.

| |
|---|
| 0 = No disease symptoms |
| 3 = few small disease lesions |
| 5 = some coalesced lesions with some defoliation |
| 7 = large coalesced lesion sporulation lesions, 50% defoliation and some dead plants |
| 9 = Extensive, heavy sporulation, stem girdling, blackening and death of more than 80% of plants. |

Source: [17].

collected from each field like mean, percent and graphs as per [21]. Analysis was conducted to describe the distribution and association of chocolate spot incidence and severity in relation to independent variables. Disease incidence and severity (PSI) were classified into distinct classes of binomial qualitative data. The associations of chocolate spot incidence and severity with independent variables were analyzed using a logistic regression model with the SAS procedure of the GENMOD [10]. At first, all independent variables were tested with chocolate spot disease incidence and severity in a single variable model. Then the association of independent variables with disease incidence and severity was tested when entered last into the model with all independent variables. Finally, those independent variables which showed a higher significant association in the disease incidence and severity were added to reduced multiple variable models. Furthermore, an estimate of parameters and standard error were analyzed both in single and multiple models. The odd ratio was obtained by exponentiation of the parameter estimates for comparisons of variable classes based on the reference point. Analysis of deviance and likelihood ratio statistics were used to compare single and variable models [22]. Contingency $X^2$ tests were used to compare the frequencies of variables based on the proportion of fields that were assigned to a given disease incidence and severity class.

## 3. Results and Discussion

### 3.1. General Features of the Surveyed Fields

Chocolate spot disease was conducted in 60 fields of six potential faba bean growing *Kebele* administrations at Tach Gayint District in North-Western Ethiopia. Out of the total surveyed 60 faba bean fields 38.3% of them were at altitude > 2700, while 33.3% and 28.3% were at an altitude of <2500 and ≥2500 - ≤2700 m.a.s.l. respectively. Soil type of most farms was Brown (48.3%) followed by Red soil (36.7%) and 15% of the farms were Black soil type. The field history of the farms was; wheat (43.3%), teff (28.3%), potato (15%) and barley (13.3%). Only 11.7% of the farmers were sown in row planting pattern and the rest 88.3% in broadcast planting. In the surveyed areas 33 farms (55%) used fertilizer (NPS), while 27 farms (45%) were not used fertilizer (NPS). The highest plant population was 54.1 $m^{-2}$ and the lowest was 28.4 $m^{-2}$ per quadrat (1 m × 1 m). Faba bean fields were at three growth stages during the survey; with 38.3% at flowering, 36.7% at pre-podding and 25% at the podding stage. 18.3% of farms were sprayed with fungicide and the rest 81.7% of the farms were unsprayed in the surveyed fields. Weeding in general was not done in all faba bean fields (**Table 3**).

### 3.2. Incidence and Severity of Chocolate Spot Disease in the Surveyed Areas

The survey results indicated that, almost all the fields surveyed were infected with chocolate spots within different levels of severity. The highest mean choco-

late spot severity was observed from Beteyohanes (58%) followed by, Agate (54.3%) and Dajat (53.7%) *Kebele* Administration (*KA*s), while the lowest was recorded on Efrata (5.48%) *KA*. The highest chocolate spot disease incidence was observed from Dajat (96.5%), followed by Beteyohanes (93%) and Agat (89.4%) *KAs*, also similarly the lowest was recorded at Efrata (23.5%) *KA* (**Table 2**). Moderate intensity of chocolate spot was observed on the rest two *KAs* (Aduka and Zhazh) with a mean value of disease incidence (60.8% and 83%) and severity (27.8 and 38.3%) respectively (**Table 2**). All the three *KAs* which have the maximum mean value of disease incidence and severity are located at high altitude (>2500 m.a.s.l.). This might be the reason for the maximum intensity of the disease. [10] reported that both disease incidence and severity were relatively higher above 2500 m.a.s.l. [16] also mentioned that disease severity was relatively higher at high altitudes than low altitudes. In Overall disease incidence and severity of the district was 74.4% and 39.6% respectively.

Data on altitude were grouped into three ranges (<2500 m.a.s.l, ≥2500 m.a.s.l. - ≤2700 m.a.s.l and >2700 m.a.s.l). The highest mean chocolate spot disease incidence and severity were observed on fields located at an altitude > 2700 m.a.s.l. (94.8% and 55.5%) and the lowest disease incidence and severity were observed at an altitude < 2500 m.a.s.l. (42.2% and 16.6%) from the given ranges (**Table 2**). This was agreed with the survey done by [16] which shows disease severity becomes higher at high altitudes than at lower altitudes. [23] also reported that the severity of chocolate spot disease was higher with an altitude greater than 2700 m.a.s.l. At higher altitudes, farmers are experienced continues faba bean production year after year. This continued growth may increase the inoculum level and could result in rapid intensification of the disease.

During the field survey three soil types were observed on the fields assessed (brown, red and black). Maximum disease incidence and severity were observed on black soils (82.1% and 46.3%) and the least disease incidence and severity were observed on red soil (68.9% and 33.7%) respectively. [24] showed that red and brown soils are preferable for the production of faba bean to black soils; since black soils are vulnerable to water lodging and as a result the crops may be attacked by root rot and chocolate spot disease. [25] also indicated that faba bean crop will not grow well in highly compacted soils (clay soils: which are mostly black in color).

In the surveyed areas, all farmers applied appreciated crop rotation system. Although farmers used good crop rotation system the highest disease incidence of chocolate spot was observed on farms that had wheat and potato farm history with mean values (86.5% and 87.4%) respectively and the maximum disease severity was observed on farms that had potato farm history with mean value (56.1%). This result may be due to the variation in surveyed field location. Most of the farms in the surveyed areas which had farm history of wheat and potato were observed in highland altitudes (*Dega*) whereas barley and *teff* were observed in *woina dega* zones. [16] showed that the inoculum may carry over from one season to the next on infected faba bean seed, stubble and volunteer plants.

**Table 2.** Mean disease incidence and severity (PSI) of faba bean chocolate spot for different independent variables during 2020/2021 cropping season in the surveyed areas.

| Variable | Variable class | Chocolate spot | | | |
|---|---|---|---|---|---|
| | | Incidence | | Severity (PSI) | |
| | | Mean | SD | Mean | SD |
| Kas | Beteyohanes | 93 | 11.951 | 58 | 15.408 |
| | Zhazh | 83 | 12.537 | 38.3 | 10.92 |
| | Aduka | 60.8 | 11.195 | 27.8 | 8.6178 |
| | Agate | 89.4 | 11.603 | 54.3 | 10.454 |
| | Efrata | 23.5 | 21.490 | 5.48 | 7.3878 |
| | Dajat | 96.5 | 7.0677 | 53.7 | 8.0446 |
| Altitude | <2500 | 42.2 | 25.374 | 16.6 | 13.862 |
| | ≥2500 - ≤2700 | 84.6 | 12.255 | 45.1 | 13.986 |
| | >2700 | 94.8 | 9.3611 | 55.5 | 11.45 |
| Soil type | Brown | 76.1 | 29.336 | 42 | 22.2 |
| | Red | 68.9 | 30.417 | 33.7 | 19.524 |
| | Black | 82.1 | 22.168 | 46.3 | 20.568 |
| Field history | Wheat | 86.5 | 16.169 | 46.7 | 14.645 |
| | Potato | 87.4 | 12.867 | 56.1 | 13.856 |
| | Barley | 64.6 | 24.115 | 25.6 | 18.1 |
| | *Teff* | 53.5 | 38.157 | 26.6 | 23.9 |
| Fertilization | NPS | 73.739 | 28.816 | 39.7 | 20.92 |
| | Non-fertilized | 75.13 | 29.2 | 39.4 | 21.96 |
| Growth stage | Flowering | 56.6 | 30.3 | 26.2 | 18.9 |
| | Pre-podding | 77 | 24.2 | 38 | 16.03 |
| | Podding | 98 | 5.71 | 62.4 | 9.43 |
| Planting density | ≥40/m$^2$ | 79.5 | 22.67 | 43 | 19.4 |
| | <40/m$^2$ | 70.4 | 32.41 | 37.1 | 22.4 |
| Planting method | Broad casting | 74.94 | 29.8 | 39.8 | 22.05 |
| | Row planting | 74.9 | 20.4 | 38.1 | 14.3 |
| Fungicide usage | Sprayed | 81.8 | 11.45 | 36 | 6.5 |
| | Unsprayed | 72.7 | 31.2 | 40.3 | 23.3 |
| Day of planting | Late May-mid-June | 92 | 13.3 | 54.2 | 13.6 |
| | Mid-June-Early July | 58 | 29.7 | 26 | 17.6 |

PSI = Percentage severity index; SD = standard deviation, KAs = *Kebele* Administrations.

[16] reported that field history of legumes was more favorable than cereals for the incidence and severity of chocolate spot disease. But in this study, there were no farms that had a field history of legumes. The minimum disease incidence and severity were observed on farm history of teff and barely crops with a mean value of (53.5% and 25.6%) respectively and followed by teff with mean value of 26.6% of disease severity (**Table 2**). This result was similar with [26] who showed that the mean minimum level of incidence (24.6%) and severity (14.9%) was recorded from previous *teff* sown fields.

During the field survey planting method (broadcasting and row planting pattern) and fertilization (use of NPS) were not influenced the status of chocolate spot disease incidence and severity distribution (**Table 2**). This might be due to the inappropriate use of seed and fertilizer rate as well as the disease incidence and severity, which may be influenced by the certain farming system and field location. [27] reported that the use of optimum fertilizer is important for reducing the disease.

Depending on fungicide usage, higher disease incidence was observed on farms that were sprayed with a fungicide with a mean value of 81.8% than on farms that were unsprayed with a mean value of 72.7% (**Table 2**). This indicated that the farmers sprayed their farm after it was highly infected with chocolate spot disease and disease incidence is recorded even a few dots are present on a plant. But disease severity was higher on farms which were unsprayed with fungicide. This indicates that application of fungicide might reduce the severity level. As [27] reported, late application of the chemical after flowering resulted in the non-effectiveness of the chemical. [10] also reported that, different management options are recommended in Ethiopia for the disease including application of fungicides such as Chlorothalonil or Mancozeb but have not been adopted by the farmers at large.

During the survey, faba bean crop was at three different growth stages (flowering, pre-podding and podding). Maximum disease incidence and severity were observed at podding stages (98% and 62.4%) respectively and the least disease incidence and severity at flowering stage (56.6% and 26.2%) respectively (**Table 2**). This result is in agreement with the survey done by [28] who showed the lowest incidences and severities were recorded in fields where faba bean was at the flowering stage. In contrast, the survey result disagreed with the survey assessed by [23] who showed that the highest disease severity of chocolate spot was recorded on fields during the flowering stage. [10] showed that under favorable conditions, chocolate spot disease increases as the plants mature. [29] also reported the significant role of the amount and quality of inoculum delivered to the crop canopy as well as the time of arrival of inoculum in relation to the stage of the crop development on the increase of the disease. High mean disease incidence and severity were recorded from podding stages.

The mean value of both disease incidence and severity was higher in farms that had plant populations $\geq 40/m^2$ (79.5% and 43%) than in farms that had plant populations $< 40/m^2$ with mean value (70.4% and 37.1%). [10] [16] re-

ported that severity of chocolate spot disease is higher in a dense population of faba bean plants than in sparsely populated, the severity increases due to more plant-to-plant spread of the *Botrytis fabae* inoculum. When plant density increased it can cause less light penetration in the crop canopy, reduce photosynthetic efficiency and may lead to chocolate spot epiphytotic.

Data on the planting date were also grouped into two (May-June 15 and June 16-July). The mean value of disease incidence and severity was higher on farms that were planted on May-June 15 with mean value (92% and 54.2%) respectively than on farms that were planted after June 16-July with mean value (58% and 26%) (**Table 2**). [30] reported that delay and shortening of chocolate spot epidemic and reduction of attack can be achieved by late sowing of faba bean. [22] showed that, planting date influences the incidence and severity of faba bean chocolate spot; high disease incidence and severity were recorded from early sown farms.

### 3.3. Association of Chocolate Spot Disease Intensity with Independent Variables

Class boundaries (<75% and ≥75%) were chosen for disease incidence and (<30% and ≥30%) for PSI data and independent variable by disease contingency table for regression analysis of faba bean chocolate spot was presented in **Table 3**.

The association of variables with disease incidence is presented in **Table 4**. The independent variables such as altitude ($X^2$ = 1660.6 and 496.9, 2 df), farm history ($X^2$ = 278.1 and 140.1, 3 df), growth stage ($X^2$ = 118.5 and 91.2, 2 df), planting density ($X^2$ = 23.4 and 63.7, 1 df) and fungicide usage ($X^2$ = 92.3 and 92.3, 1 df) were significantly associated with chocolate spot disease incidence when entered first and last into as a single variable model. This result becomes agreed with the previous work done by [22] which showed variables such as planting date, cropping system, growth stage and altitude were the most significantly important variables that are associated with chocolate spot disease incidence. Soil type ($X^2$ = 25.6, 2 df) was also significantly associated with disease incidence when entered into a logistic model as a single variable. But it was not significantly associated with disease incidence when entered last into a model. Fertilization, soil type and planting methods were not significantly associated with disease incidence when entered first and last into the logistic regression model as a single variable.

The association of variables with disease severity is also presented in **Table 5**. The independent variables such as altitude *(*$X^2$ = 743.9 and 177.3, 2 df), soil type ($X^2$ = 33.8 and 21.6, 2 df), farm history ($X^2$ = 114.1 and 50.9, 3 df), growth stage ($X^2$ = 110.5 and 55, 2 df), planting density ($X^2$ = 11.4 and 31.1, 1 df) and fungicide usage ($X^2$ = 34.8 and 34.8, 1 df) were significantly associated with chocolate spot disease severity when entered first and last in to a model. But fertilization and planting method lost their association with disease severity when entered first and last into the model. This was in line with the work of [23] variables

**Table 3.** Independent variable by disease contingency table for regression analysis of faba bean chocolate spot during 2020/2021 cropping seasons in the surveyed area.

| Variable | Variable class | No of fields | No of fields with Chocolate spot | | | |
|---|---|---|---|---|---|---|
| | | | Incidence (%) | | Severity (%) | |
| | | | <75 | ≥75 | <30 | ≥30 |
| Kas | Beteyohanes | 10 | 2 | 8 | - | 10 |
| | Zhazh | 10 | 1 | 9 | 2 | 8 |
| | Aduka | 10 | 9 | 1 | 5 | 5 |
| | Agate | 10 | 1 | 9 | - | 10 |
| | Efrata | 10 | 10 | - | 10 | - |
| | Dajat | 10 | - | 10 | - | 10 |
| Altitude | <2500 | 20 | 19 | 1 | 15 | 5 |
| | ≥2500 - ≤2700 | 17 | 2 | 15 | 2 | 15 |
| | >2700 | 23 | 2 | 21 | - | 23 |
| Soil type | Brown | 29 | 10 | 19 | 5 | 24 |
| | Red | 22 | 9 | 13 | 8 | 14 |
| | Black | 9 | 3 | 6 | 2 | 7 |
| Field history | Wheat | 26 | 6 | 20 | 3 | 23 |
| | Potato | 9 | 2 | 7 | - | 9 |
| | Barley | 8 | 5 | 3 | 5 | 3 |
| | *Teff* | 17 | 10 | 7 | 9 | 8 |
| Fertilization | NPS | 33 | 13 | 20 | 9 | 24 |
| | Non-fertilized | 27 | 10 | 17 | 8 | 19 |
| Growth stage | Flowering | 23 | 15 | 8 | 13 | 10 |
| | Pre podding | 22 | 8 | 14 | 4 | 18 |
| | Podding | 15 | - | 15 | - | 15 |
| Planting density | ≥40/m$^2$ | 26 | 8 | 18 | 6 | 20 |
| | <40/m$^2$ | 34 | 15 | 19 | 11 | 23 |
| Planting method | Broad casting | 53 | 19 | 34 | 15 | 38 |
| | Row planting | 7 | 4 | 3 | 2 | 5 |
| Fungicide usage | Used | 11 | 2 | 9 | 2 | 9 |
| | Not used | 49 | 21 | 28 | 15 | 34 |
| Day of planting | Late may-mid-June | 29 | 4 | 25 | - | 29 |
| | Mid-June-July | 31 | 19 | 12 | 17 | 14 |

Incidence is number of leaves infected and expressed as a percentage of the total number of leaves assessed and severity is percentage severity index (PSI) of chocolate spot infection on the plants.

**Table 4.** Independent variables used in logistic regression analysis and likelihood ratio statistics for independent variables entered first and last into a model for disease incidence.

| Independent variable | DF | Chocolate spot severity LRT | | | |
|---|---|---|---|---|---|
| | | Type 1 analysis[a] | | Type 3 analysis[b] | |
| | | DC | PR > $X^2$ | DC | PR > $X^2$ |
| Altitude | 2 | 1660.6 | <0.0001 | 496.9 | <0.0001 |
| Soil type | 2 | 25.6 | <0.0001 | 2.5 | <0.28 |
| Farm history | 3 | 278.1 | <0.0001 | 140.1 | <0.0001 |
| Fertilization | 1 | 0.09 | 0.76 | 0.19 | 0.66 |
| Growth stage | 2 | 118.5 | <0.0001 | 91.2 | <0.0001 |
| Planting density | 1 | 23.4 | <0.0001 | 63.7 | <0.0001 |
| Planting method | 1 | 12.5 | 0.14 | 18 | 0.07 |
| Fungicide usage | 1 | 92.3 | <0.0001 | 92.3 | <0.0001 |

Dependent Variable = Disease incidence. Model = altitude, soil type, farm history, fertilization, growth stage, planting density, planting time, planting method and fungicide usage. DF = degrees of freedom; DC = deviance change; PR, probability of a chi square value exceeding the deviance; LRT, likelihood ratio test. [a]Type 1 analysis = variable entered first in to the model. [b]Type 3 analysis = variable entered last in to the model.

**Table 5.** Independent variables used in logistic regression analysis and likelihood ratio statistics independent variables entered first and last into a model for disease severity.

| Independent variable | DF | Chocolate spot severity LRT | | | |
|---|---|---|---|---|---|
| | | Type 1 analysis[a] | | Type 3 analysis[b] | |
| | | DC | PR > $X^2$ | DC | PR > $X^2$ |
| Altitude | 2 | 743.9 | <0.0001 | 177.3 | <0.0001 |
| Soil type | 2 | 33.8 | <0.0001 | 21.6 | <0.0001 |
| Farm history | 3 | 114.1 | <0.0001 | 50.9 | <0.0001 |
| Fertilization | 1 | 0.5 | 0.47 | 0.1 | 0.74 |
| Growth stage | 2 | 110.5 | <0.0001 | 55 | <0.0001 |
| Planting density | 1 | 11.4 | 0.0007 | 31.1 | <0.0001 |
| Planting method | 1 | 0.35 | 0.55 | 3.2 | 0.06 |
| Fungicide usage | 1 | 34.8 | <0.0001 | 34.8 | <0.0001 |

Dependent Variable = Disease severity index. Model = altitude, soil type, farm history, fertilization, growth stage, planting density, planting time, planting method and fungicide usage. DF = degrees of freedom; DC = deviance change; PR, probability of a chi square value exceeding the deviance; LRT, likelihood ratio test. [a]Type 1 analysis = variable entered first in to the model. [b]Type 3 analysis = variable entered last in to the model.

such as; altitude, growth stage, crop history and planting density were significantly associated with chocolate spots.

All the independent variables were also tested in reduced multiple variable models. The deviation analysis of these variables in reduced multiple variable models showed the significance of their association with disease incidence and severity. The parameter estimates, standard error and odds ratio are presented in (Table 6 and Table 7). The Probability of lowest disease incidence (<75) and severity (<30) was highly associated with low altitudes, flowering and pre-podding growth stage, red and brown soil type, and fungicide sprayed fields. High chocolate spot incidence and severity had high probability of association with densely populated crops, field history of wheat and potato. This result was agreed with the previous researches done by [10] [16] which showed, disease incidence and severity of chocolate spot were increased; as altitude increases, when crops were at podding stage than flowering, when it was early sown and at

Table 6. Analysis of deviance, natural logarithms of odds ratio and standard error of the selected independent variables in a reduced model analyzing chocolate spot disease incidence.

| Independent Variable[a] | DF | RD | LRS | | Variable Class | Estimate[b] | SE | Odds Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | DC | PR > $X^2$ | | | | |
| Intercept | | 2852 | 234 | <0.0001 | | 4.14 | 0.27 | |
| Altitude | 2 | 1191 | 366 | <0.0001 | <2500 | −3.61 | 0.18 | 0.02 |
| | | | 51.3 | <0.0001 | ≥2500 - ≤2700 | −0.97 | 0.13 | 0.37 |
| | | | . | . | >2700 | 0* | 0* | 1 |
| Farm history | 3 | 887 | 50.7 | <0.0001 | Wheat | 0.77 | 0.1 | 2.18 |
| | | | 4.49 | 0.03 | Potato | −0.42 | 0.19 | 0.65 |
| | | | 84.5 | <0.0001 | Barley | 1.05 | 0.11 | 2.85 |
| | | | . | . | Teff | 0* | 0* | 1 |
| Growth stage | 2 | 769 | 43.5 | <0.0001 | Flowering | −1.39 | 0.21 | 0.24 |
| | | | 12 | 0.0005 | Pre podding | −0.74 | 0.21 | 0.47 |
| | | | . | . | Podding | 0* | 0* | 1 |
| Planting density | 1 | 745 | 62.4 | <0.0001 | ≥40/m$^2$ | 0.81 | 0.1 | 2.26 |
| | | | . | . | <40/m$^2$ | 0* | 0* | 1 |
| Fungicide usage | 1 | 640 | 84.7 | <0.0001 | Sprayed | −1.59 | 0.17 | 0.2 |
| | | | . | . | Unsprayed | 0* | 0* | 1 |

DF = degrees of freedom; DC = the changes in deviance; PR > $X^2$, probability of a chi square value exceeding the deviance; SE, standard error of the estimate; *Reference group. [a]Independent variables added in to the reduced model; RD = residual deviance (Unexplained variations after fitting the model); Likelihood ratio statistics. [b]Estimates from the model with the independent variables added in to a reduced model. OR = Odds ratio (Exponentiation of the estimates)

**Table 7.** Analysis of deviance, natural logarithms of odds ratio and standard error of the selected independent variables in a reduced model analyzing chocolate spot disease severity.

| Independent Variable[a] | DF | RD | LRS | | Variable Class | Estimate[b] | SE | Odds Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | DC | PR > $X^2$ | | | | |
| Intercept | | 1312 | 6.03 | 0.014 | | 0.41 | 0.16 | 1.51 |
| Altitude | 2 | 568.7 | 158.9 | <0.0001 | <2500 | −1.49 | 0.11 | 0.23 |
| | | | 5.89 | 0.015 | ≥2500 - ≤2700 | −0.19 | 0.07 | 0.83 |
| | | | . | . | >2700 | 0* | 0* | 1 |
| Soil type | 2 | 534.9 | 15.9 | <0.0001 | Brown | −0.49 | 0.12 | 0.61 |
| | | | 21.6 | <0.0001 | Red | −0.56 | 0.12 | 0.57 |
| | | | . | . | Black | 0* | 0* | 1 |
| Farm history | 3 | 420.8 | 40.58 | <0.0001 | Wheat | 0.65 | 0.1 | 1.92 |
| | | | 39.9 | <0.0001 | Potato | 0.86 | 0.13 | 2.36 |
| | | | 19.1 | <0.0001 | Barley | 0.55 | 0.12 | 1.73 |
| | | | . | . | Teff | 0* | 0* | 1 |
| Growth stage | 2 | 309.8 | 43.3 | <0.0001 | Flowering | −0.68 | 0.1 | 0.51 |
| | | | 6.1 | 0.013 | Pre podding | −0.25 | 0.1 | 0.78 |
| | | | . | . | Podding | 0* | 0* | 1 |
| Planting density | 1 | 298.3 | 30.9 | <0.0001 | ≥40/m$^2$ | 0.44 | 0.07 | 1.55 |
| | | | . | . | <40/m$^2$ | 0* | 0* | 1 |
| Fungicide usage | 1 | 263.2 | 34.47 | <0.0001 | Sprayed | −0.63 | 0.1 | 0.53 |
| | | | . | . | Unsprayed | 0* | 0* | 1 |

DF = degrees of freedom; DC = the changes in deviance; PR > $X^2$, probability of a chi square value exceeding the deviance; SE, standard error of the estimate; *Reference group. [a]Independent variables added in to the reduced model; RD = residual deviance (Unexplained variations after fitting the model); Likelihood ratio statistics. [b]Estimates from the model with the independent variables added in to a reduced model. OR = Odds ratio (Exponentiation the estimates).

densely populated plants. Other variables such as fertilization and planting method did not show a significant association with the incidence and severity of chocolate spots. Disease incidence and severity, may be influenced by the certain farming system and field locations.

## 4. Conclusion and Recommendations

Altitude, cropping history, planting density, soil type and growth stage are the major independent variables that influence the incidence and severity of the disease in the study area. Late sowing, red and brown soil type, the lower altitude, and planting density less than ≤40/m$^2$ were best for decreasing disease intensity.

In the surveyed area, chocolate spot epidemics frequently occurred since the farmers grow local susceptible varieties and do not use the correct fungicide (its specificity and rate, time and frequency of application).

## Acknowledgements

Our deepest gratitude goes to Bahir Dar University and respondent farmers for their assistance during the study.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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