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Original Research

Temporal progression of chocolate spot (*Botrytis fabae* Sard.) on faba bean (*Vicia faba* L.) yield and comparison of disease measurement methods

Tola Abdissa* & Fikiru Wakoya

Department of Plant Sciences, Wollega University, P.O. Box 395 Nekemte, Ethiopia

Abstract

The "chocolate spot" disease (Botrytis fabae Sard.) reduces faba bean output. To compare performance models, examine faba bean's effects on chocolate spot and disease assessment. The study examined AUDPC and AUDPS' relative and standard faba bean chocolate spot disease quantification forms. This explored how chocolate spot temporal advancement affects field faba bean output. At Horro and Guduru in Western Ethiopia, 15 faba bean types were tested for yield and yield components in 2016 and 2017. Disease and yield differed considerably (P 0.05) between cultivars in growth seasons and locations. No substantial faba bean type interaction. Gora, an improved variety, outperformed Mesay in yield and disease resistance. The relative AUDPS was poorly constructed to track faba bean illness across sites and years. However, fitted statistical evaluation worked effectively for all sickness assessment methods. These agricultural trials demonstrate chocolate spots diminish grain output. Botrytis fabae virulence, environmental diversity, quantitative resistance genes, and crop physical barriers affect faba bean cultivar disease responses. The best disease evaluation methodologies and host-disease interactions cannot be handled in one trip, thus crop resistance and protection must be increased.

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*Corresponding Author:

Tola Abdisa

E-mail:
tolaa2008@gmail.com

INTRODUCTION

Belonging to the fabaceae family, the faba bean (Vicia faba L.) is one of the most extensively cultivated legume crops due to its high protein content and promising yield potential. According to FAOSTAT (2019), China produces an average of 4.4 million metric tons of faba beans per year, making it the leading producer in terms of both area harvested and output. With an annual output of 921,761.5 metric tons, Ethiopia is the world's second-largest producer of faba beans. Of these regional states, Oromia's annual contribution of 483,201.66 metric tons (52.4% of the total) and Amhara's annual contribution of 283,691.26 metric tonnes (31% of the total) are the most significant (CSA 2018). Abiotic and biotic constraints both affect the productivity and output of faba beans. Among the most important biotic factors affecting faba bean crop yields globally and in Ethiopia is the chocolate spot disease (Botrytis fabae Sard.; Torres et al., 2006; Sahile et al., 2010; Wakoya et al., 2021). Damage termed as chocolate spot appears on every part of the crop that is above ground. Tissue death can occur as a result of these lesions' rapid spread surrounding the infection site (Bouhassan et al., 2003, 2004; Mikhail, 2006). It is a major worry for most places across the world where cool-temperate faba beans are grown since it is extremely difficult to control and thrives in somewhat warm (10 to 20°C) and humid conditions (Fleury, 2016).

This disease annually decreases global faba bean crop productivity unless precautions are implemented. Various researchers use various disease evaluation models to figure out how bad diseases are for crops and how much of an impact they have on population production (Madden et al. 2007). The relevance of the correlation between sickness and yield in forecasting epidemic trajectory was well acknowledged by (Vanderplank, 1963). When looking at the spread of diseases throughout time and space, there is more to the connection between epidemic shifts and crop yields than meets the eye. It is important to determine the best approach to disease evaluation methodologies in order to track the spread of chocolate spot disease in faba bean crops over time and space. Madden et al. (2007), Agrios (2005), and Madden & Hughes (1995) all predicted that better understanding of epidemics will lead to fewer infections and quicker creation of efficient, well-planned controls.

Rouse (1989) argues that instead of using common measure analysis, a simpler empirical technique would be to utilize a summary variable called AUDPC to characterize the outline of disease notes in each plot. It could be helpful for treatment comparisons when many evaluation times are aggregated into one value. The AUDPC isn't without its flaws, despite its inherent merits (Fry, 1978). In order for an epidemic to be considered adequate, it must be brief, have a steady infection rate, and occur late in the season. Especially when the host plant's disease intensity is constantly changing, a better method is needed to determine the duration and amount of plant active tissue development. When comparing multiple epidemics, it may be necessary to standardize AUDPC numbers to account for the likelihood that epidemics may vary in length and/or have sAUDPC (Savary & Cooke, 2006; Mukherjee et al., 2010).

To improve disease progress estimation, Simko and Piepho (2012) created the area under the disease progress stairs (AUDPS) formula. This method avoids underestimating the impact of the first and last observations by giving them a weight closer to ideal. Based on their findings, AUDPS is more accurate than AUDPC in most trials; the only situations in which AUDPC may be less accurate are when there is an excessive amount of fluctuation in either the first or last observations' assessments. Their recommendation was to use AUDPS or one of its derivatives, either standardized (sAUDPS) or relative (rAUDPS), when integrating data from the disease progression triangle. The objectives of this study were to (i) determine the impact of disease development on field-based faba bean yield and (ii) evaluate two disease assessment methods, AUDPC and AUDPS, in comparison to their relative and standard forms, in order to quantify chocolate spot disease in faba bean crops.

MATERIALS AND METHODS

The study was carried out in Horro Guduru Wollega at two sites, Shambu and Guduru, during the 2016 and 2017 main cropping seasons. The study was located in Western Ethiopia, Oromia Regional State, at a longitude of 36° 39′ 28.8″-37° 40′ 11.2″ E and a latitude of 9° 9′ 24.6″-10° 20′ 59.9″ N. The temperature ranged from 8 to 32 °C, the annual rainfall was between 900 and 2000 mm, and the altitude ranged from 1350 to 3170 m a.s.l. (Horro Guduru Wollega administration

2019, unpublished). To predict how chocolate spot (Botrytis fabae) illness will affect faba bean (Vicia faba) production, researchers collected data in 2016 and 2017 at two locations (Shambu and Guduru) as part of an experiment by Wakoya et al. (2021) to evaluate the efficacy of multiple disease progression models. Utilizing data from 14 publicly available faba bean varieties and Horro Local, we "checked" for yield and yield components, as well as disease evaluation methods using a number of factors that have not been published previously.

Procedures and setup for the experiment

For both locations, the chocolate spot disease was tested in the 2016 and 2017 harvest seasons using Horro local as well as fourteen newly released varieties. Krakoya et al. (2021) reported that the cultivars were supplied by the agricultural research centers in Kulumsa and Holeta. Six seeding rows were laid out in the 2 × 2 m plot, with 1 m separating blocks, 0.5 m separating plots, and 0.4 m separating each row of seeds, with 0.1 m between each row. Seed and fertiliser rates of 275 kg/ha, 46 kg/ha, and 18 kg/ha, respectively, were used, in accordance with MoANR (2016). Treatments were organized using a three-replicate randomized complete block design (RCBD).

Gathering data

Evaluations of diseases

Beginning with the appearance of the initial chocolate spot symptoms and continuing until the disease reached its peak development stage, concluding the podding phase, the percent severity index (PSI) was evaluated at seven-day intervals (Villagas-Fernández et al., 2012). The data analysis was completed by converting the scores to PSI. According to the following sources: (Hanounik and Robertson 1988; Porta-Puglia et al. 1993), PSI was graded on a 1-9 scale and divided into five levels: 1 for a very small spot or no disease indications, 3 for minor discrete lesions, 5 for certain merged lesions with particular defoliation, 7 for great merged distinct lesions, and 9 for widespread lesions on leaves, stems, pods, and plant death. The scores were then converted into a proportion for analysis.

An organism's PSI can be calculated as follows:

PSI=(Total numerical ratings)/(Number of plants scored x maximum score on scale) x 100

An estimate of the area under the disease progress curve (AUDPC) was used to quantify the average strength of the disease over time. According to several sources (Shaner et al., 1977; Madden & Campbell, 1990; Vanderplank, 1963), the time interval between the midpoints of two consecutive time intervals is the weight for each evaluation.

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

Where: AUDPC = area under disease progress curve, xi= the average coefficient of infection of the ith note, xi+1 = the average coefficient of infection of the i+1th note and, ti+1- ti= the number of days between the ith note and the i+1th note, n= number of observations.

The relative area under the disease progress curve (rAUDPC) was estimated from model parameters or from the mid-point rule by dividing the time duration to compare epidemics over different time durations or the ratio between actual AUDPC and maximum potential AUDPC (Fry, 1978; Madden et al., 2007; Simko & Piepho, 2012), or as follows:

rAUDPC=AUDPC/((ft- it)*100)

Where 'ft' is the final time of disease assessment, 'it' is the initial time of disease assessment, and rAUDPC is the relative area under the disease progress curve in terms of time differences.

A linear transformation of AUDPC yields the standard area under the disease progress curve (sAUDPC), which was developed from normalization by dividing the AUDPC value by the total time duration (Fry, 1978; Rouse, 1989; Simko & Piepho, 2012). This metric is helpful for comparing epidemics of different durations by reducing the intervals between assessments (Savary & Cooke, 2006).

sAUDPC = AUDPC/D

Where: 'D' is the total number of days in which the disease was measured from the plants (from the first to the last measurement).

By dividing the average illness evaluation by the entire time and number of observations, the area under the disease progress stairs (AUDPS) was determined. You should extrapolate the weights for these assessments in both directions, as this strategy could be a good fit for both the first and last assessments. According to Simko and Piepho (2012), the total area is determined by extrapolating a weight in the missing direction using half of the average interval duration between measurements. Here is the formula along with its relative and standard forms:

AUDPS=ȳ*Dn/(n-1)

Where: 'Dn' is the total time of all observations for the combined weight of all assessments, AUDPS is area under disease progress stairs, 'ȳ' is the arithmetic mean of all disease assessments and 'n-1' is degree freedom of number of observations.

Standard area under disease progress stairs (sAUDPS) was derived from a linear transformation of AUDPS and is preferable for studying relative weights.

sAUDPS = (AUDPS*(n-1))/Dn

Where: sAUDPS is standardization of area under disease progress stairs.

Relative area under disease progress stairs (rAUDPS) was calculated from the ratio of actual and maximum potential of the disease assessment as follow:

rAUDPS = sAUDPS/Ymax

Where: rAUDPS is relative area under disease progress stairs and 'Ymax' is maximum disease observation.

Yield assessment

In order to analyze the yield performance of faba beans in relation to the progression of chocolate spot disease, a variety of yield components were measured. These included plant height (PH) in centimeters, number of seeds per pod (NSPP), grain yield (GY) in kilogrammes per hectare, number of pods per plant (NPPP), and hundred seed weight (HSW) in grams.

Data analysis

SAS and GLM 9.3 (SAS/STAT, 2011) were used to conduct the analysis of variance. We utilized AUDPC in our regression study since it shows a strong negative association with grain yield. Using the F-value, RMSE, R2, and CV from ANOVA, we calculated the illness assessment models' variation. We compared the performance of AUDPC and AUDPS disease assessment methods with their relative and standard forms (Simko & Piepho, 2012). At the 5% level of probability, the least significant difference was used to compare the mean parameters.

RESULTS AND DISCUSSION

Results

Assessment of area under disease progress

All disease progress parameters were found to be statistically highly significant ($P < 0.05$) different among the varieties in both years (2016 and 2017 growing seasons) and locations (Shambu and Guduru sites). However, statistically, rAUDPS showed a less significant difference among the varieties in both years and both locations. At Shambu location in the year 2016, a maximum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Mesay variety (2237.5% days, 2700% days, 37.29% days, 36% days, and 0.3% days), respectively; however, a maximum mean of rAUDPS was recorded from the Moti variety (15.47% days). While a minimum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Gora variety (1237.5% days, 1575% days, 20.63% days, 21% days, and 0.17% days), respectively, a maximum mean of rAUDPS was recorded from the Dosha variety (6.24% days). Again, similar results were recorded with the Gora variety; a minimum mean of AUDPS, sAUDPS, and rAUDPC were recorded with the Degaga variety (Table 1). In the year 2017, a maximum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Mesay and Tesfa varieties (2100% days, 2550% days, 35% days, 34% days, and 0.28% days), respectively; however, a maximum mean of rAUDPS was recorded from the Dosha variety (15.75% days). While a minimum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, rAUDPS, and rAUDPC were recorded from the Gora variety (1162.5% days, 1425% days, 19.38% days, 19% days, 3.67% days, and 0.16% days), respectively (Table 1).

At the Guduru site in the year 2016, a maximum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Mesay variety (2287.5% days, 2750% days, 38.13% days, 36.67% days, and 0.31% days), respectively; however, a maximum mean of rAUDPS was recorded from the Obse variety (15.14% days). While a minimum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Degaga variety (1150% days, 1475% days, 19.17% days, 19.67% days, and 0.16% days), respectively, followed by the Gora variety (1237.5% days, 1575% days, 20.63% days, 21% days, and 0.17% days), respectively, a minimum mean of rAUDPS was recorded from the Moti variety (4.85% days). In the year 2017, a maximum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, and rAUDPC were recorded from the Mesay variety (2612.5% days, 3150% days, 43.54% days, 42% days, and 0.35% days), respectively; however, a maximum mean of rAUDPS was recorded from the Moti variety (16.87% days). While a minimum mean of AUDPC, AUDPS, sAUDPC, sAUDPS, rAUDPS, and rAUDPC were recorded from the Gora variety (1137.5% days, 1400% days, 18.96% days, 18.67% days, 5.04% days, and 0.16% days), respectively Again, a minimum result that is similar to rAUDPS was recorded from the Holeta-02 variety (Table 1).

Table 1

Chocolate spot (Vicia faba) disease development with different assessment models at Shambu and Guduru in 2016 and 2017 growing seasons

Variety	2016						2017					
	AUDPC[a]	AUDPS[b]	sAUDPC[c]	sAUDPS[d]	rAUDPS[e]	rAUDPC[f]	AUDPC	AUDPS	sAUDPC	sAUDPS	rAUDPS	rAUDPC
Shambu												
Mesay	2237.50a	2700.00a	37.29a	36.00a	8.93fde	0.30a	2100.00a	2550.00a	35.00a	34.00a	8.61dc	0.28a
Tesfa	1862.50bdc	2275.00bc	31.04bdc	30.33bc	11.72bdac	0.25bc	2100.00a	2550.00a	35.00a	34.00a	8.62dc	0.28a
Horro	1925.00bac	2350.00ba	32.09bac	31.33ba	11.02bdac	0.26ba	2000.00a	2425.00ba	33.34a	32.33ba	10.31bc	0.27a
Dosha	1950.00ba	2375.00ba	32.50ba	31.67ba	**6.24f**	0.26ba	1912.5ba	2325.00bac	31.88ba	31.00bac	**15.75a**	0.26ba
Moti	1587.50fgedc	1925fecd	26.46fgedc	25.67fecd	**15.47a**	0.21fecd	1562.5bdc	1950.00edc	26.05bdc	26.00edc	14.13ba	0.21bdc
CS20dk	1787.50bdc	2200.00bc	29.79bdc	29.33bc	10.67fbdec	0.24bc	2050.00a	2500.00ba	34.17a	33.33ba	7.96dc	0.28a
Tumsa	1675.00fbedc	2050.00becd	27.92fbedc	27.33becd	13.79bac	0.22becd	1712.5bac	2075.00bdc	28.55bac	27.67bdc	5.57de	0.23bac
Kasa	1737.50bedc	2125.00bcd	28.96bedc	28.33bcd	6.32fe	0.23bcd	2025.00a	2500.00ba	33.75a	33.33ba	14.72a	0.27a
Obse	1712.50bedc	2150.00bcd	28.55bedc	28.67bcd	15.14ba	0.23bcd	1387.50dc	1700.00edf	23.13dc	22.67edf	7.37dce	0.19dc
Hachalu	1562.50fged	1900.00fecd	26.04fged	25.33fecd	11.73bdac	0.21fecd	1337.50dc	1675.00edf	22.29dc	22.33edf	10.43bc	0.18dc
Didia	1550.00fged	1900.00fecd	25.84fged	25.33fecd	8.33fde	0.21fecd	1362.50dc	1675.00edf	22.71dc	22.33edf	8.71dc	0.18dc
Holeta02	1425.00fge	1775.00fed	23.75fge	23.67fed	11.79bdac	0.19fed	1237.50d	1550.00ef	20.63d	20.67ef	8.74dc	0.17d
Bulga70	1325.00fg	1675.00fe	22.09fg	22.33fe	10.46fdec	0.18fe	1337.50dc	1650.00edf	22.29dc	22.00edf	10.08bc	0.18dc
Gora	1237.50g	1575.00f	20.63g	21.00f	10.81bdec	0.17f	1162.50d	1425.00f	19.38d	19.00f	**3.67e**	0.16d
Degaga	1250.00g	1575.00f	20.84g	21.00f	9.09fde	0.17f	1325.00dc	1625.00edf	22.09dc	21.67edf	9.76c	0.18dc
$LSD_{0.05}$	354.48^{**}	419.05^{**}	5.91^{**}	5.59^{**}	4.51^{**}	0.05^{**}	412.16^{**}	474.01^{**}	6.87^{**}	6.32^{**}	4.06^{**}	0.05^{**}
CV	12.81	12.30	12.80	12.30	24.99	12.47	15.02	14.09	15.01	14.09	25.22	14.41
Guduru												
Mesay	2287.50a	2750.00a	38.13a	36.67a	7.92bdc	0.31a	2612.50a	3150.00a	43.54a	42.00a	16.67a	0.35a
Tesfa	2137.50ba	2600.00ba	35.63ba	34.67ba	9.30bdc	0.287ba	2100.00bc	2550.00bc	35.00bc	34.00bc	8.62bdc	0.28bc
Horro	1987.50bac	2425.00bac	33.13bac	32.33bac	8.63bdc	0.27bac	2225.00ba	2675.00ba	37.08ba	35.67ba	6.9dc	0.29ba
Dosha	1962.50bac	2400.00bac	32.71bac	32.00bac	6.57dc	0.26bac	2175.00ba	2625.00b	36.25ba	35.00b	14.67ba	0.29bc
Moti	1887.50bdc	2275.00bdc	31.46bdc	30.33bdc	**4.85d**	0.25bdc	1512.50de	1900.00de	25.21de	25.33de	**16.87a**	0.21de
CS20dk	1850.00bedc	2275.00bdc	30.84bedc	30.33bdc	8.29bdc	0.25bdc	2100.00bc	2575.00b	35.01bc	34.33b	8.98bdc	0.28bc
Tumsa	1762.50edc	2150.00edc	29.38edc	28.67edc	10.05bdac	0.24edc	1712.50dc	2075.00dc	28.55dc	27.67dc	5.57dc	0.23dc
Kasa	1762.50edc	2150.00edc	29.38edc	28.67edc	6.66dc	0.24edc	2025.00bc	2500.00bc	33.75bc	33.33bc	14.75ba	0.27bc
Obse	1712.50fedc	2150.00edc	28.55fedc	28.67edc	**15.14a**	0.23edc	1387.50de	1700.00def	23.13de	22.67def	7.37bdc	0.19de
Hachalu	1562.50fedg	1900.00edf	26.04fedg	25.33edf	11.73bac	0.21edf	1312.50de	1650.00def	21.88de	22.00def	10.10bdac	0.18de
Didia	1550.00feg	1900.00edf	25.84feg	25.33edf	8.33bdc	0.21edf	1337.50de	1650.00def	22.29de	22.00def	8.37bdc	0.18de
Holeta02	1425.00fhg	1775.00egf	23.753fhg	23.67egf	11.79bac	0.19egf	1162.50e	1475.00ef	19.38e	19.67ef	12.85bac	0.16e
Bulga70	1325.00hg	1675.00gf	22.09hg	22.33gf	10.46bac	0.18gf	1287.50de	1600.00def	21.46de	21.33def	9.41bdac	0.17e
Gora	1237.50hg	1575.00gf	20.63hg	21.00gf	10.81bac	0.17gf	1137.50e	1400.00f	18.96e	18.67f	**5.04d**	0.16e
Degaga	1150.00h	1475.00g	19.17h	19.67g	12.86ba	0.16g	1275.00de	1575.00ef	21.25de	21.00ef	9.09bdc	0.17e
$LSD_{0.05}$	331.84^{**}	390.45^{**}	5.53^{**}	5.21^{**}	5.34^{*}	0.04^{**}	437.94^{**}	496.70^{**}	7.29^{**}	6.63^{**}	7.48^{*}	0.06^{**}
CV	11.61	11.13	11.62	11.13	33.37	11.31	15.47	14.32	15.48	14.32	43.19	15.06

Percent severity index (PSI)

At the Shambu experimental site, there was a fairly significant difference (P<0.05) in the mean PSI between the types in 2017 and 2016 (Fig. 1). While FB Didia and Degaga recorded the lowest PSI in 2016, the Mesay and Kasa cultivars recorded the greatest PSI at 65% and 61%, respectively. At 73.81% and 60.62%), respectively, the Obse and Moti cultivars recorded the highest PSI in 2017, while the local cultivar and the Dosha variety recorded the lowest PSI (27.33% and 38.33%, respectively). In both 2016 and 2017, there was a less significant difference (P<0.05) in the mean PSI among the kinds at Guduru, as shown in Figure 1. The Obse and Holeta-02 kinds had the highest PSI in 2016, with results that were almost identical (52.86%), while the Kasa and CS20DK varieties had the lowest PSI, with 35.33% and 39%, respectively. Figure 1 shows that in 2017, the Tumsa and Dosha types had the highest PSI at 56.24% and 50.33%, respectively, while the Degaga variety had the lowest PSI at 27.33%.

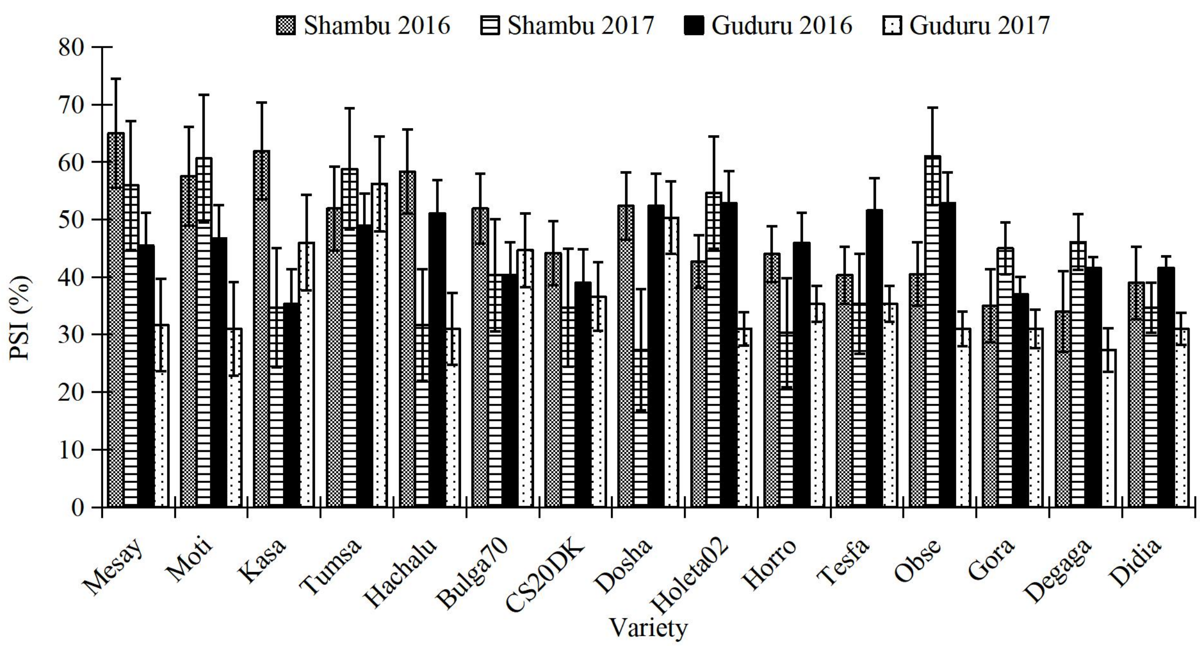

Fig. 1 *Percent severity index in both locations and times with standard deviation*

Yield assessments

In 2016, there was a statistically significant difference (P < 0.05) across the varieties in the primary effects of faba bean yield characteristics at the Shambu experimental site. On the other hand, HSW (Table 2) did not show any significant difference (P < 0.05). The Didia variety obtained the highest mean of HSW (84g), while the Gora variety reported the highest mean of PH (128.5cm), NPPP (12.67 cm), NSPP (3.67 cm), and GY (2184.17 kg/ha). The Mesay variety had the lowest mean PH, NPPP, HSW, and GY, while the Dosha and CS20dk varieties had the lowest at 6.33, the Kasa variety had the lowest at 49.67 g, and the Mesay variety had the lowest at 1698.83 kg/ha. Statistically significant differences (P < 0.05) were seen among the varieties in 2017 for the primary influences of faba bean yield parameters at this site, except for HSW, where no significant differences were discovered. Mesay varieties recorded a maximum mean of 124.5 cm for PH and Didia varieties 83.33 g for HSW in 2017, while Gora varieties 13 kg/ha for NPPP, 3.33 kg/ha for NSPP, and 2235.5 kg/ha for GY. Table 2 shows that the Hachalu variety had the lowest mean PH at 97.83 cm and HSW at 58.67 gm, whereas the CS20dk variety and the Mesay variety recorded the highest NPPP and GY, respectively, at 6.67 and 1705.83 kg/ha.

For all faba bean varieties tested at the Guduru experimental site in 2016, there were statistically significant differences (P < 0.05) in the main effects of the yield parameters. However, for HSW, there were no significant differences among the varieties in 2017. In Table 2, all yield parameters demonstrated highly significant differences. In 2016, the Gora variety had the highest mean PH, NPPP, and GY values at 125 cm, 12.67, 3.67, and 2413.97 kg/ha, respectively; on the other hand, the Hachalu variety had the highest mean HSW at 82.6 g. Once again, the Degaga variety showed a comparable outcome for PH and NPPP. In contrast, the Mesay variety had the lowest recorded minimums for PH, NSPP, and HSW (80 cm, 1.83 cm, and 55.25 g, respectively), while the local cultivar had the lowest reported NPPP (6.33 kg/ha) and the Tumsa variety had the highest recorded GY (1874.67 kg/ha). In 2017, the Gora variety had the highest mean PH, NPPP, and GY values (128 cm, 13, 3.83 kg, and 2396.17 kg/ha), although the Holeta-02 variety had the highest mean HSW value (84.33 g). While the Mesay variety had the lowest minimum means of PH, NPPP, NSPP, HSW, and GY, which were 90.67 cm, 6.67 cm, 1.75 cm, 48.98 g, and 1845.33 kg/ha, respectively, according to Table 2.

Table 2

Yield components of faba beans (Vicia faba L.) varieties at Shambu and Guduru site in 2016 and 2017 growing seasons

Variety	2016					2017				
	PH[a]	NPPP[b]	NSPP[c]	HSW[d]	GY[e]	PH	NPPP	NSPP	HSW	GY
Shambu										
Degaga	123.00ba	12.00a	3.00b	81.67ba	1998.17cd	112.17	11.00bc	3.00a	69.00	1936.83cb
Gora	128.50a	12.67a	3.67a	75.67bac	2184.17a	99.83	13.00a	3.33a	77.33	2235.50a
Bulga70	116.83bc	9.67b	3.00b	70.00ebdac	2025.50cb	117.17	9.00de	3.00a	74.00	1953.83cb
Holeta02	112.83dc	10.00b	3.00b	72.67ebdac	2095.50b	109.83	11.67ba	3.00a	60.67	2160.50a
Didia	112.50dce	9.67b	3.00b	84.00a	1881.83ef	111.83	9.00de	3.00a	83.33	1803.50ed
Kasa	103.50fge	7.67cde	2.00c	49.67f	1806.50hfg	107.17	7.00fg	2.00b	62.33	1740.83e
Hachalu	106.33dfe	8.67cb	2.33c	61.00edcf	1926.83ed	97.83	10.00dc	3.00a	58.67	1979.50b
Tumsa	108.50dfce	7.67cde	2.00c	74.33bdac	1794.17hig	109.50	7.33fg	2.00b	75.00	1752.00e
Obse	102.67hfg	7.33cde	2.00c	68.67ebdacf	1825.17fg	106.50	8.33fe	2.33b	68.67	1870.50cd
CS20dk	104.50dfge	6.33e	2.00c	60.00edcf	1734.50hij	100.83	6.67g	2.00b	66.33	1752.83e
Moti	106.83dfe	7.67cde	2.00c	55.00edf	1862.17efg	103.83	7.67feg	2.33b	70.00	1790.17ed
Local	93.83h	6.67de	2.00c	53.33ef	1704.50j	110.17	7.67feg	2.00b	65.00	1798.17ed
Tesfa	95.83hg	8.00cd	2.00c	63.67ebdcf	1814.50hfg	101.83	7.00fg	2.00b	64.67	1732.50e
Dosha	95.83hg	6.33e	2.00c	80.00bac	1721.50ij	101.50	8.00feg	2.00b	75.00	1779.17ed

Table.2 continues…

Mesay	93.83h	6.67de	2.00c	68.67ebdacf	1698.83j	124.50	7.00fg	2.00b	67.33	1705.83e
$LSD_{0.05}$	9.29**	1.53**	0.37**	20.09*	81.88**	22.04^{ns}	1.34**	0.39**	28.26 ^{ns}	106.62**
CV	5.19	10.81	9.09	17.69	2.62	12.24	9.22	9.69	24.43	3.42
					Guduru					
Degaga	125.00a	12.67a	3.50a	68.80	2299.25ba	116.67bc	11.00b	3.17b	71.50bdc	2164.50b
Gora	125.00a	12.67a	3.67a	73.85	2413.97a	128.00a	13.00a	3.83a	75.00bac	2396.17a
Bulga70	120.00ba	11.00ba	3.00b	67.92	2135.80c	115.00bc	10.33cb	2.83cb	76.72bac	2178.67b
Holeta02	120.00ba	10.67bc	2.83b	68.80	2130.57dc	120.00ba	11.00b	3.00b	84.33a	2325.33a
Didia	113.33bc	10.67bc	2.33c	75.80	2158.65bc	109.33ecd	9.00ced	2.17ed	66.83edc	2025.17cd
Kasa	108.00dc	9.00ecd	2.00dc	58.75	1903.70e	104.67efd	8.00feg	2.00ef	59.00ef	1957.17egdf
Hachalu	107.67dc	10.00bcd	2.33c	82.60	2122.30dc	113.33bcd	9.67cbd	2.50cd	80.67ba	2105.33cb
Tumsa	106.67dc	8.67efd	2.17dc	55.25	1874.67e	102.67ef	8.67ed	2.17ed	58.00ef	1949.50egdf
Obse	104.33dc	10.00bcd	2.00dc	62.42	1988.90de	111.00becd	8.33fed	2.00ef	65.83edc	1975.50edf
CS20dk	102.33de	9.00ecd	1.83d	62.83	1942.15e	98.67gf	6.67g	1.83ef	55.83ef	1860.17gf
Moti	92.67fe	7.67efg	2.00dc	58.75	1968.60e	105.00efd	8.67ed	2.00ef	66.50edc	1979.00ed
Local	91.67f	6.33g	2.00dc	58.42	1902.07e	92..00g	6.67g	1.83ef	51.33f	1849.83g
Tesfa	91.67f	7.00fg	1.83d	55.42	1897.03e	97.00gf	7.67feg	2.00ef	54.97ef	1901.17egf
Dosha	86.67fg	6.67g	2.00dc	65.00	1897.32e	95.67gf	7.00fg	2.00ef	60.00edf	1851.28g
Mesay	80.00g	7.00fg	1.83d	55.25	1913.70e	90.67g	6.67g	1.75f	48.98f	1845.33g
$LSD_{0.05}$	9.91**	1.83**	0.42**	17.89^{ns}	146.83**	9.53**	1.59**	0.41**	12.08**	115.70**
CV	5.64	11.82	10.73	16.55	4.31	5.34	10.77	10.39	11.1	3.42

Interaction effect

The interaction of disease development parameters over years was found to be statistically non-significant ($P < 0.05$) among the varieties on all parameters except rAUDPS, which was found to have highly significant differences at both the Guduru and Shambu experimental sites. In both the 2016 and 2017 growing seasons, the interaction over location was found to be statistically non-significant ($P < 0.05$) in all disease development parameters (Table 3). The interaction of yield parameters over years was found to be statistically non-significantly different ($P < 0.05$) among the varieties in all parameters at the Guduru experimental site. However, at the Shambu experimental site, there was significance for PH and GY, which showed less significance among the varieties. In 2016, the interaction analysis over locations revealed statistically non-significant differences among the varieties in all yield components. In the year 2017, it was found to have no significance except for PH and SPP, which found less significance among the varieties (Table 3).

Table 3

Interaction effects of locations and times

Disease	**2016*2017/Guduru**						**2016*2017/Shambu**					
LSD (5%)	AUDPC	AUDPS	sAUDPC	sAUDPS	rAUDPS	rAUDPC	AUDPC	AUDPS	sAUDPC	sAUDPS	rAUDPS	rAUDPC
	268.67^{ns}	308.93^{ns}	4.48^{ns}	4.12^{ns}	4.49**	0.035^{ns}	265.82^{ns}	309.37^{ns}	4.43^{ns}	4.12^{ns}	2.96**	0.04^{ns}
	Guduru*Shambu/2016						Guduru*Shambu/ 2017					
	237.43^{ns}	280.07^{ns}	3.96^{ns}	3.73^{ns}	3.41^{ns}	0.03^{ns}	294.06^{ns}	335.72^{ns}	4.90^{ns}	4.48^{ns}	4.16^{ns}	0.04^{ns}
Yield	2016*2017/Guduru						2016*2017/ Shambu					
	PH	PPP	SPP	HSW	GY			PH	PPP	SPP	HSW	GY
	6.72^{ns}	1.19^{ns}	0.29^{ns}	10.56^{ns}	91.4^{ns}			11.69**	0.99^{ns}	0.27^{ns}	16.95^{ns}	65.73*
	Guduru*Shambu/2016						Guduru*Shambu/2017					
LSD (5%)	6.64^{ns}	1.17^{ns}	0.27^{ns}	13.16^{ns}	82.20^{ns}			11.74**	1.02^{ns}	0.28*	15.03^{ns}	76.93^{ns}

Association of AUDPC with grain yield

At the Shambu experimental site in the 2016 and 2017 growing seasons, respectively, there was a negative correlation between disease development and faba bean grain yield, as shown by the logistic regression of the growth curve graph (Fig. 2). In 2016, faba bean yields were significantly lower than in 2017 due to the severe disease pressure. There was a negative correlation between disease development and faba bean grain yield at the Guduru experimental site in 2016 (with a coefficient of determination of 70%) and 2017 (83%). Despite an apparent delay at the outset, the disease burden that reduced faba bean yield in 2016 was much greater than in 2017 due to the length of time between the two growth seasons (Fig. 3). Due to varying responses from cultivar to cultivar, the impact of this temporal disease assessment on faba bean yield was not uniform.

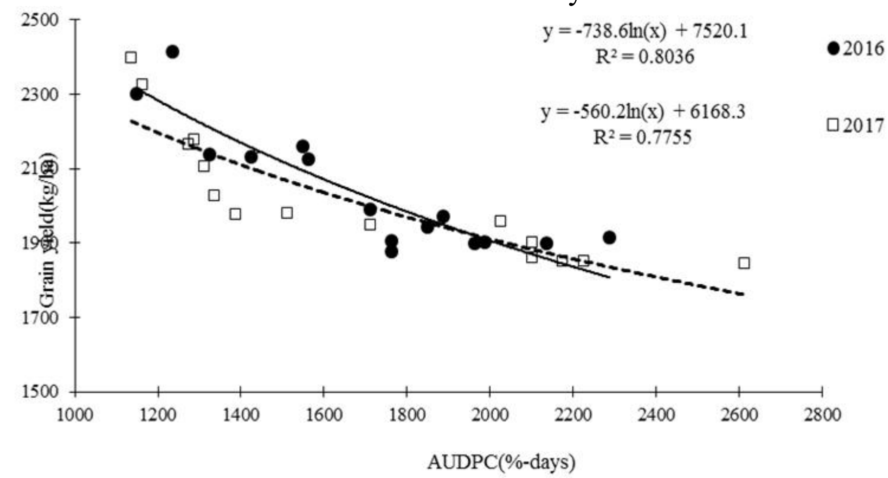

Fig. 2 Association of disease development and grain yield from the logistic curve at Shambu site (AUDPC would be appropriate, followed by a regression analysis with yield as the dependent variable and AUDPC as the independent variable).

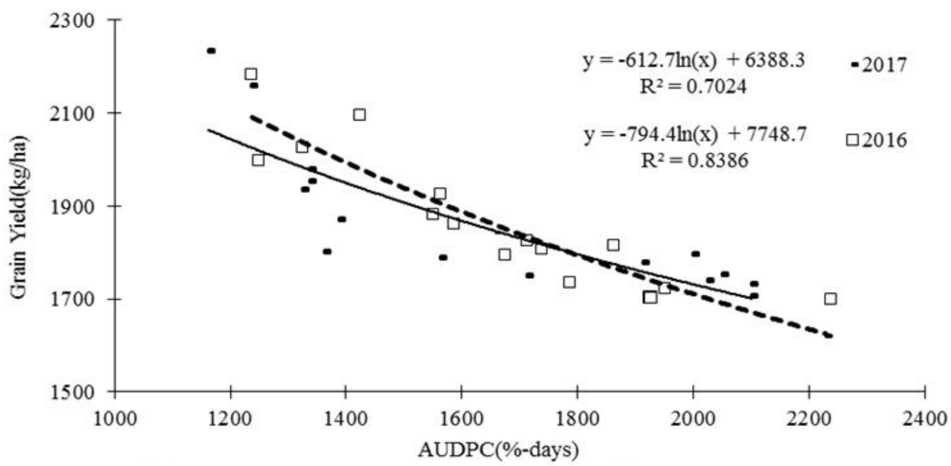

Fig. 3 Association of disease development and grain yield from the logistic curve at Guduru site (AUDPC would be appropriate, followed by a regression analysis with yield as the dependent variable and AUDPC as the independent variable).

Performances test

The performance of the AUDPC and AUDPS techniques were tested on fifteen different types of faba beans that have chocolate spot disease, along with their relative and standard forms. Results from one-way ANOVA showed that all approaches worked as expected in terms of F and P values, CV and R2, although rAUDPS was not used on the faba bean crop due to its large CV, small R2, and low P value. According to Table 4, the cumulative disease assessment approaches have shown that rAUDPC, sAUDPS, AUDPC, and sAUDPC have the best results.

Table 3

Statistical comparison of disease assessment models from one-way analysis of variance

Variety	2016					2017				
	F Value	*P* Value	CV	RMSE	R^2	*F* Value	*P* Value	CV	RMSE	R^2
Guduru										
AUDPC	7.54	<.0001	11.61	198.41	81	8.57	<.0001	15.48	261.84	83
AUDPS	7.04	<.0001	11.12	233.45	80	9.17	<.0001	14.32	296.97	83
sAUDPC	7.54	<.0001	11.62	3.31	81	8.57	<.0001	15.48	4.36	83
sAUDPS	7.04	<.0001	11.12	3.11	80	9.17	<.0001	14.32	3.96	84
rAUDPS	2.39	0.0211	33.37	3.19	58	2.35	0.023	43.18	4.47	57
rAUDPC	7.58	<.0001	11.31	0.03	81	8.58	<.0001	15.05	0.03	83
Shambu										
AUDPC	5.00	0.0001	12.81	211.94	74	5.55	<.0001	15.01	246.42	76
AUDPS	4.71	0.0002	12.30	250.55	71	5.94	<.0001	14.08	283.41	77
sAUDPC	5.00	0.0001	12.80	3.53	74	5.55	<.0001	15.01	4.10	76
sAUDPS	4.71	0.0002	12.30	3.34	73	5.94	<.0001	14.08	3.77	77
rAUDPS	3.75	0.0011	24.99	2.69	68	4.87	0.0001	25.22	2.42	73
rAUDPC	5.01	0.0001	12.47	0.03	74	5.80	<.0001	14.40	0.03	76

DISCUSSION

A study conducted by Wakoya et al. (2021) examined the impact of chocolate spot epidemics on faba bean types' resistance. The study compared disease severity, apparent infection rate, and AUDPC disease evaluation methodologies across different time periods and locations. During this stage, we will compare the disease progression models used to track chocolate spot disease. In order to measure the impact of the disease on agricultural yield, it is essential to compare disease assessment models. This study's results corroborate those of Simko & Piepho (2012) and White et al. (2020), who also discovered that minimizing general variances was possible with first and final observation values close to ideal. rAUDPC also performed better than sAUDPS and AUDPS. Actually, AUDPC was created by Madden et al. (2007) to estimate disease progress by combining multiple observations into one value. This method breaks a disease development curve into a series of trapezoids, but it usually has limitations when it comes to the impact of the first and last observations. What gives AUDPS a higher value than AUDPC in this data analysis? In order for the model to function properly, it is important that the first and last assessments be generalizable in both directions. One possible solution is to use half of the average interval duration between observations to generalize a weight in the missing path (Simko & Piepho, 2012). The AUDPS models were used to aggregate data from weekly chocolate spot disease assessment methods and provide an overall rating in earlier work. However, rAUDPS underperformed other models in describing the development of chocolate spot disease in faba bean crops. If we had used the R2, F value, and CV from the statistical comparison, we would have seen that the other models (AUDPC, AUDPS, rAUDPC, sAUDPC, and sAUDPS) performed somewhat better. According to Wakoya et al. (2021), this model (rAUDPS) has demonstrated variation among faba bean varieties in estimating the development of chocolate spot disease, which is different from other methods. The computed AUDPC has exhibited variable outcomes among crop kinds, according to the prior research.

With the exception of the rAUDPS, our work is in agreement with the illustration by Madden et al. (2007) and is supported by Wakoya et al. (2021) that suggests the computed AUDPC might not be a precise representation of the actual area on a few occasions. It is possible to compare epidemics using AUDPC, which expresses the dynamics of an epidemic as a single value, and to standardize each epidemic using the area under the disease progress curve and the area under the disease progress stairs (Fry, 1978). Thus, due to their relative standardization, the AUDPC and AUDPS would have a valuable model that incorporates inclines related to the advancement of chocolate spot disease. This model may also be used to estimate the decline in faba bean output (Savary & Cooke, 2006). Above, we saw that rAUDPC is a great tool for tracking the impact of chocolate spot (Botrytis fabae) infections on faba bean yield over time and across different regions.

A number of studies have shown that there is a lack of consistency in the empirical models used to explain crop loss because of the unpredictable nature of the interaction between epidemic traits like AUDPC and yield. Indeed, this research set out to do just that—compare faba bean variety reactions to different area under chocolate spot disease development assessment methods—and to delve into the connection between AUDPC and yield. It is in line with the findings of Bouhassan et al. (2004) that the chocolate spot disease variants showed a high level of resistance, as reported by Wakoya et al. (2021) using disease evaluation methods. Quantitative resistance is present in certain genotypes, which causes these variances. Actually, rather than using different cultivars and conditions to achieve different epidemics and yields, researchers utilize them to find out how they affect crop losses (Vanderplank, 1963; Rouse, 1989; Savary & Cooke, 2006; Madden et al., 2007). For this reason, disease epidemics are nowadays generally thought of as the gold standard for depicting the progressive spread of illness in a plant community (Madden & Campbell, 1990).

Locating this study area is crucial because the chocolate spot (Botrytis fabae) disease is a major factor affecting faba bean productivity and yield (Wakoya et al., 2021). Therefore, it is a fundamental goal of research and extension systems in Ethiopia to maximize the sustainable economic yield of the faba bean crop (Agegnehu et al., 2006). In both locations and years, the logistic regression model of AUDPC of chocolate spot disease has a negative correlation with the grain yield of faba beans. The reaction of the disease varies among varieties, which is supported by reports that suggest faba bean resistance to chocolate spot disease can be improved through selection. Additionally, the linear regression model of grain yield on chocolate spot severity had a negative effect on faba bean grain yield. (Abo-Hegazy et al., 2012; Sahile et al., 2010; Tekalign et al., 2015) Not only does the regression model of chocolate spot illness impact the grain production, but there are other factors as well. High rainfall throughout the cropping season is one possible environmental factor that could explain this variance; climate has a significant impact on the incidence of chocolate spots (Jeger, 2000; Thomas et al., 2010; Tekalign et al., 2015).

Based on the assessment of phenological data in both locations and years, this work has determined that the Mesay variety has not been promising, whereas the Gora variety has fared better than the others. Grain yield is affected in the same way by all yield components across all kinds. Similarly, when looking at disease progression, which is evaluated using various evaluation methods and correlated with faba bean grain yield, the inverse is also true. In terms of how the chocolate spot disease affects different varieties, the Gora variety reacts in quite different ways, while the Mesay variety has managed to evade the disease's effects in different years and different locales. The findings are in line with those of Wakoya et al. (2021), who investigated the disease using AUDPC, apparent infection rate, and severity as markers. It has been suggested by several writers that the crop's physical or natural barriers, such the cell wall's structural composition and the strength of the plant cuticle, are one of several elements that might affect the seasons. Another clear fact is that faba bean varieties vary greatly due to a single gene that confers resistance to chocolate spot disease. As a result, it's possible that the Gora variety has a greater concentration of defensive genes than the Mesay type in response to infection. An intriguing breeding effort that could provide resistance is the combination of varietal trials against disease (Villegas-Fernández, 2012; Abo-Hegazy et al., 2012; Tekalign et al., 2015). Finally, it is important to prioritize developing crop protection techniques and increasing crop resistance to diseases. Even with the most effective disease assessment methods in the research area, a single investigation trip will not be enough to resolve the problem.

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DECLARATION

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data generated from the field experiments and reported in the manuscript are included in the article. Further data sets are available from the corresponding author upon request.

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