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ORIGINAL RESEARCH ARTICLE

Effect of integrated management on purple blotch (*Alternaria porri* (Ellis) Cif.) progression and bulb yield of onion at Arba Minch in Southern Ethiopia

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ABSTRACT

A field experiment was conducted at Arba Minch area, southern Ethiopia during the 2018 and 2019 cropping seasons to determine the integrated effects of varieties and fungicide spray frequencies on onion purple blotch (PB) epidemics, bulb yields, and economic returns. Fifteen treatment combinations consisting of three onion varieties and five fungicide spray frequencies were arranged in a factorial experiment in a randomized complete block design with three replications. Integrating varieties with fungicide spray frequencies significantly reduced onion PB epidemics and increased bulb yields and economic returns. Due to four times spray of ridomil gold (RG) at 14-day interval, PB severities as low as 35.7, 42.2, and 58.9% were recorded on Nasik-Red, Bombay-Red, and Adama-Red varieties, respectively. The lowest area under the disease progress curve of 625.3, 706.7, and 1131.1%-days was also recorded on Nasik-Red, Bombay-Red, and Adama-Red varieties, respectively, due to four sprays of RG at a 14-day interval. Three times spray of RG at 10-day interval gave the highest bulb yields of 33.4, 38.9, and 23.7 t ha^{-1} on Nasik-Red, Bombay-Red, and Adama-Red varieties, respectively. The results showed the existence of variability in onion genetic resistance that was complemented by fungicide spray frequencies against PB epidemics to increase bulb yields. The use of Bombay-Red variety along with three and four-time spray frequency of RG was found to be the most effective option in reducing PB epidemics and increasing onion bulb yields. However, the use of Bombay-Red variety along with three-time spray frequency of RG could be recommended, because of its highest economic returns, to farmers in the study areas and elsewhere with similar agro-ecologies to manage PB and sustain onion production and productivity in the country.

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INTRODUCTION

Onion (*Allium cepa* L.) is a bulbous biennial herb and one of the most useful and essential spices of vegetable crops grown in many countries of the world, including Ethiopia. A total cultivated area covered by onion reached more than five million hectares with a production of 106,673,780.7 million tons worldwide (FAOSTAT, 2018). In Ethiopia, the crop is grown in diverse agro-ecological conditions and covered 59,858.3 hectares of the cultivated area and 556,365.9 tons of the production by smallholder farmers and the private sectors during the 2018 cropping season (CSA, 2018). The crop is used to improve the taste and flavor of the food, a source of income for many small-scale farmers, and helps them for improving their livelihood. Also, onion is used for a medicinal purpose in the control of human and plant diseases (Ebrahimi-Mamaghani *et al.*, 2014; Law *et al.*, 2016; Marrelli *et al.*, 2019). Due to these substantial benefits, onion production is becoming increasing among small-scale farmers and private investors in different parts of the world and Ethiopia as well.

Despite being an important crop for household consumptions, medicinal uses, source of income, and contribution to the national economy through export products, the crop is constrained by several abiotic, biotic and socio-economic factors (Getachew *et al.*, 2014). The national average bulb yield of onion under farmers' situations is considerably lower in Ethiopia (9.1 t ha^{-1}) (CSA, 2019) than its potential average bulb yield (30.0 t ha^{-1}) at research stations (Lemma and Shimeles, 2003; Getachew *et al.*, 2014). Even the national average productivity of onion is lower than the world's average productivity (20.0 t ha^{-1}) (FAOSTAT, 2018). This low productivity is predominantly recognized as biotic factors, diseases, and insect pests (Haile *et al.*, 2016). Of the biotic factors, fungal pathogens made for an important role in limiting the production and productivity of onion in the country (Wondirad *et al.*, 2009). The major diseases that influence onion production include purple blotch (*Alternaria porri)*, downy mildew (*Peronospora destructor*), and basal rot (*Fusarium oxysporum* f.sp. *cepae) (*Schwartz and Mohan, 2008; Gajendran *et al.*, 2016). These diseases are the three major economically important fungal diseases of onion in Ethiopia (Mishra *et al.*, 2014; Haile *et al.*, 2016).

Purple blotch (PB) is one of the most widespread and devastating diseases among biotic constraints in onion production in Ethiopia. The pathogen is polyphagous and affects bulbous crops, like onion, garlic, shallot, and other *Allium* crops. The pathogen overwinters as asexual multi-celled spores (conidia), within or on seeds, and debris of onion plants. Optimum (24 ± 2° C) temperature and high (80 to 90%) relative humidity have required for further development of disease symptoms that trigger significant yields losses (Shahanaz *et al.*, 2007). The pathogen is a seed-borne fungus known by long-distance dispersal, usually across the continent. Such kind of distribution is of great importance since a small proportion of the infected seed has the potential to cause outbreaks when seedlings are raised in a nursery and have transplanted in the main field.

Typical symptoms of the PB look on leaves, sheath, inflorescence, and stalks as small white sunken spots on the leaves, which progressively become enlarged, zonate, and under moist conditions and eventually turn to purple color. Infection can cause a semi watery rot on the necks of bulbs that turn yellow-red. Also, infected bulb tissues finally become papery (Schwartz and Mohan, 2008; Kim *et al.*, 2022). The pathogen has caused 50 to 100% losses in bulb yield, and the magnitude of loss depends on the stage of crop growth and time of infection (Shahanaz *et al.*, 2007; Priya *et al.*, 2015). In Ethiopia, yield loss due to PB has been estimated to be more than 50% of the total production with the relative occurrence of the disease (Wondirad *et al.*, 2009; Getachew *et al.*, 2014). In the study area, the disease is the main and occurs year after year and is responsible for substantial yield losses during the growing periods. Measures to reduce yield losses, sources of infection, and prevent the spread of disease are of great importance in controlling onion PB.

For the last three to four decades, research reports showed that PB influence had been increasing in different areas of the world and Ethiopia as well (Getachew *et al.*, 2014; Aejaz *et al.*, 2020). At the same time, many PB management options have developed; use of disease-free onion seeds or seedlings, removal of infected debris (Mishra *et al.*, 2014; Shumsun *et al.*, 2014), use of host resistant varieties (Wondirad *et al.*, 2009; Yadav *et al.*, 2017) and applications of fungicide as foliar sprays and seed treatments (Abdel-Hafez *et al.*, 2015; Rashid *et al.*, 2015). Management of PB through cultural approaches could play a limited extent. Also, the use of host resistance may not be guaranteed since the host resistant varieties responsible gene broken soon after their release due to either introduction of exotic races or evolvement of new local races and changes in environmental factors (Abubakar and Ado, 2013; Kim *et al.*, 2022). Similarly, the management of PB through fungicidal treatment is an efficient option; however, their long-term application may result in resistance development by the pathogen and buildup of toxic residues in goods and the environment (Agrios, 2005; Aejaz *et al.*, 2020). Accumulations of harmful residues in commodities and surroundings may result in risks to human health and other non-target organisms (World Health Organization (WHO), 2004; Mostafalou and Abdollahi, 2012). Considering such conditions, devising a proper management approach with trusty and efficient PB suppression and environmentally safe is a prerequisite.

The tendency of numerous cultivators on onion production, due to its high productivity per unit area with a short cycle of life, and the majority of previous research on PB management strategy in the study areas and Ethiopia as well was primarily towards the use of fungicides. In the study areas, farmers extensively use whatever fungicides are accessible in the locality as a sole or mix of the different fungicides altogether to manage PB. The fungicides used by the farmers have a different mode of action, contact and systemic, and indiscriminately mixed each other during application. Frequent applications of a single or more than one fungicide for all onion varieties regardless of the growing season are also very common practices in the study area. The unwise use of agrochemicals has adverse effects on human, animal health, the environment and leads to resistance development by the pathogen (WHO, 2004; Mostafalou and Abdollahi, 2012).

Thus, there is an urgent need for research data to use fungicides wisely in the study area and the country as well and in an integrated manner with other management approaches, such as host resistance and fungicide application. The different host varieties react differently to the diseases of the intended crop. The phenomenon may be the genetic inheritance of the variety and integrated fungicides with an appropriate type, rate, frequency, and time of application. Integration of varieties having different levels of reactions to the disease and fungicide application with different spray frequencies showed that the action of fungicide varies with the number of spray frequencies applied to the varieties to manage the disease. Varieties that may execute well with one or two spray frequencies may be desirable to a variety that requires more fungicide spray frequencies.

Therefore, conducting research on the integrated manner of host resistance and fungicide applications with different spray frequencies on onion PB management and bulb yield may generate information appropriate for rational use of fungicide in the study areas. Yet, an integration of host resistance and fungicide applications with different spray frequencies has not been evaluated in the study area. No or little realization by the farmers in managing PB rationally, absence of research work before in the study areas through integration of host resistance and fungicide spray frequency, and due to the reasons stated earlier has necessitated the study. The objective of this study was to determine the integrated effects of host resistant and fungicide spray frequencies on onion PB epidemics and bulb yield parameters and economic returns at Arba Minch in southern Ethiopia.

MATERIALS AND METHODS

Overview of the study site

Two consecutive years of field experiments were conducted in an open environment under rainfall with irrigation supplementary at Chano Mile in Arba Minch area, southwestern Ethiopia, during the 2018 and 2019 cropping seasons. Chano Mile is geographically positioned 06°06' 841" N and 037°35' 122" E with an altitude of 1216 m above sea level. The area has a bimodal rainfall pattern, a short rainy season (March and April), and a long rainy season (August to November). Arba Minch area receives an average total annual rainfall, and temperatures for the last decade were 810 mm and 26.3 °C. The mean monthly maximum and minimum temperatures, relative humidity, and total rainfall of the Arba Minch area for the 2018 and 2019 cropping seasons are presented in Table 1. Additionally, the area is featured by moderately alkaline pH with low (1.1%) organic contents and black sandy-loam in the soil type (Ministry of Agriculture and Natural Resources (MoANR) and Ethiopian Agricultural Transformation Agency (EATA), 2016). Table 1. Monthly mean maximum (Max) and minimum (Min) temperature, rainfall and relative humidity (RH) of Arba Minch area, southwestern Ethiopia during the 2018 and 2019 cropping seasons.

Treatments, design of experiment and field management

Three onion varieties (Nasik-Red, Bombay-Red, and Adama-Red) and one systemic fungicide (Ridomil Gold MZ 63.5% WP) with five spray frequencies, including the unsprayed control, were used in the experiment. The onion varieties are currently found under production in the study areas. These varieties exhibited different levels of resistance to PB. Nasik-Red, Bombay-Red, and Adama-Red have been characterized as resistance, moderately resistance, and susceptible, respectively. Onion seeds were obtained from Melkassa Agricultural Research Centre, Ethiopian Institute of Agricultural Research. A total of 15 treatment combinations, including three onion varieties x five fungicide spray frequencies, were arranged in a factorial experiment in a randomized complete block design with three replications.

The total width and length of the designed layout were 11.2 m × 60 m with a unit plot size of 2.4 m × 2.6 m, respectively. The spacing of 1.5 m and 2.0 m was applied to separate each plot and block, respectively. The plots consisted of six rows with a spacing of 40 cm between rows. Seeds of each onion have sown at a rate of 6.0 kg ha^{-1} on a well-prepared seedbed. The seedlings were ready for transplanting on the date of 35 after planting. Vigorous and healthy seedlings with three to four confessedly leaves were transplanted to the main experimental field with a 10 cm interval along the rows. During planting, double row planting was performed during transplanting. Seedling transplanting was conducted on 04 and 08 October 2018 and 2019, respectively. Spraying of fungicide was carried out at an interval of 14-day intervals on each intended plot. It has continued according to the spray schedule designated for each treatment. Fungicide spraying was carried out using a manual knapsack sprayer calibrated to deliver 500 to 700 L of water ha^{-1}.

Table 1. Monthly mean maximum (Max) and minimum (Min) temperature, rainfall and relative humidity (RH) of Arba Minch area, southwestern Ethiopia during the 2018 and 2019 cropping seasons.

Month	2018				2019			
	Temperature (°C)		Rainfall (mm)	RH (%)	Temperature (°C)		Rainfall (mm)	RH (%)
	Max	Min			Max	Min		
January	29.84	15.81	2.46	38.84	28.11	15.62	3.44	36.12
February	30.70	18.85	47.60	39.32	28.64	18.62	38.56	35.75
March	28.66	17.94	35.50	58.77	27.35	17.17	53.94	55.34
April	26.75	17.34	250.70	66.12	26.32	16.59	261.27	64.18
May	26.42	17.86	165.00	64.13	26.01	16.44	189.11	60.26
June	24.78	17.04	89.00	50.56	25.16	16.31	63.41	44.63
July	25.52	18.44	12.80	44.12	26.34	16.64	16.35	44.96
August	26.84	18.26	94.40	63.35	26.11	15.74	101.02	56.89
September	28.68	17.73	159.40	69.11	25.45	15.96	201.11	61.09
October	27.86	17.95	102.60	60.34	26.72	16.17	111.01	60.54
November	28.62	16.75	81.00	57.45	27.58	16.03	76.48	54.75
December	28.94	17.35	17.76	16.34	28.01	17.14	13.16	26.35

The data were obtained from National Meteorological Agency, Hawassa Branch (2019).

Unsprayed plots were left for each variety as controls to allow maximum disease development within the replication. The fungicide application was started on 41 and 46 DAP when the first symptom of PB appeared in plots during the 2018 and 2019 cropping seasons, respectively.

Nutrient management was kept up through NPS (200 kg ha^{-1}) and N-fertilizers (150 kg ha^{-1}) as a basal application. The whole calibrated NPS-fertilizer was applied during transplanting, while N-fertilizer was applied as split, one-third of it during transplanting and two-thirds of it as a top dressing on 35 days after transplanting (DAP). Weeding, hoeing, and regular monitoring were accomplished to all plots homogeneously as per the recommendations. Locslay 5% EC [Lambda-cyhalothrin 50 g/L] at the rate of 300 ml/ha with mixing water of 350 L was sprayed uniformly to whole plots for the control of onion thrips (*Thrips tabaci* (Lind.), Thysanoptera: Thripidae) and leaf minor (*Acrolepiopsis assectella* (Zeller), Lepidoptera: Acrolepiidae) in both cropping seasons. Two consecutive sprays were accomplished per season during growing periods.

Disease assessment

Purple blotch severity was assessed at weekly intervals during the epidemic periods. Twelve randomly selected and pre-tagged onion plants were inspected for disease severity assessment. Disease severity assessment was started on 41 and 46 DAT in the 2018 and 2019 cropping seasons, respectively. A total of six assessments were made per season during the two cropping seasons. During the study periods, disease severity was rated following 0 to 5 scales described by Sharma (1986), where, 0 = no visible symptom, 1 = a few spots towards the tip covering up to 10% leaf areas, 2 = several dark purplish-brown patches covering 11-20% leaf areas, 3 = several patches with paler outer zone covering 21-40% leaf areas, 4 = long streaks covering 41-75% leaf areas, and 5 = complete drying of the leaves or breaking of the leaves from the base. The severity scored for PB then transformed into a percentage severity index (PSI) for analysis using the formula stated below (Wheeler, 1969).

$$\mathrm{PSI} = \frac{\text{Sum of numerical ratings}}{\text{No. of plants scored x Maximum disease score on scale}} \mathrm{x100}$$

The area under the disease progress curve (AUDPC), the development of disease on a whole plant or part of the plant, was calculated from PSI values assessed at different days for each plot using the formula stated by Campbell and Madden (1990) as followed.

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

where, n is the total number of disease assessments, t_i is the time of the i^{th} assessment in days from the first assessment date and x_i is the PSI of PB at the i^{th} assessment. The area under disease progress curve value was expressed in %-days because severity (x) is expressed in percent and time (t) in days.

Disease progress rate (DPR) was estimated through the repetitious valuation of the percentage of leaf area infected by PB in each plot beginning from disease onset. Logistic, ln [(Y/1-Y)] (van der Plank, 1963) and Gompertz, -ln [-ln (Y)] (Berger, 1981) regression models were collated for the goodness of fit in the estimation of disease progression from each treatment combination. A logistic regression model (ln [(y/1-y)]) was selected and applied to estimate the rate of the disease progression from each treatment because it showed more significant reflection on the coefficient of determination (R^2) and lower residual standard errors for most of the studied parameters. The converted data were regressed over time to ascertain the rate of disease progression.

$$Y_t = \frac{1}{1 + \exp^{-\ln\left[\frac{Yo}{1-Yo}\right] + rLt}}$$

Where, Y_t: percentage of severity at t^{th} assessment date; Y_o: percentage of initial severity at t^{th} assessment date; t_i: time of the i^{th} assessment in days from the first assessment date; and r_L: the rate parameter determined by the production of inoculum by infected individuals/lesions per unit area of diseased tissue. The rate of disease progress was expressed in unit $days^{-1}$.

Yield assessment

Yield-related parameters including single bulb weight, marketable, and total bulb yields were collected from the four central rows of each plot. Single bulb weight was assessed from randomly sampled sellable bulbs incurred from the whole harvested bulbs of each plot. Marketable bulb yield was determined from the advisement of sellable bulbs, which were free from any damage, uniform in color, and ≥ 20 g in size obtained from the four central rows of each plot. Total bulb yield was computed as the weight of all harvested bulbs from the four central rows of each plot. Then, the harvested marketable and total bulb yields were converted into t ha^{-1}. A single bulb weight was measured in grams (g). Sensitive balance was used to determine single bulb weight as a random sample of the total harvested bulb yield.

Data analysis

Analysis of variance (ANOVA) was performed for disease and yield-related data to determine the integrated effects of host resistance and fungicide spray frequencies using the GLM procedure of the SAS software *version* 9.2 (SAS, 2009). Mean separations have been made using the least significant difference (LSD) at 5% probability levels (Gomez and Gomez, 1984). A correlation analysis was employed to examine associations between and among disease scores, growth, and yield-related parameters. Also, the relationship between the disease and bulb yield of onion was estimated using linear regression of the AUDPC and bulb yield of onion to determine the yield loss due to PB. The two cropping seasons are regarded as different environments because of the significant variation in weather conditions during the two cropping years, and heterogeneity of variances was tested following the F-test procedure suggested by

Gomez and Gomez (1984). The data were found to be homogenous, and thus the analysis was carried out on the combined values. Statistical regression was determined using MINITAB® software version 14 (Release 14.20 for windows® 2007).

Cost-benefit and yield loss analysis

A simple cost-benefit analysis was computed for each treatment using the formula of partial budget analysis (CIMMYT, 1988) to determine the profitability of onion PB management through a combination of host resistance and fungicide sprays at different frequencies. During partial budget analysis, the gross benefit, variable cost, net benefit, and marginal rate of return were considered for each treatment. The gross benefit was calculated as the products of bulb yield and market unit price. The variable cost was obtained from the total sum of all input variable costs: fungicide, knapsack sprayer, and labor. Net benefit was computed from the difference between the gross benefit and the variable cost considered. The marginal rate of return was determined as the ratio of the difference in net benefit and variable cost under consideration. All the costs and profits were transformed into a hectare basis and the United States Dollar (USD) for the intended analysis. During the study, variable costs such as expenses of fungicide, knapsack sprayer, and labor were considered. The mean cost of fungicide per kilogram was USD 50.72. In the two cropping seasons, the mean cost of knapsack sprayer and labor man^{-1}day^{-1} were USD 43.53 and 2.82, respectively. These values were taken based on the dominant market and wage rates in the locality. The mean market unit price of onion bulb yield per ton was USD 740.0. The actual bulb yield was adjusted downward by 10% to estimate the difference between the empirical research bulb yield, and the farmers' bulb yield that could expect from the same treatment. On the other hand, the relative yield loss for each treatment combination was ascertained using the following formula as suggested by Robert and James (1991).

$$\text{Relative yield loss } (\%) = \frac{Y_{bt} - Y_{lt}}{Y_{bt}} \text{x } 100$$

Where, *Ybt* is the yield of best treatment (maximum protected plot) and *Ylt* is the yield of lower treatment evaluated during the study.

RESULTS AND DISCUSSION

Mean square values for the study parameters

The combined ANOVA for disease scores and yield-related traits of onion showed various levels of variations between the cropping years, onion varieties, fungicide spray frequencies, and interactions between and among the cropping years, onion varieties, and fungicide spray frequencies (Table 2). A significant ($p < 0.01$) difference was observed between the cropping years for the mean square of disease severity, AUDPC, single bulb weight, marketable bulb yield, and unmarketable bulb yield due to integrations of onion variety and fungicide spray frequency. However, no significant ($p > 0.05$) difference was observed between the cropping years for total bulb yield. The mean square of the combined ANOVA showed significant variations of $p < 0.0001$ for all studied parameters were observed between the evaluated onion varieties and fungicide spray frequencies under assessment (Table 2). For the study disease and yield-related parameters, interaction effects between and among onion varieties and fungicide spray frequencies, except for unmarketable bulb yield, were examined with various levels of variations of $p < 0.01$ (disease severity, single bulb weight, and disease progress rate) to $p < 0.0001$ (AUDPC, marketable bulb yield, and total bulb yield) for the study parameters during the two cropping years. No interaction effects were observed among the year, onion variety, and fungicide spray frequency for the mean squares of the studied parameters on year x onion variety x fungicide spray frequency interactions. Overall, the combined ANOVA of the evaluated treatments showed the highest mean square values of all the study parameters during the two years. This indicates the tested treatments for the disease scores and yield-related traits responded similarly during the two years. The lowest mean square values of all the study parameters during the two years could be ascribed to the different responses of the tested treatments for the disease scores and yield-related traits or due to the differences between the two cropping years (Table 2).

Disease epidemics

The interaction effects of fungicide spray frequencies by onion varieties showed a significant difference in PB severity at the final assessment date among the different treatment combinations (Tables 2 and 3). The highest (80.7%) PB severity was recorded on an unsprayed plot of the Adama-Red variety. The lowest (35.7%) PB severity was recorded from a plot of the Nasik-Red variety sprayed four times with ridomil gold (RG) at a 14-day interval, which was statistically at par with the disease severity (37.7%) obtained from a plot of the same variety when sprayed three times with RG at a 14-day interval. Also, there was highly a significant difference in AUDPC among the interaction effects of fungicide spray frequencies by onion varieties (Tables 2 and 3). The highest AUDPC value of 1484.2%-days was obtained from the unsprayed plot planted with Adama-Red variety, while the lowest (625.2%-days) was recorded from the plot of Nasik-Red variety when sprayed four times with RG at a 14-day interval. The area under disease progress curve reduction of 625.3%-days on Nasik-Red variety was obtained due to four sprays of RG at 10-day interval compared to the unsprayed plot. Likewise, the rate of PB progress showed a significant difference among the interaction effects of fungicide spray frequencies by onion varieties (Tables 2 and 3). The highest (0.126 units per day) PB progress rate was obtained from an unsprayed plot of the Adama-Red variety (Table 3). The lowest (0.011 units per day) PB progress rate was obtained from a plot of Nasik-Red variety sprayed four times with RG at the 14-day interval, which was 12.4% slower than the disease progress rate on the unsprayed plot of the same variety.

Table 2. Combined analysis of mean square for disease scores and yield related traits of onion studied under integration of varieties and ridomil gold with different spray frequencies during the 2018 and 2019 main cropping seasons.

Source of variation	DF	PSI_f (%)	AUDPC (%-day)	DPR (Units/ day)	SBW (g)	MBY (t/ha)	UMBY (t/ ha)	TBY (t/ha)
Block/within Yr/	4	17.46^{ns}	2006.88^{ns}	1.45 x 10^{-3ns}	88.13^{ns}	6.35^{ns}	24.31^{ns}	19.77^{ns}
Year	1	10431.82****	4017268.77****	0.0283***	670.67***	68.55**	147.07****	14.81^{ns}
VAR	2	4690.03****	2240563.13****	0.0104**	3013.54****	1399.57****	357.37****	743.06****
FSF	4	1274.78****	264039.11****	0.0079***	5815.48****	2170.72****	15.82****	1829.85****
Yr * VAR	4	188.20****	125966.31****	0.0099*	4.14^{ns}	2.48^{ns}	25.41****	39.28*
Yr * FSF	4	50.56****	13121.95****	0.0057*	7.99^{ns}	3.86^{ns}	1.12^{ns}	8.99^{ns}
VAR * FSF	8	16.36*	126621.25****	0.0036*	111.21*	67.84****	2.92^{ns}	75.42****
Yr*VAR*FSF	8	0.61^{ns}	623.59^{ns}	0.0007^{ns}	0.15^{ns}	0.12^{ns}	0.21^{ns}	0.28^{ns}
Pooled Error	56	5.89	1558.52	4.74 x 10^{-4}	47.13	9.47	1.99	12.55
Pooled F-value		146.83*****	220.48****	2.73***	22.60****	44.10****	17.38****	26.21****
Ground mean		54.60	935.69	0.0645	73.63	20.71	4.79	25.50
CV (%)		4.45	4.22	33.75	9.32	14.86	29.46	13.89

DF = Degree of freedom; PSI_f = Percent severity index at final date; AUDPC = Area under disease progress curve; DPR = Disease progress rate; SBW = Single bulb weight in gram; MBY = Marketable bulb yield; UMBY = Unmarketable bulb yield; TBY = Total bulb yield; VAR = Variety; FSF = Fungicide spray frequency; Yr = Year; Y r* VAR = Interaction effect of year and variety; Yr * FSF = Interaction effect of year and fungicide spray frequency; VAR * FSF = Interaction effect of variety and fungicide spray frequency; Yr * VAR * FSF = Interaction effect of year, variety and fungicide spray frequency; * = Significance difference *at p < 0.05*; ** = Significance difference at *p < 0.01*; *** = Significance difference at *p < 0.001*; **** = Significance difference at *p < 0.0001*; and CV = Coefficient of variation (%).

Table 3. Mean values of the interaction effects of varieties and ridomil gold with different spray frequencies on severity, area under disease progress curve and disease progress rate of onion PB (*A. porri*) at Arba Minch, southwestern Ethiopia during the 2018 and 2019 main cropping seasons.

Variety	Spray frequency	Final disease severity (%)	AUDPC (%-days)	DPR (units day^{-1})
Nasik-Red	Unsprayed	54.28^{c-f}	819.28^{d-e}	0.0778^{a-d}
	One-time	44.99^{e-g}	753.75^{ef}	0.0705^{a-d}
	Two-time	41.44^{fg}	707.42^{ef}	0.0334^{de}
	Three-time	37.72^{g}	669.07^{ef}	0.0240^{de}
	Four-time	35.72^{g}	625.27^{f}	0.0110^{e}
Bombay-Red	Unsprayed	65.41^{bc}	1056.78^{b-d}	0.0982^{ab}
	One-time	57.99^{c-e}	919.38^{c-e}	0.0838^{a-c}
	Two-time	53.35^{c-f}	823.28^{d-f}	0.0746^{a-d}
	Three-time	47.32^{d-g}	747.63^{ef}	0.0538^{b-e}
	Four-time	42.21^{fg}	706.70^{ef}	0.0475^{b-e}
Adama-Red	Unsprayed	80.72^{a}	1484.20^{a}	0.1258^{a}
	One-time	73.29^{ab}	1290.33^{ab}	0.1007^{ab}
	Two-time	64.48^{bc}	1172.48^{bc}	0.0659^{b-e}
	Three-time	61.23^{b-d}	1128.71^{bc}	0.0661^{b-d}
	Four-time	58.91^{c-e}	1131.08^{bc}	0.0342^{c-e}
LSD (0.05)		14.16*	279.22***	0.0589*
CV (%)		4.45	4.22	33.75

Means in the same column followed by the same letter (s) are not significantly different from each other at p ≤ 0.05; * and ***, significant levels at p ≤ 0.05 and 0.0001, respectively; LSD, least significant difference; CV, coefficient of variation.

Previous researchers reported that the highest disease pressure resulted from the highest disease development on plots that were not managed with any combinations of crop varieties and fungicide application (Mishra *et al.*, 2014; Gajendran *et al.*, 2016; Jhala and Mali, 2017). In this regard, the weather variable during the growing seasons also played a significant role in the epidemic development of PB of onion. Thus, the highest disease pressure could be due to the prevailing relatively warm temperature and extended onion leaf wetness from frequent rain or dews during the infection period. Such a phenomenon was obvious in the study areas during the growing seasons (Table 1). Other studies also reported that heavy and frequent rainfall along with high humidity and warm temperature favor infection and rapid development of onion PB in the field (Mishra *et al.*, 2014; Rashid *et al.*, 2015). Earlier scholars also suggested that the magnitude of disease pressure is affected by the environment, host susceptibility, the pathogen aggressiveness during the cropping season (van der Plank, 1963; Campbell and Madden, 1990). Conversely, the lowest disease pressure might be due to the integration of host resistance, which was explained by the levels of resistance to PB and proper fungicide spray frequencies with good agricultural practices.

Table 4. Mean values of bulb yield parameters as affected by integration of varieties and ridomil gold with different spray frequencies against onion PB (*A. porri*) epidemics at Arba Minch, southwestern Ethiopia during the 2018 and 2019 main cropping seasons.

Variety	Spray frequency	Single bulb weight (g)	Marketable bulb yield (t ha^{-1})	Total bulb yield (t ha^{-1})
Nasik-Red	Unsprayed	53.23^{f}	9.09^{fg}	11.43^{h}
	One-time	69.12^{cd}	11.41^{ef}	12.71^{gh}
	Two-time	77.76^{b}	24.60^{d}	26.03^{d}
	Three-time	104.16^{a}	32.86^{b}	34.14^{bc}
	Four-time	98.21^{a}	33.38^{b}	34.56^{b}
Bombay-Red	Unsprayed	50.46^{fg}	12.30^{ef}	17.89^{e}
	One-time	68.52^{cd}	14.55^{e}	19.93^{e}
	Two-time	78.82^{b}	29.24^{c}	33.14^{bc}
	Three-time	96.84^{a}	38.94^{a}	43.23^{a}
	Four-time	96.74^{a}	38.08^{a}	41.37^{a}
Adama-Red	Unsprayed	43.83^{g}	5.53^{h}	15.60^{fg}
	One-time	55.09^{ef}	6.17^{gh}	15.86^{fg}
	Two-time	61.73^{de}	7.13^{gh}	15.70^{fg}
	Three-time	75.27^{bc}	23.64^{d}	30.66^{bc}
	Four-time	74.73^{bc}	23.69^{d}	30.27^{c}
LSD (0.05)		7.90*	3.40***	3.95***
CV (%)		9.32	14.86	13.89

Means in the same column followed by the same letter (s) are not significantly different from each other at $p \leq 0.05$; * and ***, significant levels at $p \leq 0.05$ and 0.0001, respectively; LSD, least significant difference; CV, coefficient of variation.

According to ANOVA, all evaluated fungicide spray frequencies in combination with Nasik-Red (moderately resistance) exhibited a significant effect on PB development on onion varieties. Similar trends were observed on the spray frequencies for the remaining onion varieties, Bombey-Red and Adama-Red. The genetic makeup and resistance of the onion variety supplemented by appropriate spray frequency of fungicide played a greater role in reducing disease pressure and the wellbeing and withstand of the plant during the growing periods. The findings in the present study are in confirmation with the findings of Binyam *et al.* (2014), Abdel-Hafez *et al.* (2015), and Getachew *et al.* (2018) who found that the moderately resistant varieties had the lowest disease pressure when supplemented with proper fungicide spray frequencies.

Yield parameters

The single bulb weight was significantly influenced by the interaction effects among fungicide spray frequencies by onion varieties (Tables 2 and 4). The maximum (104.2 g) single bulb weight was recorded from a plot of Nasik-Red variety sprayed three times with RG at the 14-day interval, which was statistically at par with the single bulb weight (98.2 g) derived from plots of the same variety sprayed four times with RG at 10-day interval and that of Bombay-Red variety with thrice (96.8 g) and fourth (96.7 g) sprays of RG at a 14-day interval. The minimum single bulb weight of 43.8 g was recorded from an unsprayed plot planted with Adama-Red variety (Table 4). The interaction effects, a combination of fungicide spray frequencies and onion varieties, showed a very highly significant difference in marketable and total bulb yields among the different treatment combinations (Tables 2 and 4). The highest (38.9 t ha^{-1}) marketable bulb yield was obtained from a plot of Bombay-Red variety sprayed three times with RG at a 14-day interval, which was statistically at par with the marketable bulb yield (38.1 t ha^{-1}) obtained from a plot of the same variety sprayed four times with RG at a 14-day interval. On the contrary, the lowest (5.5 t ha^{-1}) marketable bulb yield was obtained from an unsprayed plot planted with Adama-Red variety (Table 4). The marketable bulb yield was increased by 38.4, 31.1, and 26.3% on Adama-Red, Bombay-Red, and Nasik-Red varieties, respectively, when sprayed three times with RG at 14-day intervals over respective unsprayed plots. Similar to the marketable bulb yields, the highest total bulb yield of 43.2 t ha^{-1} was obtained from a plot of Bombay-Red variety sprayed three times with RG at a 14-day interval. However, it was statistically at par with the total bulb yield (41.4 t ha^{-1}) obtained from a plot of the same variety sprayed four times with RG at a 14-day interval. The lowest (11.4 t ha^{-1}) total bulb yield was recorded from the unsprayed plot of Nasik-Red variety that lowered total bulb yield by 68.4% compared to the plot sprayed three times with RG at a 14-day interval (Table 4).

Overall, it is evident that the integrated use of host resistance and fungicide spray frequencies played an important role in reducing PB pressure (Table 3) and increasing onion bulb yields (Table 4). This could be attributed to their favorable effects on yield contributing parameters (single bulb weight and a number of leaves per plant) while creating adverse effects for different metabolic activities (breakdown of host membrane and biochemical processes) of the pathogen that suppresses high disease pressure. Also, genetic variability played a significant role in the yield potential of the studied onion varieties. In line with this study, Hafiz (2009) and Jhala and Mali (2017) reported that the integration of host resistance and fungicide spray frequencies protected the onion varieties from high PB epidemics and increased bulb yield parameters. Savitha *et al.* (2014) and Gajendran *et al.* (2016) also reported that the integration of host resistance and fungicide spray frequencies significantly reduced

Table 5. Coefficient of correlation (r) between disease scores and yield attributes as affected by integration of onion varieties and ridomil gold with different spray frequencies at Arba Minch, southwestern Ethiopia during the 2018 and 2019 main cropping seasons.

Parameters [a]	Final PSI	AUDPC	DPR	SBW	MBY
Final PSI					
AUDPC	0.95****				
DPR	0.49*	0.45****			
SBW	- 0.71****	- 0.61****	- 0.25**		
MBY	- 0.61****	- 0.55****	- 0.21**	0.89****	
TBY	- 0.40****	- 0.30***	- 0.13^{ns}	0.79****	0.95****

[a] PSI = Percent severity index (%); AUDPC = Area under disease progress curve (%-day); DPR = Disease progress rate (Unit day^{-1}); MBY = Marketable bulb yield (t ha^{-1}); and TFY= Total fruit yield (t ha^{-1}). **** = Correlation is significant at p $\leq$ 0.0001; *** = Correlation is significant at p $\leq$ 0.001; **** = Correlation is significant at p $\leq$ 0.0001; *** = Correlation is significant at p $\leq$ 0.001; ** = Correlation is significant at p $\leq$ 0.01; * = Correlation is significant at p $\leq$ 0.05; and ^{ns} = Correlation is not significant (p > 0.05).

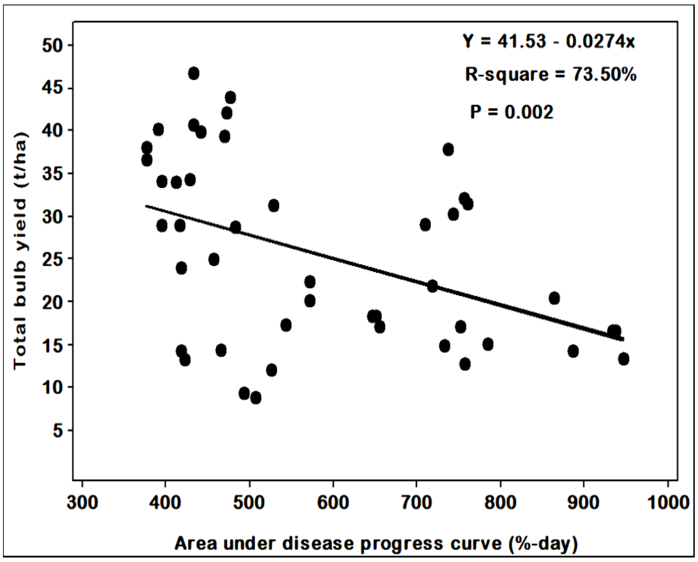

Figure 1. *Estimation of relationships between losses in bulb yield of onion and area under disease progress curve of purple blotch (Alternaria porri) at Arba Minch, southwestern Ethiopia during the 2018 and 2019 main cropping seasons.*

onion PB epidemics and gave optimum bulb yield parameters over the other treatments due to positive interactions and complementarities between them.

Association of purple blotch epidemics and bulb yield attributes

Variable levels of associations were observed among disease and yield-related parameters in both cropping seasons (Table 5). Correlation analysis results showed that there was a highly and strong positive association (r = 0.95****) and a highly significant (p < 0.0001) correlation between PSI and AUDPC. Similarly, positive and significant (p < 0.05) correlation between PSI and DPR was observed, where r = 0.49****. AUDPC also exhibited positive and significant (p < 0.0001) association with DPR, where r = 0.45****. On the other hand, SBW was very highly significantly (p < 0.0001) and negatively correlated (r = - 0.71**** and – 0.61**) with PSI and AUDPC, respectively. Marketable bulb yield was highly significantly (p < 0.0001, p < 0.0001, and p < 0.01) and negatively correlated (*r* = - 0.61****, - 0.55**** and - 0.21**) with PSI, AUDPC and DPC, respectively. Association results also exhibited negative correlation (*r* = - 0.40**** and -0.30***) and very highly significant (*p* < 0.0001 and 0.001) association between TBY and severity, and TBY and AUDPC, respectively. The correlation analysis results showed very strong positive association and very highly significant (*p* < 0.0001) association between SBW and MBY (*r* = 0.89***), SBW and TBY (*r* = 0.79***), MBY and TBY (*r* = 0.95***) (Table 5). The results observed from correlation analysis implied the disease parameters were found positive and interrelated to each other and showed the disease was developed at a faster rate on unmanaged plots than managed plots of all onion varieties with various levels of resistance and different spray frequencies of RG. Conversely, the negative association between and among the disease and yield-related parameters implied that the observed levels of PB had a significant adverse effect on bulb yields of all onion varieties. As mentioned by Guant (1995), Campbell and Madden (1990), and Agrios (2005), epidemiological parameters had been positively and strongly correlated with each other and negatively with the host growth and development. The authors stated that it is explained by the deterioration of physiological processes of the host by the pathogen, and consequently, retards the yield and yield-related traits of the crop. Previous studies also reported that disease and yield-related parameters had strong and negative correlations (Abubakar and Ado, 2015; Yadav *et al.*, 2017) and could result in considerable yield reductions. These authors also reported that growth and yield-related traits of onion had strong and positive correlations with each other during the study.

Moreover, a linear regression analysis was made to see the relationship of onion PB epidemic (AUDPC) with level of total bulb yield loss per each treatment combination. The mean values of AUDPC were used to predict the yield loss in onion. Different levels of relationships were found between AUDPC and total bulb yield, depending on the strength of the treatment combinations to manage the PB (Figure 1). It was examined that as the effect of AUDPC getting higher, the total bulb yield incurred from onion varieties becoming lower, suggesting that the higher the AUDPC the more the onion varieties susceptible to PB and the weaker of the treatment combination to manage the disease. The nearer the point to the regression line suggests that the stronger the relationship between the disease severity and the bulb yield and AUDPC and the bulb yield, concerning bulb yield loss. The coefficient of determination (R-square) suggested that 73.5% of the variation in total bulb yield loss was explained

Table 6. Partial budget analysis for the management of onion purple blotch (*A. porri*) through integration of varieties and ridomil gold with different spray frequencies at Arba Minch, southwestern Ethiopia (pooled data of the 2018 and 2019 main cropping seasons).

Variety	Spray frequency	ABY (t ha^{-1})	Gross benefit (USD ha^{-1})	Variable cost (USD ha^{-1})	Net benefit (USD ha^{-1})	MRR (%)	RYL (%)
Nasik-Red	Unsprayed	8.19	6131.21	343.49	5787.72	0.00	72.76
	One-time	10.27	7694.10	414.61	7279.49	20.70	65.82
	Two-time	22.15	16592.08	474.50	16117.58	77.86	26.28
	Three-time	29.58	22163.23	534.39	21628.84	81.94	1.53
	Four-time	30.04	22508.19	594.28	21913.91	63.50	0.00
Bombay-Red	Unsprayed	11.07	8294.89	343.49	7951.40	0.00	68.41
	One-time	13.10	9811.64	414.61	9397.04	20.07	62.63
	Two-time	26.31	19714.01	474.50	19239.51	85.09	24.93
	Three-time	35.05	26259.02	534.39	25724.63	91.94	0.00
	Four-time	34.27	25677.04	2895.64	22781.40	5.73	2.22
Adama-Red	Unsprayed	4.97	3725.79	343.49	3382.30	0.00	76.68
	One-time	5.56	4159.97	414.61	3745.36	2.21	73.96
	Two-time	6.42	4808.41	474.50	4333.92	3.69	69.90
	Three-time	21.28	15943.63	534.39	15409.24	36.18	0.19
	Four-time	21.32	15974.12	5197.00	10777.12	1.42	0.00

ABY, Adjusted bulb yield; USD, United States Dollar; MRR, Marginal rate of return; and RYL, Relative yield loss. The mean price of onion bulb per tonnes was USD 740.0 at the time of bulb selling for the 2018 and 2019 cropping seasons, at the exchange rate of 1.0 USD = 31.41 Ethiopian Birr.

by AUDPC during the cropping season. That is, the contribution of PB pressure in bulb yield reduction was higher than other factors. The negative sign in the regression equations implied that the opposite relationship of AUDPC and bulb yield, which means the estimated levels of disease have a significant adverse effect on bulb yield of onion varieties. The regression graph also exhibited that for every one-unit progression of AUDPC on average there was 0.0274-unit loss in bulb yield of onion during the cropping seasons (Figure 1). Campbell and Madden (1990), Guant (1995) and Agrios (2005) mentioned plant diseases had a strong relationship with losses of growth and yield-related parameters of the crop in their every portion of disease development.

Economic feasibility and yield loss analysis

In this regard, significant variations for the net benefit and the marginal rate of return were observed among the evaluated treatment combinations (Table 6). The highest mean (USD 25,724.6 ha^{-1}) net benefit was obtained from a combination of Bombay-Red variety with three times RG application at a 14-day interval. The lowest mean (USD 3,382.3 ha^{-1}) was obtained from an unsprayed control plot of the Adama-Red variety. The high net benefit from the abovementioned treatments could be attributed to high yield, and the low net benefit was attributed to low yield. The use of RG sprays at different frequencies gave a higher marginal rate of returns on all the three onion varieties over respective unsprayed plots. From the economic point of view, it was apparent that the use of Bombay-Red variety along with three-time spray frequencies of RG at a 14-day interval was the most profitable over all the other treatments. Gupta and Gupta (2013) and Gajendran *et al*. (2016) reported similar results on the profitability of onion integrated disease management approaches in India. Bulb yield losses were varied among plots sprayed with different spray frequencies on each onion variety (Table 6). The highest mean bulb yield losses of 68.4, 72.8, and 76.7% were computed from unsprayed plots of Bombey-Red, Nasik-Red, and Adama-Red varieties, respectively, compared to the maximum protected plots of the respective varieties. The losses in bulb yield could be attributed to the severe infection of PB at a full-grown stage of the plant, which progressively killed the leaves and reduced the total leaf area index of the plants. Under severe disease pressure, onion plants are almost devoid of leaves due to the drying of diseased leaves leading to significant yield losses. Yield losses of about 50-100% due to PB have been reported in onion crops in different parts of the world (Shahanaz *et al*., 2007; Shahanaz *et al*., 2013; Yadav *et al*., 2013; Mishra *et al*., 2014).

Conclusions and recommendations

During the growing periods, the planting of onion was seriously constrained by purple blotch. This could be due to favorable weather variables and various environmental factors that aggravate the disease. The experimental results of the current study indicated that the use of host resistance along with fungicide spray frequencies had pronounced effects in reducing onion PB epidemics and increasing bulb yield parameters and economic returns. Integrating the Bombay-Red variety with three and four-time spray frequencies of RG at a 14-day interval was proved to be the most effective treatment in reducing PB epidemics and increasing onion bulb yield parameters. Thus, Integration of Bombay-Red variety and three-time spray frequency of RG at a 14-day interval could be recommended to farmers in the study areas and elsewhere with similar agro-ecologies to reduce PB epidemics and optimize onion bulb production and productivity in the country. However, more such studies need to be conducted at various agro-ecologies for at least three consecutives to come up with a more comprehensive recommendation and to enhance onion bulb production and productivity in Ethiopia.

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Conflicts of interest

The authors declare that they have no conflict of interest

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