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ORIGINAL RESEARCH ARTICLE

Treatments of common bean seeds (*Phaseolus vulgaris* L.) with insecticides for managing bean stem maggot [*Ophiomyia* spp. (Tryon) (Diptera: Agromyzidae)] in SNNPR, Ethiopia

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ABSTRACT

Bean stem maggot (BSM) is one of the main threatening insect pests that cause significant bean plant mortalities and associated grain yield reductions. The field research work was conducted for three successive years (2018 - 2020) in Burji, southern Ethiopia, to decide the effects of insecticide seed treatment in reducing bean plant mortality and severity/damage caused by BSM and enhancing the grain yield of common bean. The research contained seven treatments and was arrayed in a randomized complete block design with three replicas. In 2018, the lowest seedling mortality (SM) (11.78%) and matured plant mortality (MPM) (21.89%) were registered from Diazinone-treated plots. However, it was not statistically varied from Thiram + Carbofuran (13.33% for SM and 22.22% for MPM). Bean seeds treated with Diazinon considerably reduced initial percent severity index (PSI_i) by 79.79% and final percent severity index (PSI_f) by 79.98%, followed by Thiram + Carbofuran with PSI_i by 55.67% and PSI_f by 76.98% over untreated plots. Lowest total number of larvae (TNL) (15.00 and 22.67) and pupae (TNP) (11.00 and 13.67) were noted from Diazinone and Thiram + Carbofuran, in that order. Comparable fashions for SM, MPM, PSI_i, PSI_f, TNL, and TNP were encountered for these insecticides in 2019 and 2020. Grain yields of 2229.37 and 2213.39 kg ha^{-1} (in 2018) and 2648.29 and 2503.20 kg ha^{-1} (in 2020) were attained from Diazinone and Thiram + Carbofuran, respectively. Monetary analysis also affirmed that Diazinone (\$126,429.52 ha^{-1}) and Thiram + Carbofuran (\$122,241.67 ha^{-1}) led to a higher monitory advantage over untreated control and other insecticides. Therefore, Diazinon and Thiram + Carbofuran, one of them as an alternative option, could be advised as a seed treatment to the growers for efficient control of BSM and optimization of grain yield.

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INTRODUCTION

Pulse crops are the most important legume crops allowing for a staple diet for the millions of populations in the world, including Ethiopia (Ali *et al*., 2006; CSA, 2018; FAOSTAT, 2018). Amongst pulse crops, the common bean (*Phaseolus vulgaris* L.) is the world's second major grain legume that is consumed for its edible seeds and pods after soybean (Celmeli *et al*., 2018; FAOSTAT, 2018; USDA, 2018). The crop is cultivated in subtropical and tropical regions, most often by smallholders, and constitutes a major staple crop in both developing and developed countries (FAOSTAT, 2018; Snapp *et al*., 2019). Global production of common bean showed that a total cultivated area of more than 30 million ha and grain yield of more than 35 million tons had been reported during the 2018 cropping year (FAOSTAT, 2018). The crop is mainly used for human consumption and is one of the significant grain legumes in the human diet at a global level. The crop nourishes nutrients for more than 300 million people in parts of Eastern Africa and Latin America, representing 65% of total protein consumed, 32% of energy, and a major source of micronutrients and folic acid (Petry *et al*., 2015).

In Ethiopia, the common bean is cultivated as a field crop for a very long time and is the most important food legume produced in the country (particularly in Southern and Eastern parts of Ethiopia) and constitutes a significant part of the human diet (Fininsa, 2003; Buruchara *et al*., 2010; CSA, 2018). During the 2018 cropping year, the common bean was cultivated on more than 500,000 hectares of land with the production of more than one million tons of grain yields in Ethiopia. In Southern Ethiopia, the crop is produced on more than 100,000 hectares of land and contributes more than 400,000 tons of grain yields (CSA, 2018). However, common bean production is hampered by various biotic and abiotic factors and those related to crop management (Fininsa, 2003; Gudero and Terefe, 2018). Due to this, the average productivity of common bean is far below both the region (1.62 t ha^{-1}) and national (1.69 t ha^{-1}) (CSA, 2018) levels than the attainable yield (3.00 t ha^{-1}) (Shumi, 2018). Of the biotic factors, several plant pathogens and plant-insect pests played a significant role in limiting the production and productivity of the common bean.

Major insect pests that influence common beans in the field include bean fly (*Ophiomyia* spp., Tryon), bean aphid (*Aphis fabae* Scop.), ootheca (*Ootheca bennigseni*), legume pod borer, (*Maruca testulalis* or *Vitrata* Fab.), flower bud thrips (*Megalurothrips sjostedti* Tryon) as well as a host of plant-sucking bugs, which include *Clavigralla tomentosicollis* Stal., *Anoplocnemis curvipes* Fab., *Aspavia armigera* Fab., *Nezera viridula*, *Riptortus dentipes*, leafhoppers (*Empoasca dolichi* and *E. lybica*) and whiteflies (*Bemisia tabacci*) (Abate *et al*., 2011; Mwanauta *et al*., 2015; Ogecha *et al*., 2019) and foliage beetle species (CBI, 1987; Minja, 2005). Bean fly, bean aphid, legume pod borer, flower bud thrips, and Mexican bean beetle are the most important insect pests of common bean in major producing areas of Ethiopia (Abate *et al*., 2011; MoANR and EATA, 2018). Amongst bean insect pests, bean fly (*Ophiomyia* spp. (Tryon) (Diptera: Agromyzidae), also cognized with the bean stem maggot (BSM), is the most important and annihilative insect pests of common bean in major producing countries of the world, including Ethiopia (Abate *et al*., 2011; MoANR and EATA, 2018; Ogecha *et al*., 2019). The incidence and severity/damage extent of BSM species is influenced by one or a combination of environmental factors, altitude, topographic features, vegetation cover, sowing date, growth stage, soil fertility, and type of the host plant (Nderitu and Buruchara, 1997; Songa and Ampofo, 1999). Among BSM species, *O. phaseoli* and *O. centrosematis* are more prevalent in warmer areas, mostly in the south and south western part of the country at the elevation of <1800 m above sea level in Ethiopia (Mulatwa *et al*., 2017).

The adult bean fly oviposits in leaves, stems, and hypocotyl of young bean seedlings. Emerging bean fly maggots mine their way to the root zone where pupation takes place and where feeding becomes concentrated between the woody stem and the epidermal tissue (Ampofo and Massomo, 1998; Ochilo and Nyamasyo, 2010). This mode of feeding interferes with nutrient transport and creates avenues for the entry of pathogens (Leteourneau *et al*., 1992; Ampofo and Massomo, 1998; Kamneria, 2007). The damage caused by BSM is more problematic during the seedling stage of the bean plant, followed by matured bean plants. Bean stem maggots attack the bean plant at the starting of the unfolding of the first pair of bean leaves, and they start to attack as other new leaves unfold (Odendo *et al*., 2005). The insect can cause a yield loss of 80 to 100% in the total production of common bean (Ochilo and Nyamasyo, 2010; Munyasa, 2013). In Ethiopia, common bean yield loss due to BSM was estimated to be 30 to 40% of the total production (Abate *et al*., 2011; MoANR and EATA, 2018). Under severe conditions, the BSM could cause 70 to 100% losses in grain yield, and the magnitude of loss depends on the stage of crop growth, susceptibility of the cultivars, and favorable environmental conditions for the insect (MoANR and EATA, 2018). The periodic occurrences caused significant yield losses in the study areas (Burji district). Measures to reduce yield losses are of great importance in controlling BSM and sustaining common bean production and productivity.

Several BSM control measures have been reported for the last three decades, including cultural control practices such as adjustment of planting date (Muleke *et al*., 2013), crop rotation, and associated cropping (Abate and Ampofo, 1996; Amoabeng *et al*., 2014), earthing or hilling up soil around the stem of seedlings (Forbes *et al*., 2009), mulching and fertilizer applications (Gogo *et al*., 2012), cultivation of resistant crop varieties (Tsedeke, 1990; Ampofo, 1993; Ampofo and Massomo, 1998; Kiptoo *et al*., 2016) and use of seed dressing insecticides (Abate, 1991; Williamson *et al*., 2008; Uburyo, 2016). In this regard, the inclination of the year after year production of common bean in Ethiopia asked for a BSM control strategy mainly towards the use of insecticides either as a seed treatment or foliar application since cultural approaches could merely control BSM to a limited extent. In the country, Mulatwa *et al.* (2017) reported that the dominant seed dressing insecticide available for the last two decades in BSM control was Imidalm 70 WS [Imidaclopride 700 gm/kg].

However, the growers suggested that the BSM resist this insecticide and did not defend their fields from BSM infestation, according to the annual report of the Bureau of Agriculture and Natural Resource in the district (Burji) and the Ministry of Agriculture and Natural Resource in 2017. The recurrent use of the same insecticide for several years under extensive bean production might favor the development of resistance by the insect pests and a tendency of loss in efficacy. Research reports supported that the unwise use of agrochemicals had led to the development of resistance by the pest population, eliminations of non-target organisms, pollution of the environment, poisoning of millions of agricultural workers, and about 300,000 deaths each year globally (Green *et al*., 1990; Gunnell *et al*., 2007). To prevent the bean yield loss due to BSM in the study areas and the country as well, farmers use indiscriminately whatever insecticides they got in their areas with frequent foliar sprays without considering their efficacy up to harvesting of the grains. However, frequent sprays are time and labor consuming, increase the cost of production, lead to secondary pest problems, insecticide resistance buildup, undesirable accumulation of pesticide residue in the produce, and pesticide poisoning (Seif *et al*., 2001; Nderitu *et al*., 2008; Oesterlund *et al*., 2014). To this, the utilization of seed dressing chemicals could minimize the recurring sprays by safe guarding the crop for up to nine weeks during growing period (Bethke and Redak, 1997; Wyman and Chapman, 2004). Therefore, devising suitable control measures and information regarding factors that influence the intensity of BSM is a prerequisite for the study areas as well as the country.

In Ethiopia, most of the insecticides used were registered for foliar application of other insect pests of other crops, including common bean. However, no research work has been reported on the use of these insecticides as a seed treatment for the control of BSM on common beans in the study areas in particular and the country in general. Therefore, there is a need for an immediate response to produce empirical field data concerning the reasonable use of these insecticides as a seed treatment for the control of BSM since the severe death of bean plants/damage caused by BSM is more serious during the seedling stage of the bean plant. Economically feasible and efficient insecticide seed treatment(s) is/are well preferred by the farming communities, and the approach could help to produce a profitable crop. This paper reported the results of three years (2018-2020) field experiment conducted in Burji, Southern Nation Nationality and Peoples' Regional state (SNNPRs), Ethiopia. The objective was to determine (i) the effects of insecticide seed treatments in reducing bean plant mortality and severity/damage caused by BSM under field conditions and (ii) growth and yield-related traits of common bean.

MATERIALS AND METHODS

Experimental site

The experiment was carried out on a farmer's field at Denibecho *kebele* (peasant association village) in Burji, SNNPRs, Ethiopia, during the 2018, 2019, and 2020 main cropping seasons (August to December). The areas are among the major common bean-growing and a hot spot for BSM. The site is geographically positioned at 05° 30' 30.9" N latitude and 037°54' 01.7" E longitude with an altitude of 1680 meters above sea level. The agroecological conditions of the area are characterized by a bimodal rainfall pattern, short-rainy season (March to May), and main-rainy season (July to November). Mean monthly minimum and maximum temperatures, total rainfall, and relative humidity conditions of the study areas for the three growing seasons are displayed in Figure 1. The meteorological data were obtained from the Ethiopian Meteorological Agency at Hawassa Branch. The soils of the study site are characterized by neutral pH (7.20) with low organic matter contents (1.11 to 3.96%) and sandy-loam texture (MoANR and EATA, 2016). The landforms of the experimental site are characterized by riffling and rolling to regular plateaus, scattered moderate to high hills, steeply to regular topographic gradients, low to dense vegetation, and several river gorges.

Treatment and experimental design

The study was conducted in the field where the area was known for high BSM infestation at the begging of the study, the plots were subjected to natural bean stem maggot infestation. The susceptible common bean cultivar (Nasir) was used during the three growing seasons. Seeds of common bean cultivar were obtained from Hawassa agricultural research centre, Southern Agricultural Research Institute. Six insecticides were used as a seed treatment. The insecticide includes Agro-Thoate 40% SC, Dynamic 400 FS, Diazol 60 EC, Ethiosulfan 25% ULV, Karate 5% EC, and Profit 72% EC. Details of insecticide regarding chemical name, the active ingredient, mode of action, and rates used were depicted in Table 1. The experimental treatments consisted of six insecticides and an untreated control plot. A total of seven treatments were designed and laid out in a randomized complete block design with three replications. Each treatment was assigned at random to experimental plots within a block. The untreated control plot was aimed to allow maximum BSM infestation and intensity for an easy trace of treatment effects on the study parameters.

Experimental procedures

The experiment was set up with a gross area of 12.5 m × 17.2 m = 215 m^2. A unit plot size was 2.0 m width × 1.6 m length = 3.2 m^2. The plot consists of six rows with an inter-row of 0.40 m and an intra-row of 0.10 m. Each of the adjacent plots and replications was spaced at 1 and 1.5 m, respectively. Seed sowing was carried out on 20th, 22th, and 27th of August 2018, 2019, and 2020 cropping seasons, respectively. The seeds were sown at a soil depth of 4 cm. Both treated and untreated control plots were sown within 24 hrs. Each row within the experimental plots consisted of 16 plants, and a total of 80 plants per plot were comprised. Nitrogen, Phosphorus, and Sulfur blended fertilizer at the rate of 121 kg ha^{-1} was applied at the time of sow-

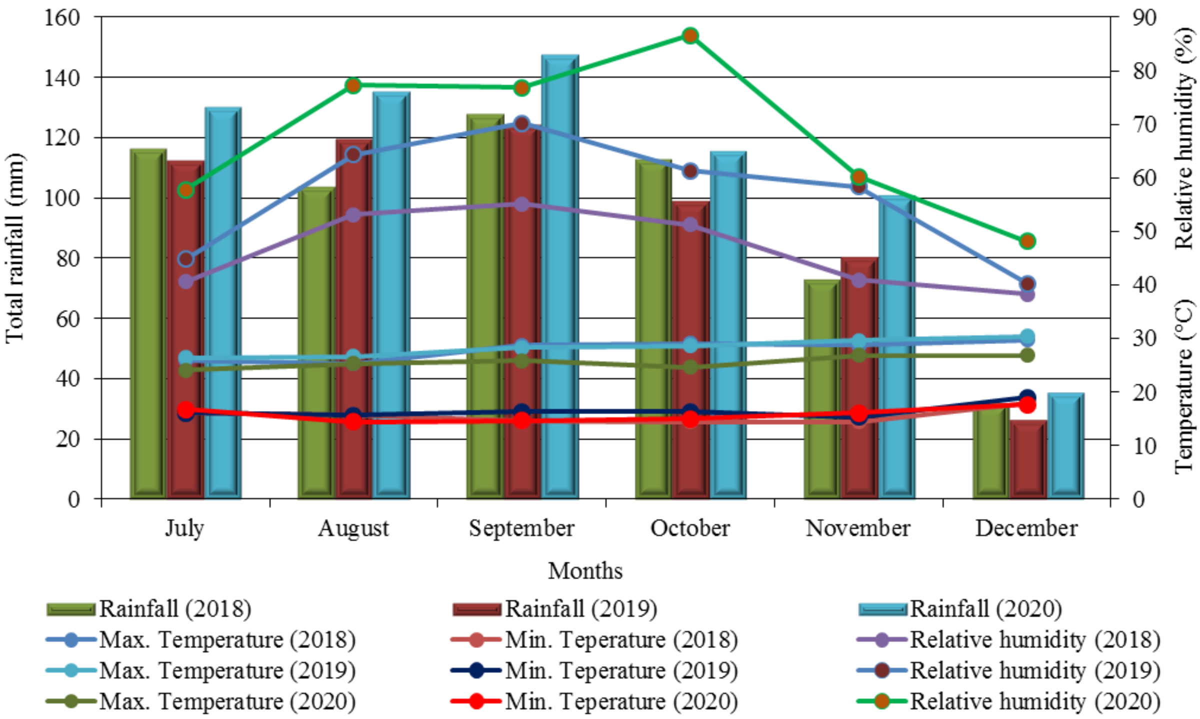

Figure 1. Monthly mean minimum and maximum temperature, relative humidity and rainfall during the 2018, 2019 and 2020 cropping seasons in Burji, Southern Ethiopia.
Max. and Min. = Stands for maximum and minimum temperatures, respectively. The meteorological data were obtained from National Meteorological Agency at Hawassa Branch (2021).

Table 1. Details of insecticide seed treatments and rates used in the study during the 2018, 2019 and 2020 main cropping seasons.

Trade name	Chemical name	Active ingredient	Mode of action	Application rate	Supplier
Agro-Thoate 40% SC	Dimethoate	Dimethoate 400 g/L	Systemic	15 ml kg^{-1} seed	Chemtrade International
Dynamic 400 FS	Thiram + Carbofuran	Thiram 20% WV + Carbofuran 20% WV	Contact + Systemic	2.5 ml kg^{-1} seed	Lions International Trading (Pvt) Co.
Diazol 60 EC	Diazinon	Diazinon 60% EC	Contact	45 ml kg^{-1} seed	General Chemical & Trading Pvt. Co
Ethiosulfan 25% ULV	Endosulfan	Ethiosulfan 250 g/L	Contact	20 ml kg^{-1} seed	Adami-Tulu Pesticides Processing Factory
Karate 5% EC	Lambda-cyhalothrin	Lambda-cyhalothrin 50 g/L	Contact	15 ml kg^{-1} seed	Syngenta Agro-services Ag. Ethiopia
Profit 72% EC	Profenofos	Profenofos 720 g/L	Contact	30 ml kg^{-1} seed	Lions International Trading (Pvt) Co.

Source: Data were sourced and organized from MoA (2015 and 2018) and products package booklet.

ing. All other necessary field management practices were executed uniformly for all treatments as per the recommendations (MoANR and EATA, 2018). Emabendox 90 SC (a.i. = Emamectin benzoate + Indoxcarb) at the rate of 2.0 L ha^{-1} diluted with 300 L water was applied for control of legume pod borer, including the control plots. Also, ACE 750 SP (a.i. = acephate) at the rate of 1.0 L ha^{-1} was homogeneously sprayed to all plots for the control of bean aphids, whiteflies, and flower bud thrips. A total of two sprays for each of the two insecticides were performed per cropping year during the growing periods.

Data collection and analysis

Bean stem maggot monitoring

The effects of BSM assessment were started from 20 (in 2018), 22 (in 2019), and 26 (in 2020) days after emergence (DAE) to determine percent seedling mortality (SM), matured plant mortality (MPM), severity/damage, the total number of larvae (TNL), and the total number of pupae (TNP). The assessment was ceased with 50% of the bean plant per plot attained physiologically matured. From central rows of each plot, 15 systematically selected bean plants were used for severity assessment at 10 days intervals. A total of six assessments were made per season. The first three assessment dates were constituted under seedling mortality, which was started from DAE to third trifoliate leaves fully open and the buds on the lower nodes produce branches (20 to 40-DAE in 2018 and 2019, and 26 to 46 in 2020). While the other three assessments were considered under the bean plants assessed at pre-flowering to pod filling (50 to 72-DAE in 2018 and 2019, and 56 to 76 in 2020), which was considered as a matured plant. The bean plants were dissected at the base where the pupae lodge and, the pupae were removed and kept in a clean dry cloth. Ten pupae were randomly collected from damaged plants each season on every assessment date and reared to adults to confirm accurate identification as BSM. The collected pupae color was a look-alike brown color. These pupae developed into flies which started their life cycle again by laying eggs on the bean leaves, which were developed in a pot under the greenhouse at Arba Minch Plant Protection Clinic. The eggs hatched into larvae which channeled through the stem to the base where they pupate. Bean plants containing larvae and pupae, as well as those without larvae and pupae but clearly damaged by BSM, were recorded as dead and removed from the experimental plots.

The TNL and TNP were determined from the total sum of the larvae and pupae during the growing periods. Percent plant mortality was rated as the mean percentage of the number of counting dead plants per total number of plants considered within the plot. BSM severity was rated using a 1 to 9 rating scale described by van Schoonhoven and Pastor-Corrales (1987) where 1 = infested plants are as vigorous as un-infested plants, no considerable damage observed, 3 = infested plants with slight growth delay, 5 = infested plants with considerable growth delay, 7 = infested plants with severe growth delay, and 9 = five infested plants are dead or almost dead. Total numbers of bean plants infested by BSM were considered to determine the percent plant mortality and severity. BSM severity scores were transformed into a percentage severity index (PSI) for analysis. This conversion of the rated scale has been adopted from the work of Wheeler (1969).

$$\text{Percent severity index} = \frac{\text{Sum of numerical ratings}}{\text{Number of plants scored x maximum score on scale}} \text{ x } 100$$

Agronomic parameters and yield loss assessment

Data on growth and yield-related parameters, including plant height (PH), stand count per plot (SC), number of productive pods per plant (NPP), hundred seed weight (HSW), and grain yields (GY) were collected from the four central rows, carried out during 90% bean attain physiologically matured and harvesting time. Concerning growth and yield-related parameters, data were considered only for the 2018 and 2020 cropping years. The reason was the loss of the experimental plots due to animal damage at a late stage of the crop, prior to harvesting, in the 2019 cropping year. Harvesting was carried out on 125 and 130-days after planting for the 2018 and 2020 cropping years, respectively. Plant height (cm) was assessed from the ground to the tip of the plant during physiological maturity. Stand count per plant and NPP were assessed through the counting of the stand bean plants and productive pods within the plots during harvesting. Five bean plants were randomly selected from central rows to assess the NPP. Grain yield (g) was determined by weighing grain yields obtained from each plot. The harvested GY was corrected to a storable moisture content of 12% (Taran *et al.*, 1998) and converted to kg ha^{-1} for analysis. Hundred seed weight (g) was determined by weighing 100 randomly sampled grains at 12% moisture content acquired from the total harvested grains of each plot. On the other hand, yield losses were determined to examine the effect of the BSM damage on the test common bean cultivars. Thus, the relative yield loss for each treatment was assessed as the percentage yield reduction of less protected plots as compared to maximum protected plots following the procedure suggested by Robert and James (1991).

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

Where, Y_{bt} = mean yield of the best treatment in the experiment (maximum protected plot) and Y_{lt} = mean yield of the other treatments (low to medium protected plots). Moreover, the relative yield for each treatment was determined as the ratio of the yield obtained from individual treatment compared with the maximum yield obtained under treatment considered and multiplied by 100%.

Data analysis

Seedling mortality, MPM, PSI, TNL, TNP, PH, SC, NPP, HSW, and GY data were subjected to analysis of variance (ANOVA) to determine the treatment effects. The data were analyzed using the general linear model procedure of SAS version 9.4 (SAS, 2014). The treatment means were separated using Fisher protected least significance difference (LSD) test at 5% probability level (Gomez and Gomez, 1984). Correlation analyses were used to examine associations between and among the study parameters. Pearson correlation coefficients (r) were used as indices for the strength of the associations. The three seasons were considered as different environments because of the heterogeneity of variances of data, and Bartlett's chi-square test was tested for the error variances of the study parameters (Gomez and Gomez, 1984). Thus, separate data analyses were performed for each season due to the heterogeneity of the data ($Pr < \chi^2$) between and among the seasons.

Partial budget analysis

Partial budget analysis was achieved following the procedures described by CIMMYT (1988). This was employed to appraise the cost-effectiveness of insecticide seed treatment used for BSM control. Before employing partial budget analysis, statistical analysis was performed on GY to relate the mean yield between treatment means. To perform the partial budget analysis, pooled data obtained from the two seasons were used. Partial budget analysis was made based on the current cost of insecticide, labor, and market price of grain yield of common bean. Net benefit was determined from the difference between the sell revenue (multiplying of unit market price and grain yield) and the total variable input costs. Variable costs were comprised of costs of fungicide, knapsack sprayer, and labor. The marginal rate of return was determined as the ratio of the difference in net benefit and total variable input cost. During partial budget analysis, economic data were considered for the 2018 and 2020 cropping years excluding the 2019 cropping year data due to data unavailability for GY.

During marketing, the price of GY was \$0.047 (in 2018) and 0.068

Table 2. Combined analysis of variance for mean squares of the study parameters at Denibecho in Burji, Southern Ethiopia, during the 2018, 2019 and 2020 main cropping seasons.

SV	DF	SM	MPM	PSI_i	PSI_f	TNL	TNP
Block/within year/	4	17.66^{ns}	7.23^{ns}	23.34^{ns}	5.58^{ns}	101.76^{ns}	141.54*
Year	2	856.32****	590.94***	475.45****	9.01*	665.19****	44.49^{ns}
IST	6	736.77****	2291.56****	682.40****	553.09****	1737.77****	1347.92****
Year * IST	6	5.99^{ns}	66.99^{ns}	39.69*	11.45*	21.45^{ns}	23.49^{ns}
Pooled error	72	22.77	64.87	22.54	5.50	46.60	36.59
Pooled F-value		13.62****	12.13****	12.25****	31.57****	12.89****	11.56****
Grand mean		21.15	33.76	20.24	16.14	29.86	23.60
CV (%)		22.56	23.86	23.46	14.54	22.86	25.63

Table 2. *Contd.....*

SV	DF	PH (cm)	SC	NPP	HSW (g)	GY (kg ha^{-1})
Block/within year/	4	102.99^{ns}	3.43^{ns}	121.66****	14.29^{ns}	180785.76*
Year	1	1398.44****	77.36***	13.29^{ns}	69.51***	124151.58*
IST	6	356.49****	676.30****	179.52****	71.40****	3604779.59****
Year * IST	6	3.23^{ns}	20.75^{ns}	2.42^{ns}	1.87^{ns}	85563.69^{ns}
Pooled error	48	24.73	18.71	16.41	4.74	51289.43
Pooled F-value		11.06****	17.51****	5.18****	8.27****	33.39****
Grand mean		43.72	41.64	18.72	28.18	1419.12
CV (%)		20.45	10.39	21.64	7.72	15.96

SV = Source of variation; DF = Degree of freedom; SM = Seedling bean plant mortality between 20 to 40-DAE (in 2018 and 2019) and 26 to 46-DAE (in 2020); MPM = Matured plant mortality between 50 to 72-DAE (in 2018 and 2019) and 56 to 76-DAE (in 2020); PSI_i = Percent severity index at initial assessment dates during seedling stage of the plants (20 (in 2018), 22 (in 2019) and 26-DAE (in 2020); PSI_f = Percent severity index at final assessment dates during 50% plants per plot attained physiologically matured (70, 72 and 76-DAE in 2018, 2019, and 2020 cropping seasons, respectively); IST = Insecticide seed treatment; TNL = Total number of larvae during the growing period; TNP = Total number of pupae during the growing period; PH = Plant height measured in cm; SC = Stand count in number; NPP = Number of productive pods per plant; HSW = Hundred seed weight measured in gram; GY = Grain yield measured in kg ha^{-1}; **** = Significantly different at $P \leq 0.0001$; *** = Significantly different at $P \leq 0.001$; ** = Significantly different at $P \leq 0.01$; * = Significantly different at $P \leq 0.05$; ns = Not significant ($P > 0.05$); CV = Coefficient of variation (%).

(in 2020) kg^{-1} at Burji, at the exchange rate of 1$ = Ethiopian birr 27.73 (2018) and 38.11 (2020). The costs of insecticides such as Diazinon ($22.18 and 23.63 L^{-1}), Endosulfan ($33.90 and 31.49 L^{-1}), Thiram + Carbofuran ($34.92 and 38.58 L^{-1}), Lambda-cyhalothrin ($38.95 and 39.36 L^{-1}), Profenofos ($57.34 and 55.10 L^{-1}), and Dimethoate ($61.67 and 53.14 L^{-1}) were recorded at the time of purchasing during the 2018 and 2020 cropping seasons, respectively. In addition, the cost of a knapsack sprayer per unit item was $54.09. Based on the prevailing wage rates in the locality, the cost of labor per man-day^{-1} was $1.80 and 1.57 during the 2018 and 2020 cropping seasons, respectively. All the costs were changed to hectares for the proposed analysis.

RESULTS AND DISCUSSION

Analysis of variance

The combined analysis of variance for the study parameters showed significant variations among the study years (Table 2). Various levels of significant (P < 0.0001 to 0.05) variations were observed between the study years for the mean square of SM, MPM, PSI_i, PSI_f, and TNL for the three years and PH, SC, HSW, and GY for the two years (2018 and 2020) due to the use of insecticide seed treatments. No significant differences were observed among (BSM monitoring) and between (yield traits) the study years for the mean square of TNP and NPP parameters (Table 2). The mean squares showed highly significant (P < 0.0001) variations among and between insecticide seed treatments for SM, MPM, initial and final PSI, TNL, TNP, PH, SC, NPP, HSW, and GY parameters. However, the combined ANOVA for the mean square values indicated that no interaction (P > 0.05) effects among and between the study years and insecticide seed treatments were observed for all study parameters, except for PSI_i and PSI_f (Table 2). The higher or lower difference for the mean square values of all the study parameters might be due to the effects of evaluated treatments and the years. That means insecticidal seed treatments responded differently in reducing BSM intensity in the three years, and consequently, enhancing growth and yield-related parameters in the two years.

Bean stem maggot monitoring

The effects of insecticide seed treatment exhibited significant (P < 0.0001) differences in BSM intensity and number of larvae and pupae (Figure 2). Results showed that the mean SM (26.77, 22.48, and 14.21%), MPM (65.26, 34.00, and 28.33%), and PSI_f (16.85, 15.98, and 15.57%) were higher in 2019, followed by 2018 and 2020, respectively. The total number of larvae was highest in 2018 (34.29%) than in 2019 (31.76%) and 2020 (23.52%). The mean highest PSI_i (24.46, 21.17, and 15.08%) was higher in 2020, followed by 2019 and 2018, respectively. However, the mean TNP indices as high as 22.52, 25.00, and 23.71% were noted in 2018, 2019, and 2020, respectively (Figure 2).

Analysis of variance revealed that the mean highest SM of 38.33, 42.71, and 27.78% were recorded from untreated control plots in 2018, 2019, and 2020, respectively. However, it

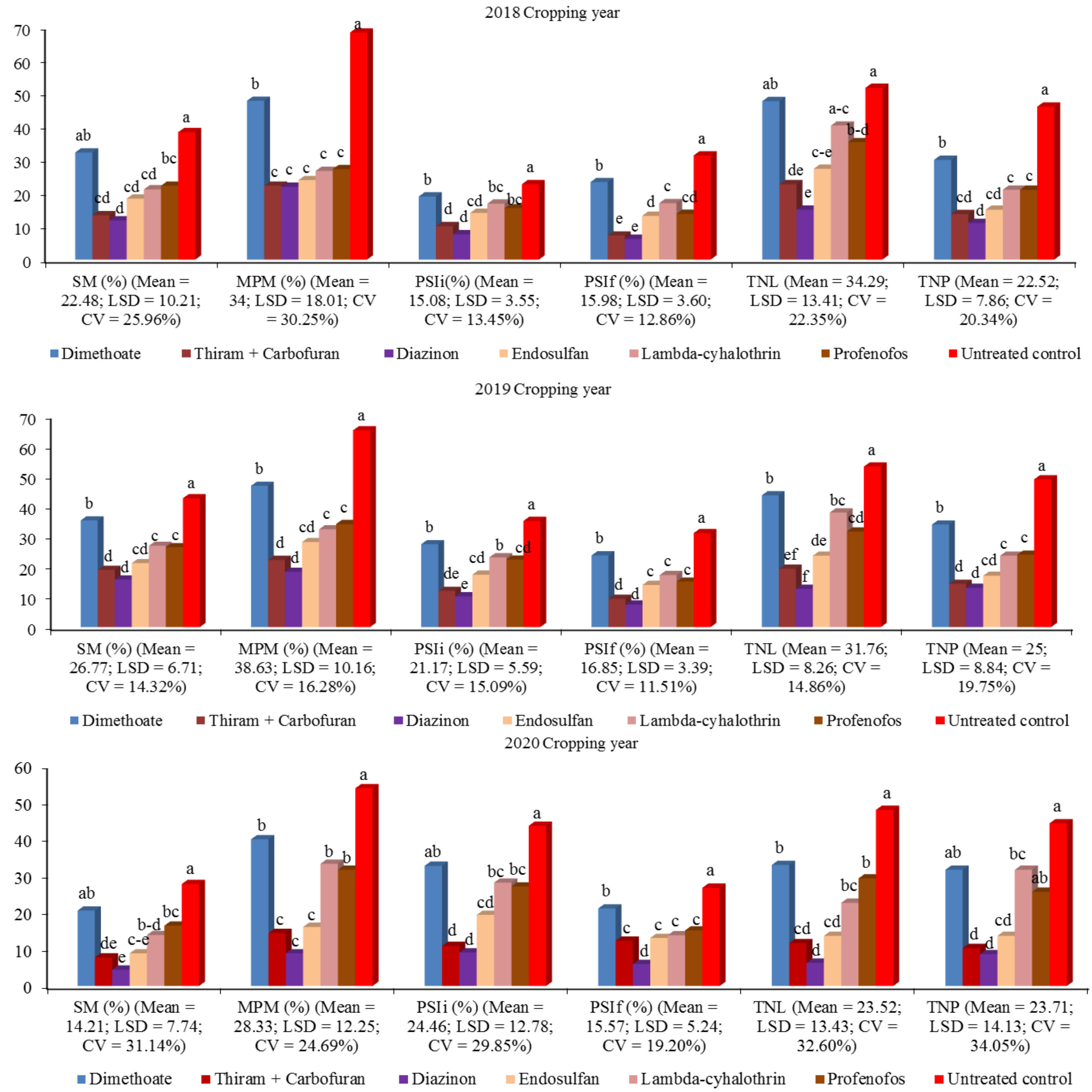

Figure 2. *Mean performance of insecticidal seed treatments in the reducing bean plant mortality, number of larvae and pupae and damage caused by bean stem maggot at Denibecho in Burji, Southern Ethiopia, during the 2018, 2019 and 2020 main cropping seasons.*
Means followed by the same letter within the column are not significantly different at $p < 0.05$. SM = Seedling bean plant mortality between 20 to 40-DAE (in 2018 and 2019) and 26 to 46-DAE (in 2020); MPM = Matured plant mortality between 50 to 72-DAE (in 2018 and 2019) and 56 to 76-DAE (in 2020); PSI_i = Percent severity index at initial assessment dates during seedling stage of the plants (20 (in 2018), 22 (in 2019) and 26-DAE (in 2020); PSI_f = Percent severity index at final assessment dates during 50% plants per plot attained physiologically matured (70, 72 and 76-DAE in 2018, 2019, and 2020 cropping seasons, respectively); TNL = Total number of larvae during the growing period; TNP = Total number of pupae during the growing period; LSD = Least significant difference at 5% probability level; and CV = Coefficient of variation (%).

was not statistically different from Dimethoate in 2018 (32.22%) and 2020 (20.56%). The mean lowest SM (11.78, 15.78, and 4.44%) was observed from bean cultivars treated with Diazinon in 2018, 2019, and 2020, respectively. However, it was statistically on par with Thiram + Carbofuran (13.33%), Endosulfan (18.33%), and Lambda-cyhalothrin (21.11%) in 2018, Thiram + Carbofuran (18.86%) and Endosulfan (21.19%) in 2019 and Thiram + Carbofuran (7.78%) in 2020 for the respective years. Also, the mean highest MPM of 68.33, 65.26, and 53.89% were noted from untreated control plots in 2018, 2019, and 2020, respectively. The mean lowest MPM was recorded from bean cultivars treated with Diazinon in 2018 (21.89%), 2019 (18.32%), and 2020 (8.89%). However, it was not statistically different from Thiram + Carbofuran (22.22%), Endosulfan (23.89%), Lambda-cyhalothrin (26.67%), and Profenofos (27.22%) in 2018, Thiram + Carbofuran (22.26%) and Endosulfan (28.19%) in 2019, and Thiram + Carbofuran (14.44%) and Endosulfan (16.11%) in 2020 for the respective years (Figure 2). Compared to the insecticides, Diazinon and Thiram + Carbofuran reduced mean SM by 69.27% and 65.22% and MPM by

67.79% and 67.48%, respectively, as compared to untreated control plots in 2018. In 2019, mean SM was reduced by 63.1% (Diazinon) and 55.6% (Thiram + Carbofuran), and MPM was reduced by 71.9% (Diazinon) and 65.9% (Thiram + Carbofuran) compared with the level of SM and MPM registered on untreated control plots. Similarly, mean SM was reduced by 84.02% (Diazinon) and 71.99% (Thiram + Carbofuran), and MPM was reduced by 83.50% (Diazinon) and 72.65% (Thiram + Carbofuran) compared with the level of mean SM and MPM recorded on untreated control plots in 2020. The overall SM was relatively higher in 2018 (22.48%), followed by in 2019 (26.77%) and 2020 (14.21%), while MPM was relatively higher in 2019 (38.63%) 34%), followed by in 2018 (34%) and 2020 (28.33%) (Figure 2).

On the other hand, the mean highest BSM severity (PSI_i) indices were recorded from untreated control plots with 22.65% at 20-DAE in 2018, 35.20% in 2019, and 43.68% at 20-DAE in 2020. The mean lowest PSI_i was noted from bean cultivar treated with Diazinon (7.60, 10.19, and 9.16%) and Thiram + Carbofuran (10.04, 11.97, and 10.92%) in 2018, 2019, and 2020 cropping years, respectively (Figure 2). However, BSM severity (PSI_f) indices as low as 31.32, 23.30, 16.82, 15.43, 14.05, 7.21, and 6.22% at 70-DAE were recorded from untreated control, Dimethoate, Lambda-cyhalothrin, Profenofos, Endosulfan, Thiram + Carbofuran, and Diazinon seed-treating plots, respectively, during the 2018 cropping year. Comparable trends were observed in that order for PSI_f in the 2019 cropping year. However, inconsistent results for Lambda-cyhalothrin and Profenofos were observed in 2020 compared with 2018 and 2019 (Figure 2). The mean PSI_i was reduced by 66.45, 71.05, and 77.62% (Diazinon) and 79.98, 55.77, 65.99, and 59.94% (Thiram + Carbofuran) over untreated control plots during 2018, 2019, and 2020 cropping seasons, respectively. Also, the mean PSI_f was reduced by 77.62, 76.12, and 86.81% (Diazinon) and 76.98, 69.96, and 75.69% (Thiram + Carbofuran) over untreated control plots during 2018, 2019, and 2020 cropping seasons, respectively.

According to ANOVA results, the mean highest TNL (51.67, 53.33, and 48.00) was recorded from untreated control plots in 2018, 2019, and 2020, respectively. The mean lowest TNL (15.00, 12.67, and 6.33) was noted from Diazinon seed-treating insecticide in 2018, 2019, and 2020, respectively. However, the TNL values were not significantly different from Thiram + Carbofuran (22.67 in 2018, 19.33 in 2019, and 11.67 in 2020) and Endosulfan (13.67) in 2020 (Figure 2). Diazinon and Thiram + Carbofuran reduced TNL by 70.97 and 56.13% in 2018, 76.24 and 63.75% in 2019, and 86.81 and 75.69% in 2020, respectively. Likewise, the mean highest TNP (46.00, 49.00, and 44.33) was registered from untreated control plots in 2018, 2019, and 2020 cropping years, respectively. However, the mean highest TNP value was not statistically different from Dimethoate (31.67%) and Lambda-cyhalothrin (31.67%) in 2020 for the same year. The mean lowest TNP (11.00, 13.00, and 8.67) was observed from seeds treated with Diazinon in 2018, 2019, and 2020, respectively (Figure 2). However, it was statistically on par with Thiram + Carbofuran (13.67), Endosulfan (15.00), Lambda-cyhalothrin (21.00), and Profenofos (21.00) in 2018, and Thiram + Carbofuran (14.33 and 10.33) and Endosulfan (17.00 and 10.33) in 2019 and 2020, respectively. Diazinon reduced mean TNP by 76.09% (in 2018), 45.83% (in 2019) and 80.44% (in 2020) compared with untreated control plots. Similarly, the mean TNP was reduced by 70.28% (in 2018), 40.29% (in 2019), and 76.70% (in 2020) due to the use of Thiram + Carbofuran compared with the level of mean TNP noted from untreated control plots (Figure 2).

Overall, SM, MPM, PSI_i, PSI_f, TNL, and TNP were found lower in plots treated with all seed treatment insecticides than in untreated control plots. However, the results indicated that the intensity at which BSM pressure lowered when Diazinon, Thiram + Carbofuran, and Endosulfan were applied as compared to the untreated plots in all cropping years. In this regard, Diazinon, Thiram + Carbofuran, and Endosulfan kept consistent results in reducing SM, MPM, PSI_i, PSI_f, TNL, and TNP in all cropping years. While Lambda-cyhalothrin and Profenofos exhibited lost their consistency for the aforementioned parameters in the 2020 year. Thus, Diazinon, Thiram + Carbofuran, and Endosulfan resulted in the highest protection, thereby reducing BSM pressure and enhancing common bean cultivar withstand to BSM in the two cropping seasons. These insecticides could help to use as seed treatment agents to control BSM infestation in the study areas and similar agro-ecologies in Ethiopia.

Agronomic parameters

Plant heights, SC, NPP, HSW, and GY were significantly ($P < 0.001$) varied due to the use of insecticide seed treatments in the 2018 and 2020 cropping years (Tables 2 and 3). The mean highest (49.96 and 63.87 cm) for PH was measured from Thiram + Carbofuran in the 2018 and 2020 cropping years, respectively. The mean lowest PH of 28.65 cm (in 2018) and 40.27 cm (in 2020) were recorded from untreated control plots. However, the mean highest PH value measured from Thiram + Carbofuran was statistically on par with Diazinon, 46.98 cm in 2018 and 58.20 cm in 2020. Also, the mean lowest PH value measured from untreated control plots was statistically on par with Dimethoate, 34.36 cm in 2019 and 43.80 cm in 2020 (Table 3). During the 2018 cropping year, the mean highest SC (54.67), NPP (25.60), and HSW (31.81 g) were recorded from Diazinon, but it was not statistically different from Thiram + Carbofuran and Endosulfan for SC (51.33 and 50.33), NPP (24.60 and 22.34) and HSW (30.20 and 28.27 g), respectively. The mean lowest SC (27.67), NPP (10.77), and HSW (21.32 g) were recorded from untreated control plots in 2018. Similar trends were observed for SC and NPP on Diazinon, Thiram + Carbofuran, and Endosulfan (except SC) in 2020. During the 2020 cropping year, the mean heavier (34.31 g) HSW was obtained from Diazinon than other treatments. But, the lowest (23.97 g) HSW was harvested from untreated control plots, which were not significantly different from the mean HSW obtained from Dimethoate (Table 3).

On the other hand, the mean highest GY was obtained from Diazinon (2229.37 and 2648.29 kg ha^{-1}) and Thiram + Carbofuran (2213.39 and 2503.20 kg ha^{-1}) in the 2018 and 2020 cropping years, respectively. The mean highest GY obtained from

Table 3. Mean effects of insecticidal seed treatments on plant health, stand count and grain yields of common bean at Denibecho in Burji, southern Ethiopia, during 2018 and 2020 main cropping seasons.

Treatment		PH (cm)	SC	NPP	HSW (g)	GY (kg ha^{-1})
Year	Insecticides					
2018						
	Dimethoate	34.16^{de}	36.00^{b}	12.75^{b}	23.74^{de}	659.52^{c}
	Thiram + Carbofuran	49.96^{a}	51.33^{a}	24.60^{a}	30.20^{a}	2213.39^{a}
	Diazinon	46.98^{ab}	54.67^{a}	25.60^{a}	31.81^{a}	2229.37^{a}
	Endosulfan	42.80^{bc}	50.33^{a}	22.34^{a}	28.27^{a-c}	1919.97^{a}
	Lambda-cyhalothrin	38.23^{cd}	41.00^{b}	16.01^{b}	27.38^{b-d}	1179.10^{b}
	Profenofos	37.23^{cd}	40.00^{b}	15.02^{b}	25.60^{cd}	837.65^{bc}
	Untreated control	28.65^{e}	27.67^{c}	10.77^{b}	21.32^{e}	514.29^{c}
	Grand mean	39.57	43.00	18.15	26.90	1364.75
	LSD (0.05)	6.78	7.35	5.43	4.03	424.41
	CV (%)	9.79	9.76	17.08	8.56	17.76
2020						
	Dimethoate	43.80^{cd}	31.33^{d}	14.47^{bc}	27.26^{cd}	872.64^{cd}
	Thiram + Carbofuran	63.87^{a}	51.67^{ab}	23.64^{a}	30.55^{bc}	2503.20^{a}
	Diazinon	58.20^{ab}	52.67^{a}	25.92^{a}	34.31^{a}	2648.29^{a}
	Endosulfan	54.07^{a-c}	44.67^{bc}	22.74^{ab}	31.96^{bc}	1640.08^{b}
	Lambda-cyhalothrin	48.13^{cd}	41.67^{c}	18.22^{a-c}	29.61^{bc}	1094.17^{c}
	Profenofos	49.47^{b-d}	41.00^{c}	17.73^{a-c}	28.67^{bc}	1044.34^{c}
	Untreated control	40.27^{d}	19.00^{e}	12.24^{c}	23.97^{d}	511.73^{d}
	Grand mean	51.11	40.29	19.28	29.48	1473.49
	LSD (0.05)	10.27	7.79	8.43	3.57	357.14
	CV (%)	11.48	11.05	24.99	6.92	13.84

Means followed by the same letter within the column are not significantly different at $p < 0.05$. PH = Plant height measured in cm; SC = Stand count in number; NPP = Number of productive pod per plant; HSW = Hundred seed weight measured in gram; GY = Grain yield measured in kg ha^{-1} LSD = Least significant difference at 5% probability level; and CV = Coefficient of variation (%).

Table 4. Effect of insecticidal seed treatments on relative yield loss of common due to damage caused by bean stem maggot at Denibecho in Burji, Southern Ethiopia, during 2018 and 2020 main cropping seasons.

Treatment	Relative yield loss, 2018			Relative yield loss, 2020		
	Yield (Kg ha^{-1})	Relative yield (%)	Yield loss (%)	Yield (Kg ha^{-1})	Relative yield (%)	Yield loss (%)
Dimethoate	659.52	29.58	-70.42	872.64	32.95	-67.05
Thiram + Carbofuran	2213.39	99.28	-0.72	2503.20	94.52	-5.48
Diazinon	2229.37	100.00	0.00	2648.29	100.00	0.00
Endosulfan	1919.97	86.12	-13.88	1640.08	61.93	-38.07
Lambda-cyhalothrin	1179.10	52.89	-47.11	1094.17	41.32	-58.68
Profenofos	837.65	37.57	-62.43	1044.34	39.43	-60.57
Untreated control	514.29	23.07	-76.93	511.73	19.32	-80.68

Diazinon and Thiram + Carbofuran was not significantly different from the mean GY obtained from Endosulfan (1919.97 kg ha^{-1}) in 2018. The mean lowest GY was recorded from the untreated control (514.29 and 511.73 kg ha^{-1}), and Dimethoate treated (659.52 (2018) and 872.64 kg ha^{-1} (2020) plots. These were significant GY reductions among the evaluated treatments and were severely affected by BSM during the 2018 and 2020 cropping years (Tables 3 and Figure 2). Diazinon and Thiram + Carbofuran maintained consistent results for growth and yield-related traits in both cropping years. About 81.26 and 81.15% in 2018 and 83.81 and 83.03% in 2020 GY gap were recorded between the Diazinon and untreated control, and Thiram + Carbofuran and untreated control, respectively.

Relative yield loss and relative yield advantage

The mean relative yield losses and relative yield advantages computed for each treatment against the maximum protected plot during the 2018 and 2020 cropping years are summarized in Table 4. Among the treatments, a common bean cultivar treated with Diazinon was used as a reference to calculate relative yield loss and relative yield in both years. Comparatively, the highest relative yield advantage was observed on Diazinon (100% in both years), followed by Thiram + Carbofuran (99.28 and 94.52%) and Endosulfan (86.12 and 61.93) in the 2018 and 2020 years, respectively. The lowest relative yield advantages of 23.07 and 29.58% in 2018 and 19.32 and 32.95% in 2020 were recorded on untreated control and Dimethoate plots, respectively (Table 4). In the two years, the mean relative yield loss was higher in 2020 (38.78%) than in 2018 (44.36%). The level of grain yield loss was lowered compared with the untreated control due to the use of insecticide seed treatments. In this regard, yield losses as low as 0.72, 13.88, 47.11, 62.43, 70.42, and 76.93% in 2018 and 5.48, 38.07, 58.68, 60.57, 67.05, and 80.68% in 2020 were recorded on Thiram + Carbofuran, Endosulfan, Lambda-cyhalothrin, Profenofos, Dimethoate, and untreated control plots, respectively, compared with the maximum protected plot, Diazinon. Overall, all insecticides evaluated with susceptible common bean cultivar reduced the BSM

Table 5. Coefficients of correlation (*r*) between study parameters under the different insecticidal seed treatments at Denibecho in Burji, Southern Ethiopia, during 2018 (lower diagonal) and 2020 (upper diagonal) main cropping seasons.

Parameter	SM	FGPM	PSI_i	PSI_f	TNL	TNP	PH	SC	NPP	HSW	GY
$SBPM_i$		0.96****	0.74***	0.73***	0.98****	0.88****	-0.55**	-0.79****	-0.57**	-0.74****	-0.75****
$SBPM_f$	0.85****		0.96****	0.77****	0.95****	0.96****	-0.64**	-0.82****	-0.59**	-0.76****	-0.82****
PSI_i	0.77****	0.67***		0.81****	0.78****	0.76****	-0.70***	-0.81****	-0.57**	-0.67***	-0.83****
PSI_f	0.88****	0.87****	0.90****		0.74***	0.69***	-0.67**	-0.83****	-0.60**	-0.66**	-0.72***
TNL	0.91****	0.70***	0.80****	0.70***		0.87***	-0.59***	-0.78****	-0.57**	-0.76****	-0.77****
TNP	0.77****	0.78****	0.85****	0.77****	0.71****		-0.67***	-0.87****	-0.65***	-0.81****	-0.75****
PH	-0.74****	-0.71***	-0.85****	-0.84****	-0.74****	-0.81****		0.81****	0.72***	0.72***	0.83****
SC	-0.72***	-0.68***	-0.68***	-0.87****	-0.71***	-0.92****	0.83****		0.77***	0.76****	0.84****
NPP	-0.84****	-0.67***	-0.77****	-0.83***	-0.92****	-0.75****	0.68***	0.76****		0.74***	0.78****
HSW	-0.74****	-0.66**	-0.82****	-0.83****	-0.69***	-0.79****	0.67***	0.85****	0.73***		0.83****
GY	-0.77****	-0.67***	-0.82****	-0.84****	-0.81****	-0.79****	0.76****	0.88****	0.90****	0.89****	

SM = Seedling bean plant mortality between 20 to 40-DAE (in 2018 and 2019) and 26 to 46-DAE (in 2020); FGPM = Fully-grown plant mortality between 50 to 70-DAE (in 2018 and 2019) and 56 to 76-DAE (in 2020); PSI_i = Percent severity index at initial assessment dates during seedling stage of the plants (20 and 26-DAE in 2018 and 2019, and 2020 cropping seasons, respectively); PSI_f = Percent severity index at final assessment dates during 50% plants per plot attained physiologically matured (70 and 76-DAE in 2018 and 2019, and 2020 cropping seasons, respectively); TNL = Total number of larvae during the growing period; TNP = Total number of pupae during the growing period; PH = Plant height measured in cm; SC = Stand count in number; NPP = Number of productive pod per plant; HSW = Hundred seed weight measured in gram; GY = Grain yield measured in kg ha^{-1}; **** = Significantly different at *P* ≤ *0.0001*; *** = Significantly different at *P* ≤ *0.001*; and ** = Significantly different at *P* ≤ *0.01.*

pressure, and subsequently, minimized the level of yield losses in both cropping years (Table 4).

Association between the study parameters

The associations between SM, MPM, PSI_i, PSI_f, TNL, TNP, PH, SC, NPP, HSW, and GY parameters were studied using simple correlation analysis, and correlation coefficients (r) are presented in Table 5. Seedling mortality, MPM, PSI_i, PSI_f, TNL and TNP showed outstandingly different levels of associations with PH, SC, NPP, HSW and GY in 2018 and 2020. During the 2018 year, SM had a positive and highly significant ($P < 0.001$) association with MPM (r = 0.85****), PSI_i (r = 0.77****), PSI_f (r = 0.88***), TNL (r = 0.91****) and TNP (r = 0.77****). At the same time, MPM exhibited a positive and highly significant ($P < 0.001$) relationships with PSI_i (r = 0.67***), PSI_f (r = 0.87****), TNL (r = 0.70***) and TNP (r = 0.78****). Also, PSI_i was positively and significantly correlated with PSI_f (r = 0.90****), TNL (r = 0.80****) and TNP (r = 0.85****). Positive and highly significant ($P < 0.001$) associations between PSI_f and TNL (r = 0.70****), PSI_f and TNP (r = 0.77****) and TNL and TNP (r = 0.81***) were observed in 2018 (Table 5). Conversely, PH was highly significantly ($p < 0.001$) and negatively associations (*r* = – 0.74****, – 0.71****, -0.85****, -0.84****, -0.74**** and – 0.81****) with SM, MPM, PSI_i, PSI_f, TNL and TNP, respectively. Negative and highly significant ($P < 0.001$) associations between SC and SM MPM, PSI_f, TNL and TNP were observed with r - values of -0.72***, -0.68***, -0.68***, -0.87****, -0.71*** and -0.92****, respectively. Number of productive pods, HSW and GY also had negative and highly significant ($P < 0.001$ to 0.01) correlation with SM (*r* = – 0.84****, -0.74**** and -0.77****), MPM (*r* = – 0.67***, -0.66** and -0.67***), PSI_i (*r* = – 0.77****, -0.82***** and -0.82****), PSI_f (*r* = – 0.83***, -0.84**** and -0.84****), TNL (*r* = – 0.92****, -0.69*** and -0.81****) and TNP (*r* = – 0.75***, -0.79**** and -0.79****), respectively. On the other hand, growth and yield-related parameters perceived a positive and strong association with each other. In this regard, PH exhibited positive and significant ($P < 0.001$) association with SC (r = 0.83****), NPP (r = 0.68***), HSW (r = 0.67***) and GY (r = 0.76****). Number of productive pods showed positive and significant correlation with SC (r = 0.76***) and HSW (r = 0.73***). Also, SC had a positive and highly significant ($p < 0.0001$) correlation with HSW (r = 0.85****). Grain yield exhibited highly significant ($P < 0.001$) and positive correlation with SC (*r* = 0.88****), NPP (*r* = 0.90****) and HSW (*r* = 0.89****) in 2018. Closely similar trends were traced on the relationships between and among BSM pressure, growth and yield-related parameters in 2020 (Table 5).

Partial budget analysis

Partial budget analysis indicated that variation in net benefit and marginal rate of return was observed between and among the evaluated treatments (Table 6). The pooled results of the two cropping years (2018 and 2020) revealed that the highest net benefit of \$126,429.52 ha^{-1} was obtained from Diazinon, followed by \$122,241.67 ha^{-1} from Thiram + Carbofuran. The lowest net benefit of \$26,364.12 ha^{-1} was computed from untreated control plots. On the other hand, the highest marginal rate of return of 422.07 was calculated from Diazinon, followed by 416.08 and 309.72 from Thiram + Carbofuran and Endosulfan, respectively (Table 6). Net benefits and marginal rate of returns computed from the planting of common bean cultivar (Nasir) showed economically not feasible when the cultivar was cultivated with the use of Dimethoate, Profenofos, and Lambda-cyhalothrin as a seed treatment because their combination (cultivar + insecticide) was resulted in unprofitable for bean production. The high net benefits and marginal rate of returns from the abovementioned treatments could be attributed to high yield, and the low net benefit and marginal rate of returns were attributed to low yield (Table 6).

Bean stem maggot has caused considerable quantitative and qualitative yield losses (30 to 100%) of common beans worldwide (Ochilo and Nyamasyo, 2010; Abate *et al.*, 2011; Munyasa, 2013; MoANR and EATA, 2018). Yield losses had significantly

Table 6. Mean economic feasibility analysis for the management of bean stem maggot using insecticidal seed treatments at Denibecho in Burji, Southern Ethiopia, during 2018 and 2020 main cropping seasons.

Treatment	GY (kg ha^{-1})	AGY 10% down (kg ha^{-1})	TVC (\$ ha^{-1})	GB (\$ ha^{-1})	NB (\$ ha^{-1})	MRR (%)
Dimethoate	766.08	689.47	557.56	39899.74	39342.18	64.06
Thiram + Carbofuran	2358.30	2122.47	585.41	122827.08	122241.67	416.08
Diazinon	2438.83	2194.95	592.06	127021.58	126429.52	422.07
Endosulfan	1780.03	1602.02	567.36	92709.04	92141.69	309.72
Lambda-cyhalothrin	1136.64	1022.97	573.82	59199.36	58625.54	147.42
Profenofos	941.00	846.90	590.89	49009.84	48418.95	93.49
Untreated control	513.01	461.71	354.98	26719.10	26364.12	0.00

GY = Grain yield; AGY = Adjustable grain yield; TVC = Total variable cost; GB = Gross benefit; NB = Net benefit; and MRR = Marginal rate of return. Mean unit price of grain yield per ton was \$57.87 ton^{-1} at Burji during the two cropping seasons at the time of marketing.

associated with higher damage/severity, bean plant mortality, stunting, interference with water and mineral translocation due to oviposit of BSM with plant tissue and allowing for root rot diseases (Leteourneau and Msuku, 1992; Odendo *et al*., 2005; Mwang'ombe *et al*., 2007; Ochilo and Nyamasyo, 2010; Kiptoo *et al*., 2016; MoANR and EATA, 2018). Evaluation of insecticide seed treatment performance is best when BSM pressure is high and when environmental conditions are variable, especially rainfall and temperature (Songa and Ampofo, 1999; Abate *et al*., 2011). These conditions were met during the study periods in the three cropping years (Figure 1). Especially in the 2018 and 2019 cropping years in the study areas, as the observation indicated that there were intermittent and erratic rainfall and temperature fluctuation during the growing periods. These might favor a high infestation of BSM year after year in the study areas. Songa and Ampofo (1999) and Abate *et al.* (2011) reported that conducting any management approaches for BSM had vital under high infestation and favorable environmental conditions during the growing periods.

In this regard, previous research reports indicated that insecticide seed treatment is an effective approach for soil-born infested insect pests like BSM. Because the pest had significantly interconnected with environmental conditions and bean plant mortality during the early stage of the crop, and subsequently reduced bean plant population and associated grain yield of legume crops (Kapeya *et al*., 2005; Belmain *et al*., 2013; Douglas and Tooker, 2015; Labrie *et al*., 2020). In the current study, the effects of six insecticide seed treatments against BSM infestation, damage/severity, and agronomic performances of common bean were evaluated under field conditions at Denibecho in Burji, Southern Ethiopia. The insecticide seed treatments attained significantly varying levels of effectiveness against BSM control, growth, and yield-related traits in the three cropping years.

The results of the current study have shown that the use of insecticides as seed treatment can effectively reduce SM, MPM, PSI_i, PSI_f, TNL, and TNP of BSM, although various levels of intensity were observed among the evaluated insecticide seed treatments in the three cropping seasons. In all cropping years, Diazinon and Thiram + Carbofuran were the most effective insecticide seed treatments and exhibited consistent results in controlling BSM as shown by the lowest SM, MPM, PSI_i, PSI_f, TNL, and TNP. The results obtained in this study were similar to the work that had been done on susceptible bean cultivars, which showed the applied insecticide seed treatments were effective against soil-dwelling insect pests by reducing bean plant mortality and damage worldwide (Koch *et al*., 2005; Nault *et al*., 2006; Rahaman and Prodhan, 2007; Otim *et al*., 2016; James *et al*., 2018; Labrie *et al*., 2020). Endosulfan seed treatment insecticide was moderately effective against BSM control (SM, MPM, PSI_i, PSI_f, TNL, and TNP), whereas the effects of Lambda-cyhalothrin, Profenofos, and Dimethoate were less effective and showed inconsistent results (except for Dimethoate) for these parameters in the three cropping years. In all cropping years, the highest SM, MPM, PSI_i, PSI_f, TNL, and TNP of BSM were recorded from untreated control plots. Peter *et al*. (2009) reported that the BSM pressure of various plots increased with increased BSM maggot as well as pupae infestation on common bean plants. Thus, failure to take any measure to BSM control strategy can lead to high infestation by BSM and uneconomic of the bean crop (Seif *et al*., 2001).

Analysis of variance also exhibited a considerable treatment variation for PH, SC, NPP, HSW, and GY in both the 2018 and 2020 cropping years. Various previous studies also confirmed the existence of seed treatments among the evaluated insecticide seed treatments in reducing BSM pressure and enhancing growth and yield-related parameters (Seif *et al*., 2001; Koch *et al*., 2005; Otim *et al*., 2016; James *et al*., 2018; Labrie *et al*., 2020). In both the 2018 and 2020 cropping years, the best performing insecticide seed treatments were Diazinon, Thiram + Carbofuran, and Endosulfan, and showed consistent results on PH, SC, NPP, HSW, and GY. Whereas SC, NPP, HSW, and GY were as low as on Lambda-cyhalothrin, Profenofos, Dimethoate, and untreated control plots and exhibited consistent results in the two cropping years. Generally, Diazinon, Thiram + Carbofuran, and Endosulfan maintained consistent BSM pressure reductions and consequently increased growth and yield-related parameters in both cropping years. The growth and yield-related parameters of various plots reduced with increased maggot/pupae infestation on bean crops as reported by several researchers (Srivastava *et al*., 1990; Koch *et al*., 2005; Rahaman and Prodhan, 2007; Peter *et al*., 2009; Mishek, 2011; Allah, 2010; James *et al*., 2018; Labrie *et al*., 2020). Thus, failure to take measure any BSM control strategy can lead to uneconomic growth and yield-related trait performance of bean crops (Ogecha *et al*., 2000; Seif *et al*., 2001; Ogecha *et al*., 2019; Labrie *et al*., 2020).

In the two cropping seasons (2018 and 2020), relative yield loss assessment and yield advantage analysis also confirmed that there existed variation among the evaluated insecticide seed treatments. The present study has shown that seed treatments exhibited effectiveness in lowering BSM pressure and associated yield losses and the highest yield advantages in the two cropping years (2018 and 2020). However, common bean growers in the study areas, as well as other similar agro-ecologies, have to be attentive to the profitability and hazards associated with unwise use of them. Among the insecticides, Diazinon and Thiram + Carbofuran were the most effective and showed consistent results in controlling BSM, gave the highest yield advantage, and significantly lowered relative yield losses in all years. Grain yield losses in common bean cultivation could be attributed to the severe damage caused by BSM at all phenologies of the plant, which resulted in the reduced physiological activity that eventually killed the bean plants. Under severe BSM pressure, bean plants within rows are almost none due to drying of dead plants leading to considerable yield losses. Bean plant mortality would lead to plant population reductions and consequently reduced yield advantage and increased substantial yield losses.

Related findings regarding the effect of insecticide seed treatments on BSM intensity and yield loss indicated that the best-performing insecticides among various treatments showed the lowest BSM intensity and yield loss on bean crops in the major growth of the world (Srivastava *et al*., 1990; Koch *et al*., 2005; Mishek, 2011; Otim *et al*., 2016; James *et al*., 2018; Labrie *et al*., 2020). These authors also reported that the highest yield losses in bean crops had been recorded from the plots left as untreated control. Yield losses of about 30-100% due to BSM have been reported in bean crops in different parts of the world (Ochilo and Nyamasyo, 2010; Abate *et al*., 2011; Munyasa, 2013; MoANR and EATA, 2018). Grain yield losses computed in this study could not be solely accredited to BSM intensity considering the medium levels of intensity of bean aphid, legume pod borer, common bacterial blight (*Xanthomonas axonopodis* pv. *phaseol*), angular leaf spot (*Pseudocercospora griseola*), Fusarium root rot (*Fusarium cuneirostrum*) and environmental conditions. Among these insect pests and diseases, Fusarium root rot (especially during 2020 on control plots) played a significant role next to BSM in reducing the bean plant population within the plot, which led to a low bean plant population (stand counts) for the intended treatments. The effects of these factors (insect pests and diseases) did not fully explain by the present study, and their confounding effect cannot be underestimated in the grain yield losses.

The correlation analyses showed a positive and highly significant association between and among mean values of SM, MPM, PSI_i, PSI_f, TNL, and TNP. This result implied that these parameters were found interconnected to each other and showed the BSM pressure was developed at a faster rate on uncontrolled plots than controlled with various levels of intensity. While the negative and significant associations between and among mean values of BSM monitoring parameters and growth and yield-related (PH, SC, NPP, HSW, and GY) traits were observed in the two cropping years (2018 and 2020). This could suggest that BSM intensity played a significant role in reducing growth and yield-related traits. A study reported by Nderitu and Buruchara (1997), Kamneria (2007), and Kiptoo *et al.* (2016) positive and high correlations between and among BSM monitoring parameters and negative and high associations between and among BSM monitoring, growth, and yield-related parameters had observed in their studies and could result in recognizable yield reductions. However, growth and yield-related parameters also had positive and significant associations between and among themselves. The positive associations among growth and yield-related parameters could indicate the vital contributions of yield traits to the grain yield of common bean. In line with this asseveration, Mustafa *et al.* (2013), Panagiota *et al.* (2018), and Simon *et al.* (2020) showed that positive correlations between and among growth and yield-related traits could indicate the significance of the parameters in determining the final grain yield of common bean.

Partial budget analysis based on the pooled results of two cropping years showed that variation in the net benefits and marginal rate of returns were apparent among the evaluated insecticide seed treatments. The mean highest net benefits and marginal rate of returns were computed from Diazinon, followed by Thiram + Carbofuran and Endosulfan. Conversely, the lowest net benefit and marginal rate of returns were recorded from untreated control plots. The high net benefits and marginal rate of returns from the abovementioned treatments could be attributed to high yield, and the low net benefit and marginal rate of returns were attributed to low yield. Also, variations in net benefits and marginal rate of returns might be due to BSM pressure, agro-ecology, management approaches followed, and total input costs of production during the study.

As mentioned by CIMMYT (1988), the total input cost of production, time of crop production, the choice of nutrient and pest management options, the quality and quantity of products, and the selling price of the product in the locality at the time of marketing are the main factors in an economic feasibility study and had a significant influence on high or low economic benefits returns. In agreement with the present study, similar results on best-performing insecticide seed treatments have been reported in other research where seed treatment has been utilized successfully in the management of bean leaf beetle (Koch *et al*., 2005), red spider mite, and bean fly (Allah, 2010), bean pests (Otim *et al*., 2017) and whiteflies (*Bemisia tabaci*), thrips (*Frankliniella occidentalis)* and BSM (James *et al*., 2018) in beans worldwide. Therefore, from the economic benefit point of view, it was apparent that planting common bean cultivars supplemented with insecticide seed treatments (Diazinon or Thiram + Carbofuran) for the control of BSM was more profitable as well as saves satisfactory advantages than all other treatments in the study.

Conclusion

The experimental evidence of the present research showed that the use of insecticide seed treatments had a pronounced effect in minimizing BSM pressure and increasing the growth and yield-related traits of common beans in all cropping years. In this regard, Diazinon, followed by Thiram + Carbofuran and Endosulfan significantly reduced seedling mortality, mature plant mortality, severity/damage, the total number of larvae, and the total number of pupae. Consequently, these conditions increased grain yield advantages and gave higher net benefits and marginal rate of returns than untreated control plots and other insecticides in the 2018 and 2020 cropping years. Therefore, the uses of Diazinon and Thiram + Carbofuran were proved to be the most cost-effective seed treatments in reducing BSM pressure and increasing the production and productivity of common bean in the two years. Thus, Diazinon and Thiram + Carbofuran, one of them as an alternative option, could be suggested as an insecticide seed treatment to the growers in the study areas and elsewhere with similar agro-ecological conditions for efficient control of BSM and optimization of common bean yield. However, the lonely use of insecticide seed treatment may not be efficient for the rest of the growing period of the crop. Therefore, few applications of foliar sprays after five and six weeks to protect bean plants should be considered in addition to seed treatment for efficient control of BSM. Further studies should be conducted in other agro-ecologies for at least three hot spot areas and consecutive years (including a few applications of foliar sprays) for developing a concrete recommendation on BSM control options to enhance sustainable common bean production. On the other hand, bean aphid, legume pod borer, common bacterial blight, angular leaf spot, and Fusarium root rot problems in common bean cultivation need further investigations.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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