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Research Article

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Organic and inorganic source fertilizer application reduces seedling diseases, insect pest occurrence and enhances growth performance of *Citrus limon* (L.) in Arba Minch, South Ethiopia

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ABSTRACT

Lemon, *Citrus limon* (L.) Burm, is one of the vital fruit crops in terms of vitamins and minerals. Citrus anthracnose, leafminer (CLM), butterfly (CBF), and soil fertility problems are the main production constraints throughout the growing stages worldwide, including in Ethiopia. The study was designed to evaluate the sole as well as combined effects of powdered flowers of *Hagenia abyssinica*, farmyard manure (FYM), and blended nitrogen-phosphorus-sulfur (NPS) fertilizer on the citrus anthracnose, CLM, and CBF intensity as well as the growth performance of lemon seedlings. The experiment was conducted with eight treatments under various ratios of *H. abyssinica*, FYM, and NPS fertilizer in a simple and integrated manner at the main station of the research center for two consecutive years, 2021 and 2022. The treatments were arranged in a randomized complete block design with three replications. The results revealed a significant ($P<0.05$ to <0.0001) difference among the evaluated treatments for all study parameters. Accordingly, the lowest anthracnose incidence (8.75%), severity (5.54%), and area under the disease progress curve (131.66% days) were noted for powdered flowers of *H. abyssinica* (50 g, 100%). Similarly, this treatment showed the lowest CLM percent infestation (10.36%), larval density (0.49), CBF percent infestation (7.42%), and injury level (7.12%). A remarkable treatment difference for quantitative high-growth performance was observed in plant height (69.45 cm), number of primary branch lengths (24.28), number of primary (12.91), secondary (7.97), and tertiary (3.55) leaves, and total number of leaves per plant (310.50) from the application of *H. abyssinica* (50 g, 100%), while the highest leaf area (13.43 cm^2) and stem girth (1.22 cm) were recorded from FYM (5 kg, 100%) applied ones. The unmanaged control plot had higher anthracnose, CLM, and CBF intensity as well as lower growth performance. Overall, among the evaluated treatments, powdered flowers of *H. abyssinica* (50 g, 100%) showed the best performance in terms of reducing anthracnose, CLM, and CBF intensity and enhancing the growth performance of the seedlings, so it could be suggested for lemon-growing farmers to manage their seedlings for anthracnose, CLM, and CBF. However, further research that comprises powdered flower of *H. abyssinica* on quality as well as quantity, along with other proper agronomic practices over locations and years, is required to develop a concrete recommendation for the wider community about the roles of the combination of organic and inorganic fertilization in minimizing citrus anthracnose, leafminer, and butterfly effects and for well-beingness seedling growth and physiological activities of lemon. Moreover, molecular characterization is essential to understand the specific nature of the *C. gloeosporioides* infecting lemon seedlings.

KEYWORDS: Citrus anthracnose, Citrus butterfly, Citrus leafminer, *Hagenia abyssinica*, Integrated manner, Larval density, Severity

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INTRODUCTION

Lemon (*Citrus limon* (L.) Burm.) is one of the most popular fruits in the citrus group around the world. The crop was produced both in the tropics and temperate regions, and total production reached >21.57 million tons worldwide in 2020 (FAOSTAT, 2021). Nutritionally, it contains vitamin C, soluble fiber, and compounds with a variety of health benefits, such as aiding in weight loss, lowering the risk of heart disease, kidney stones, anemia, digestive issues, cancer, and antimicrobial activity (Ajugwo *et al.*, 2012; Liu *et al.*, 2012). Lemon is one of the most economically important fruit crops grown by smallholder farmers and private investors in Ethiopia (Mariam, 2003; Tessega *et al.*, 2006). In the country, lemon is cultivated in diverse agro-ecological conditions (low to mid-altitude). Commercial as well as homestead farming of lemons can be a potential source of livelihood for rural people in low-income areas of the country. The crop was cultivated on 1378.23 hectares of land, and from which 61815.45 tons of yield were harvested in 2020/2021. The land cover and harvested yield were reduced compared with the previous year (2019/2020), in which there were 1409.64 hectares of cultivated area and 79514.18 tons of harvested yield (CSA, 2021).

Reductions in the production and productivity of lemons could be due to several factors, including a combination of biotic and abiotic factors, socioeconomic conditions, and those related to poor agronomic practices. As reported by Dagnew *et al.* (2014), Kebede (2015) and Gebreslasie and Meresa (2018), soil fertility problems, lack of improved varieties, diseases, insect pests, and poor nursery and field management are identified as the growth- and yield-limiting factors for citrus production. A combination of these factors resulted in low (4.46 t ha^{-1}) productivity of lemons in the country during 2020/2021 (CSA, 2021). Among biotic constraints, several kinds of bacterial, fungal, viral, nematode, insect pests, and weeds are major threats to the cultivation of lemons. In Ethiopia, many diseases caused by bacteria, fungi, viruses, nematodes, and insect pests were identified in many citrus farms in the country (Dagnew *et al.*, 2014; Tola *et al.*, 2014; Gebreslasie & Meresa, 2018). In addition, the authors reported that nutrient imbalance is more or less equally important besides biological constraints.

In the study areas, several diseases and insect pests of lemon at various growth stages are observed and documented for future management studies (unpublished data). Citrus anthracnose (*Colletotrichum* species), leafminer (CLM) [*Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae)], and butterfly (CBF) [*Papilio demoleus* Linnaeus (Lepidoptera: Papilionidae)] are commonly observed diseases and insect pests of lemon on which no management studies have been conducted. Under nursery conditions in the study areas, *Colletotrichum* species cause twig blight dieback, leaf spots, necrotic spots, and premature leaf drop on lemon seedlings. Such characteristic symptoms of the disease have been reported by various scholars (Mahiout *et al.*, 2018; Pérez-Mora *et al.*, 2020; Vitale *et al.*, 2021). Temperatures of 25-28 °C, soil pH of 5.8-6.5, and a moist environment are ideal for disease development. The pathogen is inactive when the surroundings become dry and turn to active stages when convenient environmental conditions are met (Phoulivong *et al.*, 2012; Sharma & Kulshrestha, 2015; Ben *et al.*, 2021). The disease can affect the crops at various stages and result in the loss of the crop. Pre-harvest occurrences influence growth and yield-related attributes, while post-harvest incidents affect fruit quality and quantity, which leads to a negative impact on fruit export and marketability (Phoulivong *et al.*, 2012; Guarnaccia *et al.*, 2017; Riolo *et al.*, 2021).

On the other hand, CLM is one of the most destructive citrus insect pests and frequently assaults young flushes. It causes direct and indirect harm to the citrus crops, and the larvae produce serpentine mines on leaves as a result of this necrosis, curling, and dropping of leaves. In citrus nurseries, CLM decreases the normal seedling growth and reduces the canopy development for fruit production (Stansly *et al.*, 1996; Jesus *et al.*, 2006; Atiq *et al.*, 2013; Arshad *et al.*, 2019). The CBF, also known as "lime swallowtail," "chequered" or "citrus swallowtail," is a prominent severe insect pest of young citrus plants in many growing parts of the world (Vattikonda & Sangam, 2016; Ehsanullah *et al.*, 2017; Haque *et al.*, 2019). It is an economically important insect pest and directly affects the growth and development of citrus plants and fruits. The larvae of CBF causes serious damage and complete defoliation of infested young citrus plants (Sarada *et al.*, 2014; Mangrio *et al.*, 2021). It is a major insect pest of young seedlings in nurseries and new flushes in mature citrus trees. It causes 83% defoliation in young citrus plants. The larvae feed voraciously and cause comprehensive damage to the seedlings in nurseries, leaving only the young seedlings' midribs (Narayanamma *et al.*, 2001; Sarada *et al.*, 2014). Therefore, measures to reduce the effects and prevent the spread are of great importance in controlling citrus anthracnose, CLM, and CBF under nursery conditions.

To manage citrus anthracnose, CLM, and CBF, various management options such as cultural practices, the use of resistance varieties, horticultural mineral oils, botanicals, pesticides, and integrated approaches are being used (Ullah *et al.*, 2019; Dowling *et al.*, 2020; Khan & Molla, 2021). In recent years, synthetic pesticides have not been suggested as a proper management strategy due to effects on humans, pesticide resistance, and effects on non-target organisms like natural enemies, air pollution, high costs, and many other reasons (Green *et al.*, 1990; Agrios, 2005; Mostafalou & Abdollahi, 2012). Even though several research studies for major diseases and insect pests of lemon crops have been demonstrated, as summarized by Segarra-Carmona *et al.* (2010), Sarada *et al.* (2014) and Dowling *et al.* (2020), few research works have been carried out to develop eco-friendly and sustainable management strategies for citrus anthracnose, CLM, and CBF using organic farming (Bhutani & Jotwan, 1975; Ullah *et al.*, 2019; Srivastava *et al.*, 2021). Considering the harmful effects of pesticides, some eco-friendly management approaches like cultural practices through the application of organic and inorganic sources of nutrient management, which are easily biodegradable, water-soluble, environmentally safe, less risky to apply in the presence of natural enemies, less persistent, and more toxic to pests compared to synthetic pesticides, need to be appraised for suppressing citrus anthracnose, CLM, and CBF on lemon seedlings.

In this regard, kosso tree (*Hagenia abyssinica* (J.F. Gmel.)), farmyard manure (FYM), and blended inorganic fertilizer (Nitrogen-Phosphorus-Sulfur (NPS)) were considered. In view of the above facts, some eco-friendly management strategies with organic and inorganic sources of nutrients were evaluated in the current study. *H. abyssinica* is a multipurpose tree, which is sparsely distributed in the highlands of Ethiopia. It is used for medicinal purposes for humans and animals, as a soil additive, and many others (Assefa *et al.*, 2010; Akale *et al.*, 2019; Bitew *et al.*, 2019). The foliage and flowers have a higher quality of N and P for managing soil fertility (Kindu *et al.*, 2008; Akale *et al.*, 2019). Farmers use *H. abyssinica* foliage and dried/powdered flowers for seedling raises of various fruit crops (apple, orange, lemon, and mango), and they harvest dried foliage and flowers and spread them to main annual crop lands, incorporating and aerating well before sowing. In addition, FYM and some NPS-sourced fertilizers are utilized for seedling raising under nursery conditions.

The application of nutrients to both young as well as mature lemon trees determines the vegetative development of the trees. In addition to nutrient supply, organic materials enhance plant vigor and also improve the ability of plants to resist or tolerate diseases and insect attacks during the growing period (Srivastava *et al.*, 2021; Wu *et al.*, 2021). Furthermore, Meyer (2000), Ramesh *et al.* (2005), Bonanomi *et al.* (2007), and Ullah *et al.* (2019) reported that soil nutrient availability affects not only the amount of damage caused by insect herbivores but also plant diseases. Hence, the present study was carried out based on the indigenous knowledge of the farmers who are involved in fruit seedling raising for their own use and selling in the locality. As a result, the study was designed to assess the effects of powdered flowers, *H. abyssinica*, FYM, and blended NPS fertilizer on the intensity of citrus anthracnose, CLM and CBF, as well as the growth performance of lemon seedlings.

MATERIALS AND METHODS

Study Site

The study was executed at the Arba Minch Research Center main station in Southern Ethiopia during the 2021 and 2022 cropping years. The experiment has been implemented in an open environment to ensure pest occurrence under natural infection. The site is located at geographic coordinates of 6°02'12" N latitude and 37°34'32" E longitude and an altitude of 1218 meters above sea level. A bimodal rainfall pattern is a basic feature of the areas where the short rainy season occurs during the March and April months, and the main rainy season starts in mid-August and extends to mid-November. Thus, the Arba Minch areas received total annual rainfall and average temperatures of 720 and 670 mm, respectively, and temperatures of 26.40 and 27.80 °C during the cropping seasons of 2021 and 2022. Information regarding total annual rainfall and mean annual temperature was obtained from the National Meteorology Agency, Hawassa branch, in 2022.

Experimental Material Descriptions and Preparation

The study materials consisted of sole and a combination of *H. abyssinica*, FYM, and blended inorganic fertilizer (NPS). *Hagenia abyssinica* is a monotypic genus, a species having no subspecies, of flowering plants in the kingdom of Plantae. It is native to the high-elevation Afromontane regions of central and eastern Africa. Naturally, it is a dry-to-moist tropical plant. It is a multipurpose, wind-pollinated, and wind-dispersed broadleaf dioecious tree in the plant family Rosaceae. It is also a slender, open-crowned, dioecious tree growing from 5-25 meters tall and has red flowers (Bekele-Tesemma & Biernie, 1993; Negash, 1995). The tree is a highly valued medicinal plant for humans against tapeworms and ruminant animals against anthelmintics (Assefa *et al.*, 2010; Bitew *et al.*, 2019). The plant is sometimes deliberately left on farmlands or derived grasslands and maybe occasionally planted where it occurs naturally because of its medicinal properties and many other reasons, including soil conservation, agroforestry, and timber and fuel (Negash, 1995; Desta *et al.*, 2000), and also as a soil additive upon decomposing of foliage and flowers, a source of N and P elements (Kindu *et al.*, 2008; Assefa & Glatzel, 2010; Akale *et al.*, 2019). In this regard, Kindu *et al.* (2008) reported that the macronutrient composition of the foliage and flower are 30.07, 3.71, 21.22, 9.69, 2.38, 2.03, 15.49, 1.79, 5.71, and 7.50 mg g^{-1} and 27.20, 4.94, 22.04, 5.54, 2.53, 2.70, 17.99, 2.84, 8.84, and 11.64 mg g^{-1} dry matter of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, carbon: nitrogen, lignin: nitrogen, soluble phenolics: nitrogen, and soluble phenolics + lignin: nitrogen, respectively.

In this study, FYM refers to the decomposed mixture of animal dung and urine along with litter and leftover materials from roughages or fodder fed to cattle, sheep, and goats. Farmyard manure improves the soil structure and is used as a natural fertilizer in farming. It increases the soil's capacity to hold more water and nutrients. It also increases the microbial activity of the soil to improve its mineral supply and the plant nutrients. In Ethiopia, FYM is applied to all annual, biennial, and perennial crops as organic nutrient management of the cultivated lands (MoANR & EATA, 2018). A well-decomposed FYM contains 0.5-1.5% N, 0.2-0.4% P_2O_5 and 0.5-1.0% K_2O. It is a good source of organic carbon, which activates the biotic life of the soil flora and fauna (Bhandari et al., 2018; Rana et al., 2020; Kumar *et al.*, 2021). Inorganic fertilizer, on the other hand, is a fertilizer made of mineral-based nutrients and intended for immediate application to a crop. It is artificial, consisting of minerals and synthetic chemicals that are manufactured under factory conditions. In this study, NPS fertilizer having a proportion of 19% N, 38% P_2O_5, and 7% S (Ethio SIS, 2016) was considered. According to the writer, this proportion is sufficient to satisfy the demand for crops with high yield potential and compensate for the nutrients lost by the removal of plant products and leaching during the growing season.

For powdered flowers of *H. abyssinica*, flower samples were collected from rural areas of the Chencha district in the Gamo zone, southern Ethiopia, and dried away from direct sunlight in a cool and dry place for 15 days. The well-dried flowers were stored in the sack container, which allowed plenty of air around the flowers. One kilogram of dried flowers was placed in a large, sturdy bowl and ground by hand until the desired amount of powdered flowers was obtained. The ground flower was sieved again using a kitchen sieve until it got finer and better for the measurement of the required powdered flower. Once the powdered flower of *H. abyssinica* was prepared, it was applied according to the amount predetermined and designated for each treatment in the study. On the other hand, FYM was obtained from the cattle ranch of a private investor involved in beef production around the Arba Minch area in the Gamo zone, southern Ethiopia. Well-decomposed FYM was prepared and applied for each treatment based on the design of the study. Likewise, NPS fertilizer was obtained from the Arba Minch Zuriya District Office of Agriculture input supply department and was arranged and applied for each treatment according to the study's design.

Treatment, Experimental Design and Seedling Management

The study consisted of *H. abyssinica* powder, FYM, and NPS fertilizer as sole and integrated applications. According to information obtained from growers, they use these materials for various purposes and apply them at least twice per year to manage soil fertility to withstand harsh environmental conditions and pest occurrences. During the study, a locally available lemon cultivar that is vernally resistant to essential soil nutrient materials and pests (anthracnose disease and leafminer) was used. A total of eight treatments were designed under the sole and combined use of the experimental materials in various ratios. These include (1) powdered flower of *H. abyssinica* (17 g, 33%) + FYM (1.7 kg, 33%) + NPS fertilizer (32 g, 33%) recommended dose, (2) powdered flower of *H. abyssinica* (25 g, 50%) + FYM (2.5 kg, 50%), (3) powdered flower of *H. abyssinica* (25 g, 50%) + NPS fertilizer (50 g, 50%), (4) FYM (2.5 kg, 50%) + NPS fertilizer (50 g, 50%), (6) sole application of powdered flower of *H. abyssinica* (50 g, 100%), (7) FYM (5 kg, 100%) and NPS fertilizer (100 g, 100%), (8) unmanaged control for check. A randomized complete block design (RCBD) with three replications was used as the design of the experiment. Individual treatments were allocated randomly to the experimental units within a replication.

On the other hand, the lemon seedlings were raised in polyethylene tubes at the Chano Mile nursery site, Arba Minch, Ethiopia, for a year and then transferred to plastic pots in August 2021. Half of all fertilizers were applied with predetermined application rates manually during planting on polyethylene tubes, while the remaining half was applied after establishment in the plastic pots. A spacing of 0.3 m, 0.5 m, and 1 m was utilized between pots, plots, and replications, respectively. Each plot consisted of five pots, each of which contained one plant. A total of 120 lemon seedlings were evaluated during the study. All the crop-raising practices, such as supplementary irrigation, weeding, and earthing-up practices, were manually operated whenever necessary to maintain healthy crops. In both the 2020 and 2021 cropping years, no pesticides were applied.

Citrus Anthracnose, Leafminer and Butterfly Monitoring

Citrus anthracnose, CLM, and CBF monitoring began when the first symptoms of disease, mines due to CLM, and injuries caused by CBF were observed on the leaves 60, 64 and 73 days after seedlings were transferred (DAST) to the main plastic pots, respectively. Diseased samples of infected leaves having characteristic symptoms of citrus anthracnose were taken from seedlings and brought to the Arba Minch Crop Protection Clinic, Ethiopia, to identify the causal pathogen. Pathogen identification was done following standard methods for fungus isolation (Agrios, 2005). Citrus anthracnose incidence and severity were assessed at 10-day intervals. For the disease, a total of nine scores were made during the growing time. The incidence and severity scores ceased when one of the control plot seedlings reached more than 90% severity/extent of tissue damage during the study, which was approximately 160 DAST. To determine citrus anthracnose incidence and severity, all seedlings per plot were considered. Citrus anthracnose incidence was determined as the number of diseased seedlings per total number of seedlings regarded in the following formula:

$$\text{Disease incidence}(\%) = \frac{\text{Number of plants showing diseased smptoms}}{\text{Total number of plants sampled and rated}} \times 100$$

Citrus anthracnose severity was rated for each seedling using a 0-4 severity scoring scale (Agostini *et al.*, 1992), where 0 = no disease symptoms on the leaf, 1 = isolated chlorotic spots 1-3 mm in diameter, 2 = numerous small necrotic spots, 3 = large confluent necrotic areas on the leaves, and 4 = defoliation and necrosis of the shoot tip. For data analysis, the severity scores were transformed into percentage severity indexes (PSI) following the formula proposed by Wheeler (1969).

$$\text{PSI} = \frac{\text{Sum of numerical ratings}}{\text{Number of plants scored x maximum score on the scale}} \times 100$$

The area under the disease progression curve, AUDPC (%-days), was worked out from PSI values regressed over different days for each treatment using the formula suggested by Campbell and Madden (1990) as follows.

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{x_i + x_{i+1}}{2}\right)\left(t_{i+1} - t_i\right)$$

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 disease severity of FHB at the i^{th} assessment. Its value was articulated in % days because disease severity (x) is evinced in percent and time (t) in days.

On the other hand, all lemon seedlings were used for CLM infestation and larva density and CBF infestation and injury assessment. A total of five and nine scores were carried out for CLM and CBF, respectively, during the growing period. Concerning CLM, the number of infested and total number of mined leaves per plant were counted at 10-day intervals. The total number of leaves per plant was recorded following the nondestructive method for infested leaves, i.e., the leaves were not picked out of the plant while counting for CLM. Accordingly, the percent CLM infestation of leaves was calculated using the following formula as suggested by Mustafa *et al.* (2014).

$$\text{Percent CLM infestation} = \frac{\text{Infested leaves per plant}}{\text{Total number of leaves per plant}} \times 100$$

Similarly, the number of mines per leaf per plant was recorded to determine the CLM density. Mines containing larvae at any stage, pupae, and mines free of larvae were considered for larval density. The CLM larval density was computed using the formula indicated by Pena *et al.* (2000).

$$\text{CLM larval density} = \frac{\text{Number of mined leaves per plant}}{\text{Total number of leaves per plant}} \times 100$$

Moreover, the number of CBF-invaded and total leaves per plant were noted at weekly intervals during the growing period, and a total of four assessments were made. Citrus butterfly infestation was ascertained as the mean percentage of the number of infested leaves per total number of leaves and was recorded within the plot as indicated by the following formula.

$$\text{Percent CBF infestation} = \frac{\text{Infested(or damaged) leaves per plant}}{\text{Total number of leaves per plant}} \times 100$$

Likewise, seedling leaf injury level, or the percent area of leaf consumed by CBF larvae, was assessed by visual estimation of each seedling leaf in each plot and determined by using the following formula.

$$\text{CBF injury(\%)} = \frac{\text{Injuried leaf area}}{\text{Total leaf area}} \times 100$$

Growth Characters Assessment

Growth parameters such as plant height (PH), the total number of leaves per plant (NLP), leaf area (LA), stem girth (SG), primary branch length (PBL), and the number of primary (NPB), secondary (NSB), and tertiary (NTB) branches were considered. Plant height (cm) was measured on five plants from the soil surface to the tip of the longest leaves before the seedlings were transferred to the main field. Leaf area (cm^2) was determined by multiplying the leaf length (cm) and width (cm) of 12 randomly selected leaves obtained from primary, secondary, and tertiary branches. Stem girth (cm) was assessed by measuring the circumference of the stem on five plants. The PBL (cm) was measured using a ruler from the twig of the main stem to the tip of the longest leaf on the branch before seedlings were transferred to the main field. For data analysis, mean values of PH, LA, SG, and PBL were measured and analysed for five plants. The total NPB, NPL, NSB, and NTB were recorded by counting the number of leaves found on the overall plant and primary, secondary, and tertiary branches.

Data Analysis

The data collected such as CA incidence and severity, CLM infestation and larval density, CBF infestation and injury level, and agronomic characters, were subjected to statistical analysis of variances for RCBD, exploiting GLM procedures of SAS software version 9.2 (SAS, 2009). For data analysis, the last date collected data was utilized for all study parameters. Whenever as well as wherever the analysis of variance was significant, the mean separation was done by employing Fisher's protected LSD to compare the significant differences between and among the treatments at a 5% significance level following Gomez and Gomez's (1984) procedures. A Pearson's correlation square matrix was employed to determine the degree of associations between and among the pest monitoring and agronomic parameters using SAS version 9.2 (SAS, 2009).

RESULTS AND DISCUSSION

Symptoms and Identified Causative Pathogen

Citrus anthracnose was discovered for the first time on the treatments FYM + NPS fertilizer, NPS fertilizer, and unmanaged controls. The symptoms include small greyish-brown spots and rounded/irregular to oval sunken spots limited by a yellow margin; irregular spoilt grey to slightly brown lesions with a light purple margin; necrotic spots with a yellow halo expanded on the leaf; mesophyll collapse; twig blight and dieback; and premature leaf drop. Dead leaves and twigs were covered with black fungal masses/spores by which the pathogen maybe spread. In the above-listed treatment plots, severe symptoms of citrus anthracnose were ascertained on the leaves during the last date of assessment. The symptoms observed on the lemon seedlings were consistent with those reported by other researchers from around the world (Aiello *et al.*, 2015; Ramose *et al.*, 2016; Rhaiem & Taylor, 2016; Mahiout *et al.*, 2018; Daoud *et al.*, 2019; Feyyaz *et al.*, 2020; Pérez-Mora *et al.*, 2020; Riolo *et al.*, 2021).

Laboratory results of the pathogen characterization exhibited the pathogen producing light grey to dark olive colonies, white fluffy and feathery aerial mycelium, plenty of spore masses having light to deep pink and dark-based *acervuli* on potato dextrose agar culture media, and the conidia were relatively cylindrical, straight, and obtuse at the apex as observed under a 40 x 10 magnification power compound microscope. These findings were typical cultural and morphological characteristics of *C. gloeosporioides* isolates that were reported by Huang *et al.* (2013), Aiello *et al.* (2015), Honger *et al.* (2016), Patricia *et al.* (2021) and Uysal *et al.* (2022). Therefore, *C. gloeosporioides* was the causal agent of citrus anthracnose, although *Colletotrichum* species are hard to ascertain based on cultural and morphological characteristics. To confirm the exact *C. gloeosporioides*, molecular characterization should be conducted for the pathogen. The pathogen was formerly believed to be the only *Colletotrichum* species inducing post-harvest citrus anthracnose (Brown, 1975; Sutton, 1992; Freeman, 1996). However, several of the most recent research studies have revealed that many species of *Colletotrichum* are related to pre-harvest anthracnose disease worldwide (Peng *et al.*, 2012; Weir *et al.*, 2012; Aiello *et al.*, 2015; Perrone *et al.*, 2016; Ramos *et al.*, 2016; Rhaiem & Taylor, 2016).

Analysis of Variance for the Study Parameters

Analysis of variance revealed various degrees of significant variations among the test treatments for mean squares of pest monitoring and agronomic parameters (Table 1). Interestingly, there were various degrees of significant ($P<0.05$ to $P<0.0001$) variation in the mean squares of replication for all disease scores, CLM percent infestation and larval density, CBF percent infection and injury level, and stem girth among the agronomic parameters. However, the rest of the agronomic parameters were shown to be non-significant ($P>0.05$) for the mean squares of the replication (Table 1). Significant differences in those parameters indicate differences in the response to disease development and insect pest occurrence, as well as increased stem girth as a result of either the sole or combined application of organic and inorganic fertilizers on the growing medium. The addition of different experimental materials to the study posts caused variations among the evaluated treatments.

Concerning treatment among the sources of variations, it showed different levels of significant (P<0.05 to P<0.0001) variations for the mean squares of anthracnose incidence and severity, CLM percent infestation and larval density, CBF percent infection and injury level, and agronomic characters (Table 1). This suggests a difference in the response to disease development, insect pest occurrence, and growth performance within the tested treatments on lemon seedlings during the study. Overall, the analysis of variance for the evaluated treatments exhibited various degrees of mean square values (low or high) of the study parameters (Table 1). The highest mean square values evoke the tested experimental materials for disease development, insect pest occurrence, and growth performance responded in a similar way across the replications. The lowest mean square values of anthracnose incidence and severity, CLM percent infestation and larval density, CBF percent infection and injury level, and agronomic characteristics across replications, on the other hand, could be attributed to the various responses of the evaluated experimental materials for disease development, insect pest occurrence, and growth performance (Table 2).

Citrus Anthracnose Intensity

Results obtained from the analysis of variance for citrus anthracnose incidence, severity, and AUDPC exhibited significant ($P<0.0001$) differences between and among treatments (Tables 1 & 2). It seems that citrus anthracnose was significantly influenced by the sole as well as the integrated use of organic and inorganic nutrient sources. According to the analysis of variance, the lowest mean anthracnose incidence (8.75%) and severity (5.64%) were noticed from plots maintained by sole application of powdered flower of

Table 1: Mean square values were obtained from the analysis of variance for the study parameters at Arba Minch in southern Ethiopia during the 2021 and 2022 cropping years

Source of variation	DF	Mean squares							
		DI_f (%)	PSI_f (%)	AUDPC (% days)	CLM PI_f (%)	CLM LD	CBF PI_f (%)	CBF IL_f (%)	
Replication	2	60.04****	25.16****	19977.14****	458.93****	2.29**	253.38***	947.03****	
Treatment	7	162.33****	115.91****	51576.10****	331.08****	1.55**	405.20****	840.38****	
Error	14	3.10	0.41	586.07	13.68	0.22	15.21	37.46	
F-value		45.04****	234.95****	76.02*****	26.28****	7.72***	24.41****	23.07****	
Grand mean		18.25	12.49	315.20	26.68	1.49	24.19	27.47	
CV (%)		9.65	5.11	7.68	13.86	31.69	16.13	22.28	
	DF	Mean squares							
		PH (cm)	MLPB (cm)	LA (cm²)	SG (cm)	NPB	NSB	NTB	TNLP
Replication	2	7.67ns	1.85ns	0.68ns	0.04*	2.58ns	5.49*ns	0.41ns	3540.70ns
Treatment	7	211.20**	31.93****	5.32***	0.11****	4.71*	4.11***	2.33****	7489.41***
Error	14	31.01	3.49	0.64	0.01	1.14	0.58	0.15	1553.53
F-value		7.52***	9.70****	8.20***	10.95****	3.57*	7.67***	12.34***	4.16***
Grand mean		56.12	19.27	11.79	0.86	10.85	6.30	1.80	237.98
CV (%)		9.92	9.71	6.80	9.85	9.83	12.05	21.83	16.56

DF=Degree of freedom; DI_f (%) = Citrus anthracnose disease incidence at final date of assessment; PSI_f (%) = Citrus anthracnose percent severity index at final date of assessment; AUDPC (%-days) = Citrus anthracnose area under disease progress curve; CLM PI_f (%) = Citrus leafminer percent infestation assessed at final date of assessment; CLM LV=Citrus leafminer larval density noted at final date of assessment; CBF PI_f (%) = Citrus butterfly percent infestation assessed at final date of assessment; CBF IL_f (%) = Citrus butterfly injury level scored at final date of assessment; PH (cm) = Plant Height (cm); MLPB (cm) = Mean length of primary branch; LA (cm²) = Leaf area; SG (cm) = Stem girth; NPB=Number of primary branches per plant; NSB=Number of secondary branches per plant; NTB=Number of tertiary branches per plant; TNLP=Total number of leaves per plant; **** = Significantly different at *P<0.0001*; *** = Significantly different at *P<0.001*; ** = Significantly different at *P<0.01*; * = Significantly different at *P<0.05*; ns=Not significant (*P>0.05*); CV=Coefficient of variation (%)

Table 2: Citrus anthracnose intensity as influenced by sole and integrated application of organic and inorganic source fertilizers in the study site at the last date of assessment, 2020 and 2021 years

Treatment	Citrus anthracnose intensity		
	Incidence (%)	Severity (%)	AUDPC (% days)
H. abyssinica (17 g, 33%) + FYM (1.7 kg, 33%) + NPS (32 g, 33%)	16.07[c]	10.37[d]	253.41[e]
H. abyssinica (25 g, 50%) + NPS (50 g, 50%)	16.69[c]	11.41[cd]	302.10[d]
H. abyssinica (25 g, 50%) + FYM (2.5 kg, 50%)	10.89[d]	7.03[e]	188.49[f]
FYM (2.5 kg, 50%) + NPS (50 g, 50%)	19.07[c]	12.30[c]	353.35[c]
H. abyssinica (50 g, 100%)	8.75[d]	5.64[f]	131.66[g]
FYM (5 kg, 100%)	18.38[c]	11.86[c]	331.21[cd]
NPS (100 g, 100%)	22.39[b]	15.45[b]	409.53[b]
Unmanaged control	32.79[a]	25.86[a]	551.85[a]
Grand mean	18.25	12.49	315.20
Coefficient of variation (%)	9.65	5.11	7.68
Least significant difference (5%)	3.08	1.11	42.39

Means followed by the same letter within the column are not significantly different at $P<0.05$. AUDPC=Area under disease progress curve assessed in % days

H. abyssinica, which was statistically similar to the incidence (10.89%) and severity (7.03%) values scored on plots maintained by integrated application of powdered flower of *H. abyssinica* + FYM. The unmanaged control plots, on the other hand, had the highest mean anthracnose incidence (32.79%) and severity (25.86%) (Table 2). On the other hand, the highest mean (551.85% days) AUDPC, which means the development and build-up of anthracnose on the whole plant or part of the plant during the epidemic periods, was recorded from the unmanaged control plots, while the lowest (131.665 days) mean AUDPC was recorded from the sole application of powdered flower of *H. abyssinica*, followed by the integrated application of *H. abyssinica* + FYM, in which the value of AUDPC was 188.49% days (Table 2). Comparatively, powdered flower of *H. abyssinica* and powdered flower of *H. abyssinica* + FYM applications reduced citrus anthracnose incidence, severity, and AUDPC by 73.32, 78.19 and 76.14%, and 66.79, 72.82 and 65.84%, respectively, compared with unmanaged control plots.

In this regard, the present study indicated that lemon seedlings with an optimal nutritional supply of organic and/or inorganic nutrient sources have the highest tolerance or resistance to anthracnose and other diseases that might not be observed under study since there are several seedling diseases of citrus crops as identified and reported by several scholars. Plot observation indicated that susceptibility increases as nutritional status deviates from this optimum and vice versa, for example, in unmanaged control plots. Depending on the amount and source of nutrients, plant nutrition can influence the tolerance or resistance of the plant against the disease and/or virulence of the pathogen. This could be because there were nutrient elements responsible for reducing disease development and increasing plant vigor.

Accordingly, Meyer (2000), Ramesh *et al.* (2005), Ullah *et al.* (2019), and Dowling *et al.* (2020) reported that organic fertilizers increase the ability of plants to resist or tolerate pest attacks and enhance the plant vigor during the growing periods. The incorporation of organic material into the soil may result in the invitation of beneficial soil biomes and the suppression of pathogenic agents due to the availability of responsible elements in the added organic materials, resulting in pest resistance and increased vigor. In this study, the sole application of powdered *H. abyssinica* flower resulted in the lowest anthracnose pressure compared to others, which could be due to the presence of active materials) that suppresses or retards disease development. Bonanomi *et al.* (2007), Cardoso *et al.* (2009), Ullah *et al.* (2019), Cheng *et al.* (2020) and Wu *et al.* (2021) for example, proposed that using organic materials as nutrient management could be an alternative to synthetic pesticides for managing plant diseases and insect pests. The authors also suggested that organic fertilizers may be more efficient in inducing growth and enhancing the resistance level of the plants against diseases and insect pests as compared to synthetic fertilizers.

Citrus Leafminer and Butterfly Intensity

The CLM percent infestation and larval density and the CBF percent infection and injury level on lemon seedlings were significantly ($P<0.01$ to $P<0.0001$) affected by the sole as well as integrated application of organic and inorganic source fertilizers (Tables 1 & 3). Snake-like mines and severely infested leaves had pale colour and curly badness due to CLM, and young foliage damage and consumption inwards from the top and margins due to CBF were first observed on the plots of unmanaged control, NPS fertilizer, FYM + NPS fertilizer, and powdered flower of *H. abyssinica* + NPS fertilizer at the time of occurrence. This observation was consistent with earlier research reports that confirmed the existence of variable symptoms of regular to irregular snake-like mines and curly leaves on severely infested leaves due to CLM (Stansly *et al.*, 1996; Pena *et al.*, 2000; Jesus *et al.*, 2006; Ullah *et al.*, 2019) and injuries or damage to the top and/or edges of the young leaves due to CBF (Murthy *et al.*, 2009; Sarada *et al.*, 2014; Vattikonda & Sangam, 2016; Khan & Molla, 2021; Pawandeep *et al.*, 2021).

Analysis of variance revealed that the lowest mean CLM percent infestation (10.36%), CLM larval density (0.49), CBF percent infection (7.42%), and CBF injury level (7.12%) were recorded from the sole application of powdered flower of *H. abyssinica*. However, it was not statistically different from *H. abyssinica* the application of powdered flower of *H. abyssinica* + FYM and powdered flower of *H. abyssinica* + FYM + NPS fertilizer correspondingly with 15.75 and 22.61% CLM percent infestation and 0.99 and 1.09 CLM larval density and 13.77 and 19.18% CBF percent infestation and 9.70 and 14.61% CBF injury level, respectively. Conversely, the highest mean CLM percent infestation (42.86%), CLM larval density (1.97), CBF percent infection (44.84%), and CBF injury level (54.96%) were noted from unmanaged control plots (Table 3). Highly mined due to CLM and injured leaves due to CBF were observed during the last date of assessment. Sole application of powdered flower of *H. abyssinica* and integrated application of powdered flower of *H. abyssinica* + FYM reduced mean CLM percent infestation,

Table 3: Effects of organic and inorganic fertilizer source nutrients on citrus leafminer and butterfly occurrence in the study site at the last date of assessment, 2020 and 2021

Treatment	Citrus leafminer intensity		Citrus butterfly intensity	
	PI_f (%)	LD_f	PI_f (%)	IL_f (%)
H. abyssinica (17 g, 33%) + FYM (1.7 kg, 33%) + NPS (32 g, 33%)	22.61^{de}	1.09^{de}	19.18^{de}	14.61^{de}
H. abyssinica (25 g, 50%) + NPS (50 g, 50%)	27.52^{cd}	1.42^{b-d}	21.38^{d}	23.84^{cd}
H. abyssinica (25 g, 50%) + FYM (2.5 kg, 50%)	15.75^{e}	0.66^{de}	13.77^{ef}	9.70^{e}
FYM (2.5 kg, 50%) + NPS (50 g, 50%)	36.08^{b}	1.92^{ab}	29.92^{bc}	36.80^{b}
H. abyssinica (50 g, 100%)	10.36^{e}	0.49^{e}	7.42^{f}	7.12^{e}
FYM (5 kg, 100%)	27.23^{cd}	1.71^{bc}	24.86^{cd}	31.34^{bc}
NPS (100 g, 100%)	31.06^{bc}	1.97^{ab}	32.14^{b}	41.41^{b}
Unmanaged control	42.86^{a}	1.97^{ab}	44.84^{a}	54.96^{a}
Grand mean	26.68	1.49	24.19	27.47
Coefficient of variation (%)	13.86	31.69	16.13	22.28
Least significant difference (5%)	6.47	0.82	6.83	10.71

Means followed by the same letter within the column are not significantly different at $P<0.05$. PI=Percent infestation at final date of assessment; LD=Larval density at final date of assessment; and IL_f (%) = Injury level at final date of assessment

CLM larval density, CBF percent infection, and CBF injury level by 75.83, 75.13, 63.25, and 66.50%, and 83.45, 87.05, 69.29, and 82.35%, respectively, as compared to unmanaged controls. Overall, CLM and CBF pressure were comparatively higher in unmanaged control than in well-managed plots (Table 3).

Citrus leafminer and CBF are major insect pests that attack seedlings and negatively impact growth performance. The influence of the organic and inorganic source nutrient application on CLM and CBF was found to be significant, as indicated by lower pressure compared with unmanaged controls (Table 3). The CLM and CBF activities remained lower on the seedlings getting the organic fertilizer, especially with the sole application of powdered flower of *H. abyssinica* and integrated application of powdered flower of *H. abyssinica* + FYM, compared with synthetic fertilizer, NPS fertilizer. Other related studies also confirmed that citrus trees showed variable responses to various sources of nutrients for insect pests. For instance, Godase and Patel (2001), Phelan (2004), Mustafa *et al.* (2014) and Ullah *et al.* (2019) reported that insect pests were significantly reduced after the application of organic fertilizer during the study. Inorganic fertilizers may reduce plant tolerance or resistance to insect pests by improving nutritional quality, allowing the plant to become more succulent and have fresh leaves (Fragoyiannis *et al.*, 2001; Herms, 2002; Ullah *et al.*, 2019; Mangrio & Sahito, 2021). As reported by Jaafar *et al.* (2013), Ullah *et al.* (2019) and Mangrio and Sahito (2021), female insect pests of citrus crops prefer young leaves for their egg-laying; thus, inorganic fertilizer could be of assistance to enhance their population.

The current study findings were in accordance with previous scholars who reported that insect pests of citrus crops do not choose the plants maintained with organic fertilizer, and the highest intensity was observed on the plants managed with inorganic fertilizers (Godase & Patel, 2001; Biradar *et al.*, 2009; Rao *et al.*, 2013). Fertilizer, either from organic or inorganic sources, provides the essential nutrients to the plant that are vital for development and growth and helps them resist or tolerate diseases and insect pests if it is applied at the right time with the right amounts or rates. An excessive amount of nitrogen-source fertilizers significantly affects plants, as explained by more vegetative growth with new, soft, and succulent leaves, which can be helpful for pest attacks. Herms (2002), Arancon *et al.* (2005), Schumann *et al.* (2010) and Mangrio *et al.* (2020) reported that the optimum rate or amount of macro- and micronutrients in the tissue of citrus plants could aid in decreasing the pest pressure. Overall, seedlings with an optimal nutritional status, besides the insecticidal properties of some organic source fertilizers, like *H. abyssinica*, have the highest resistance to insect pests, and susceptibility increases as nutritional status deviates from optimum conditions and the loss of insecticidal properties of the fertilizers.

Effects of Organic and Inorganic Nutrient Sources on Growth Parameters

Plant height, MLPB, LA, SG, NPB, NSB, NTB, and TNLP were significantly ($P<0.05$ to $P<0.0001$) varied between and among the evaluated treatments (Tables 1 and 4a, b). The tallest (69.45 cm) mean PH was assessed on the powdered flower of *H. abyssinica* applied plots, which was statistically similar to FYM (66.31 cm) and FYM + NPS fertilizer (60.11 cm) applied plots. The shortest (45.37 cm) mean PH was noted from unmanaged control plots (Tables 4a & b). Plots with nutritionally maintained FYM and powdered flower of *H. abyssinica* were ranked first in the same mean statistically significant differences for MLPB, LA, SG, NPB, NSB, and TNLP, and the remaining treatments also differed from each other. *H. abyssinica*-applied plots took the highest (3.55) mean NTB, followed by FYM-applied plots (2.41). The lowest mean MLPB, LA, SG, NPB, NSB, NTB, and TNLP were noted from unmanaged control, which was not statistically different from NPS fertilizer (Tables 4a & b).

Growth performance is highly affected by the application of powdered flowers of *H. abyssinica*, showing that the rise in growth parameters could be due to the fact that plants receive an optimum supply of nutrients during the entire course of growth, ultimately leading to more accumulation of metabolites, resulting in high growth performance of the seedlings. In this study, the application of organic source fertilizers showed a

Table 4a: The effect of organic and inorganic fertilizers applied alone and in combination on lemon seedlings' height, primary branch length, leaf area, and stem girth in the study site during the crop years 2020 and 2021

Treatment	PH (cm)	MLPB (cm)	LA (cm^2)	SG (cm)
H. abyssinica (17 g, 33%) + FYM (1.7 kg, 33%) + NPS (32 g, 33%)	54.31^{bc}	19.67^{bc}	12.48^{a-c}	0.88^{b}
H. abyssinica (25 g, 50%) + NPS (50 g, 50%)	51.88^{bc}	18.43^{c}	11.08^{d}	0.82^{bc}
H. abyssinica (25 g, 50%) + FYM (2.5 kg, 50%)	51.75^{bc}	19.64^{bc}	11.92^{b-d}	0.76^{b-d}
Farm yard manure (2.5 kg, 50%) + NPS (50 g, 50%)	60.11^{ab}	18.58^{c}	11.36^{cd}	0.80^{bc}
H. abyssinica (50 g, 100%)	69.45^{a}	24.28^{a}	13.13^{ab}	1.11^{a}
Farm yard manure (5 kg, 100%)	66.31^{a}	22.68^{ab}	13.43^{a}	1.22^{a}
NPS fertilizer (100 g, 100%)	49.83^{c}	17.33^{c}	11.78^{b-d}	0.71^{cd}
Unmanaged control	45.37^{c}	13.56^{d}	9.19^{e}	0.61^{d}
Grand mean	56.12	19.27	11.79	0.86
Coefficient of variation (%)	9.92	9.71	6.80	9.85
Least significant difference (5%)	9.75	3.27	1.40	0.14

Means in the same column followed by the same letter (s) are not statistically different at the 5% level of significance according to RCBD.
PH (cm) = Plant Height measured in cm; MLPB (cm) = Mean length of primary branch measured in cm; LA=Leaf area computed as cm^2; and SG (cm) = Stem girth appraised in cm

Table 4b: Main branch length and number of primary, secondary, and tertiary leaves of lemon seedlings as influenced by sole and integrated application of organic and inorganic fertilizers in the study site during the crop years 2020 and 2021

Treatment	NPB	NSB	NTB	TNLP
H. abyssinica (17 g, 33%) + FYM (1.7 kg, 33%) + NPS (32 g, 33%)	11.55^{a-c}	7.13^{a-c}	2.03^{bc}	218.66^{bc}
H. abyssinica (25 g, 50%) + NPS (50 g, 50%)	10.07^{cd}	5.95^{cd}	1.51^{cd}	228.40^{bc}
H. abyssinica (25 g, 50%) + FYM (2.5 kg, 50%)	9.91^{cd}	6.20^{b-d}	1.37^{c-e}	229.00^{bc}
Farm yard manure (2.5 kg, 50%) + NPS (50 g, 50%)	10.70^{b-d}	5.75^{de}	1.73^{bc}	237.54^{b}
H. abyssinica (50 g, 100%)	12.91^{a}	7.97^{a}	3.55^{a}	310.50^{a}
Farm yard manure (5 kg, 100%)	12.27^{ab}	7.53^{ab}	2.41^{b}	310.30^{a}
NPS fertilizer (100 g, 100%)	9.75^{cd}	5.36^{de}	0.99^{de}	204.21^{bc}
Unmanaged control	9.63^{d}	4.49^{e}	0.79^{e}	165.19^{c}
Grand mean	10.85	6.30	1.80	237.98
Coefficient of variation (%)	9.83	12.05	22.38	16.56
Least significant difference (5%)	1.86	1.32	0.70	69.02

Means in the same column followed by the same letter (s) are not statistically different at the 5% level of significance according to RCBD. NPB=Number of primary branches per plant; NSB=Number of secondary branches per plant; NTB=Number of tertiary branches per plant; and TNLP=Total number of leaves per plant

considerable effect on the citrus anthracnose, CLM, and CBF, as well as the growth performance of lemon seedlings. These findings regarding the fruitful suppression of citrus diseases and insect pests and enhancement of growth performance using organic source fertilizers are supported by earlier studies (Ramesh *et al*., 2005; Assefa *et al*., 2010; Dheware *et al*., 2010; Mustafa *et al*., 2014; Lakra *et al*., 2019). Among all study parameters (pest monitoring and growth characters), the powdered flower of *H. abyssinica* was given the best result in improving seedling growth and reducing disease and insect pest pressures (Tables 2, 3, 4a & b). Thus, the application of powdered flowers of *H. abyssinica*, followed by FYM, might be suggested, as it exhibited a high rank in most of the study parameters to reduce pest pressure and obtain high growth performance of lemon seedlings.

Correlation of Pest Intensity and Agronomic Characters

Using simple correlation analysis, the correlations between pest monitoring parameters (citrus anthracnose incidence, severity, and AUDPC; CLM percent infestation and larval density; and CBF percent infestation and injury level) and growth characteristics (PH, MLPB, LA, SG, NPB, NSB, NTB, and TNLP) were investigated. Variable degrees of associations were found between and among study parameters (Table 5). The findings revealed highly significant positive associations (r = 0.87****, 0.82****, and 0.96****) as well as highly significant ($P<0.0001$) correlations between disease incidence and severity, incidence and AUDPC, and severity and AUDPC. This result indicated that disease parameters were discovered to be interconnected and that the disease advanced faster on unmanageable plots than on manageable plots. Campbell and Madden (1990) and Agrios (2005) stated that disease parameters are considerably connected to each other during outbreak periods. Interestingly, disease scores and insect pest monitoring parameters showed very strong positive and highly significant ($P<0.01$ to $P<0.0001$) association (Table 5). Previous studies also confirmed similar associations between plant disease and insect pest monitoring parameters in citrus crops (Chagas *et al*., 2001; Jesus *et al*., 2006).

On the other hand, a highly negative and significant ($P<0.05$ to <0.0001) correlation was observed between disease scores, insect pest monitoring parameters, and growth characteristics (Table 5). For instance, DI_f had a negative and highly significant association with PH (r = –0.54***), MLPB (r = –0.54**), LA (r = –0.59**), SG (r = –0.65***), NPB (r = –0.43*), NSB (r = –0.54**), NTB (r = –0.56**), and TNLP (r = –0.53**). Comparable fashions of correlations between other disease scores, insect pest monitoring, and growth parameters were observed, although some of the parameters exhibited non-significant correlations in the study (Table 5). The inverse correlation between disease scores, insect pest monitoring parameters, and growth characteristics informs us that the observed degrees of pest intensity exhibited a significant adverse consequence on the growth performance of lemon seedlings.

Table 5: Correlation coefficients (*r*) between pest intensity and agronomic characters of lemon at Arba Minch in southern Ethiopia during the 2020 and 2021 cropping years

Parameters	DI_f	PSI_f	AUDPC	CLM PI_f	CLM LD	CBF PI_f	CBF IL_f	PH	MLPB	LA	SG	NPB	NSB	NTB	TNLP
DI_f	1	0.87****	0.82****	0.72****	0.77****	0.91****	0.88****	-0.54**	-0.59**	-0.65***	-0.57**	-0.43*	-0.54**	-0.56**	-0.53**
PSI_f	*<0.0001*	1	0.96****	0.85****	0.76****	0.76****	0.69***	-0.55**	-0.67***	-0.70***	-0.51*	-0.45*	-0.50*	-0.56**	-0.48*
AUDPC	*<0.0001*	*<0.0001*	1	0.92****	0.81****	0.73****	0.67***	-0.48*	-0.59**	-0.64***	-0.48*	-0.41*	-0.48*	-0.60**	-0.39ns
CLM PI_f	*<0.0001*	*<0.0001*	*<0.0001*	1	0.88****	0.59**	0.58**	-0.42*	-0.46*	-0.56**	-0.35ns	-0.22ns	-0.22ns	-0.50*	-0.28ns
CLM LD	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	1	0.64***	0.70***	-0.28ns	-0.30ns	-0.54**	-0.25ns	-0.16ns	-0.17ns	-0.37ns	-0.12ns
CBF PI_f	*<0.0001*	*<0.0001*	*<0.0001*	*<0.01*	*<0.001*	1	0.92****	-0.52**	-0.60**	-0.63**	-0.61**	-0.44*	-0.60**	-0.58**	-0.50*
CBF IL_f	*<0.0001*	*<0.0001*	*<0.001*	*<0.01*	*<0.001*	*<0.0001*	1	-0.35ns	-0.51*	-0.59**	-0.49*	-0.42*	-0.51*	-0.45*	-0.45*
PH	*<0.01*	*<0.01*	*<0.05*	*<0.05*	*>0.05*	*<0.01*	*>0.05*	1	0.75****	0.58**	0.77****	0.59**	0.62**	0.75****	0.70***
MLPB	*<0.01*	*<0.001*	*<0.01*	*<0.05*	*>0.05*	*<0.01*	*<0.05*	*<0.0001*	1	0.77****	0.78****	0.69***	0.76****	0.73****	0.86****
LA	*<0.001*	*<0.001*	*<0.001*	*<0.01*	*<0.01*	*<0.01*	*<0.01*	*<0.01*	*<0.0001*	1	0.66***	0.77****	0.54**	0.57**	0.61**
SG	*<0.01*	*<0.05*	*<0.05*	*>0.05*	*>0.05*	*<0.01*	*<0.05*	*<0.0001*	*<0.0001*	*<0.001*	1	0.69***	0.80****	0.79****	0.79****
NPB	*<0.05*	*<0.05*	*<0.05*	*>0.05*	*>0.05*	*<0.05*	*<0.05*	*<0.01*	*<0.001*	*<0.0001*	*<0.001*	1	0.77****	0.75****	0.76****
NSB	*<0.01*	*<0.05*	*<0.05*	*>0.05*	*>0.05*	*<0.01*	*<0.05*	*<0.01*	*<0.0001*	*<0.01*	*<0.0001*	*<0.0001*	1	0.77****	0.71****
NTB	*<0.01*	*<0.01*	*<0.01*	*<0.05*	*>0.05*	*<0.01*	*<0.05*	*<0.0001*	*<0.0001*	*<0.01*	*<0.0001*	*<0.0001*	*<0.0001*	1	0.77****
TNLP	*<0.01*	*<0.05*	*>0.05*	*>0.05*	*>0.05*	*>0.05*	*<0.05*	*<0.001*	*<0.0001*	*<0.01*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	1

DI_f (%) = Citrus anthracnose disease incidence at final date of assessment; PSI_f (%) = Citrus anthracnose percent severity index at final date of assessment; AUDPC (%-days) = Citrus anthracnose area under disease progress curve; CLM PI_f (%) = Citrus leafminer percent infestation assessed at final date of assessment; CLM LV=Citrus leafminer larval density noted at final date of assessment; CBF PI_f (%) = Citrus butterfly percent infestation assessed at final date of assessment; CBF IL_f (%) = Citrus butterfly injury level scored at final date of assessment; PH (cm) = Plant Height (cm); MLPB (cm) = Mean length of primary branch; LA (cm^2) = Leaf area; SG (cm) = Stem girth; NPB=Number of primary branches per plant; NSB=Number of secondary branches per plant; NTB=Number of tertiary branches per plant; TNLP=Total number of leaves per plant; and ns=Correlation is not significant (*P>0.05*)

Earlier scholars stated that pest monitoring parameters had a strong association with the host's growth and cell differentiation, which is elucidated by the retardation of physiological functions of the crop. As a result, it retards the agronomic traits of the crop (Campbell & Madden, 1990; Guant, 1995; Stansly *et al.*, 1996; Agrios, 2005). In this study, growth parameters showed a strong positive and noteworthy association among themselves. For instance, PH had a positive and significant connection with days to MLPB, LA, SG, NPB, NSB, NTB, and TNLP. Similarly, other growth parameters also had positive and significant relationships with one another in the study (Table 5). Guant (1995) and Stansly *et al.* (1996) found the agronomic parameters had a positive and substantial relationship with one another.

CONCLUSION AND RECOMMENDATION

Based on the results of the present study, citrus anthracnose, leafminer, and butterfly were major seedling constraints of lemon. The application of organic and inorganic fertilizers reduced pest occurrence and enhanced the growth performance of lemon seedlings. Considering the results obtained, it is concluded that the powdered flower of *H. abyssinica* (50 g, 100%) was found to be preeminent and effective in terms of lower citrus anthracnose, leafminer, and butterfly intensity with higher plant height, length of primary branches, leaf areas, stem girth, number of primary, secondary, and tertiary branches, and total number of leaves per plant compared to unmanageable control and other evaluated treatments. Therefore, it is auspicious to grow lemon seedlings with powdered flowers of *H. abyssinica* along with farmyard manure fertilization and other seedling management approaches to manage citrus anthracnose, leafminer, and butterfly in the nursery. Further study should be conducted in some place and time to reach a concrete recommendation for managing the listed diseases and insect pests or other factors if they occur during the nursery. Additionally, much more research can be done with the powdered flower of *H. abyssinica* on quality as well as quantity and the effects on citrus anthracnose, leafminer, and butterfly, and the mechanisms by which the powdered flower of *H. abyssinica* fertilization reduces the listed disease and insect pests. Moreover, molecular characterization is compulsory to know the overall nature of the exact *C. gloeosporioides* infecting lemon seedlings.

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AUTHORSHIP CONTRIBUTIONS

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