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Physical characteristics of several corn varieties and the interaction between planting patterns and varieties on pest attacks *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) and ant population *Oecophylla smaragdina* (Fabricius)

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The selection of superior maize varieties and appropriate planting arrangements plays a crucial role in improving crop productivity and managing pest infestations. *Spodoptera frugiperda* (fall armyworm) is a major pest in maize cultivation, while natural predators such as *Oecophylla smaragdina* (weaver ants) offer potential for biological control. This study aimed to examine the effects of two planting models and seven maize varieties on agronomic traits, grain yield, pest damage, and predator abundance. A split-plot randomized block design was implemented with three replications. The main plots consisted of two planting arrangements: the conventional tile pattern (70 cm × 40 cm) and the legowo 2:1 system ((50 cm × 35 cm) × 90 cm). Sub-plots included seven maize varieties: Srikandi Kuning, Pulut Uri, Provit A1, Anoman, Srikandi Ungu, Bisma, and Sukmaraga, each grown in 150 m^2 plots. Results showed significant varietal differences in plant height (168.78 -219.30 cm), leaf area (6.60 -7.85 cm^2), flowering time (45.33 -49.00 days), and ear height (89.42 -119.32 cm). The legowo 2:1 planting model significantly increased grain yield (7.89 t ha^{-1}) compared to the tile model (5.38 t ha^{-1} and reduced leaf (19.12% vs. 21.26%) and cob damage (11.58% vs. 13.09%) by *S. frugiperda*. Larval density varied among varieties, with Bisma showing the lowest incidence (0.43 larvae per plant; 12.32% leaf damage, 8.80% cob damage) and Sukmaraga the highest (1.23 larvae per plant; 25.23% leaf, 15.03% cob damage). Weaver ant abundance was negatively correlated with pest population and damage intensity. Biplot analysis indicated that Bisma performed best under the legowo system, while Anoman showed optimal performance under the tile model. These findings suggest that integrating the appropriate planting configuration with resistant maize varieties can enhance productivity and reduce pest damage, offering valuable strategies for sustainable maize cultivation.

KEYWORDS

maize varieties, planting model, *Spodoptera frugiperda*, *Oecophylla smaragdina*, seed yield

1 Introduction

Corn is a C4 cereal plant that has many benefits for human life. Generally, corn is used as a source of feed, food, and as a source of raw materials for industry (Wang et al., 2021; Erenstein et al., 2022). Corn generally contains 72% starch in dry form and is low in fiber. Starch is found in the endosperm as granules in a protein matrix. Corn has a relatively low protein content, ranging from 7 to 14%, depending on the cultivation conditions and the type of corn cultivated (Loy and Lundy, 2019).

The average productivity of corn plants in Indonesia over the past 5 years has only reached 5.58 t ha^{-1} (Central Bureau of Statistics, 2023). This grain yield is still very far compared to the 3 world corn production centers, such as the USA, Russia, and China, which average 7.5 t ha^{-1} per year (FAO, 2023). The difference in corn production is greatly influenced by environmental factors and plant cultivation techniques (Below and Seebauer, 2019; Bhat et al., 2024). Cultivation techniques play an essential role in influencing corn yields. Several cultivation techniques that affect seed production include variety selection, soil cultivation systems, planting models, fertilization, and control of plant pests (Baudron et al., 2019; Mutyambai et al., 2022). Several of these techniques are interrelated with the optimum growing environment, such as good soil conditions, availability of nutrients for plants, and the presence of pests in the field (Constantine et al., 2020; Nurkomar et al., 2023; Bhat et al., 2024). Therefore, selecting the right variety with optimal cultivation techniques is key to increasing corn seed production.

Indonesia has produced several corn varieties that have different advantages, such as Srikandi Kuning, Srikandi Ungu, Pulut Uri, Provit A1, Anoman1, Bisma, and Sukmaraga (Purba and Hadiatry, 2022). According to Rahmi et al. (2020), the Srikandi Kuning variety has a plant height of around 185 cm, a flowering age of 56–58 days, and is resistant to stem borers. The Pulut Uri variety has a plant height of around 177 cm, a flowering age of 50 days, and is somewhat resistant to downy mildew. Likewise, the Srikandi Ungu variety has a plant height of around 194 cm, a flowering age of 51 days, and is somewhat resistant to downy mildew. Meanwhile, the Bisma variety has a plant height of around 190 cm, a flowering age of 60 days, and is resistant to lodging. Sukmaraga has a plant height of around 200–220 cm, a flowering age of 58 days, and is adaptive to acidic soil. The Anoman-1 variety has a plant height of around 161 cm, a flowering age of 55 days, and is resistant to downy mildew disease (Description of Superior Corn Varieties, 2016).

In addition to the variety factor, the corn planting model is a component of the cultivation technique that can affect corn productivity. The right planting model and spacing can increase plant population, affecting plant productivity (Haarhoff and Swanepoel, 2022). One planting model that can affect corn productivity is legowo 2:1. This planting model is a modification of the planting distance model (70 cm × 40 cm), which is commonly used as a legowo plant model with a planting distance of (50 cm × 35 cm) × 90 cm. The legowo 2: 1 planting pattern has several advantages, such as placing all plants as edge plants, which can facilitate weed and pest control and affect the increase in the planting index (Sulaeman et al., 2024). The legowo 2:1 planting model can optimize sunlight absorption, air circulation, and better soil nutrient competition to increase corn productivity positively. The study of Liu et al. (2022) stated that plant spacing has a significant effect on the efficiency of resource utilization and seed yields. Furthermore, Zhao et al. (2022) noted that the of plant variety also significantly affects seed yield through differences in plant height, cob height, number of leaves, leaf segment length, leaf angle, leaf orientation value, leaf area, exceptional density, canopy structure, differences in light distribution ability, light absorption interception, leaf area, and photosynthesis rate.

Another factor that affects corn productivity is the level of pest attack. One type of pest that most affects corn productivity is *S. frugiperda* (FAW). According to Kumela et al. (2018) the pest that causes the most damage to corn plants is *S. frugiperda* (FAW). *S. frugiperda* pests are polyphagous and attack more than 353 plant species, especially the *Poaceae* family (106 taxa), *Asteraceae*, and *Fabaceae* (31 taxa each) (Montezano et al., 2018). *S. frugiperda* is often found in cereal plants (Herlinda et al., 2022; Nurkomar et al., 2023). Furthermore, Baudron et al. (2019) stated that *S. frugiperda* can damage corn plants at all phases of plant growth and cause relatively high grain yield losses. The damaging power of *S. frugiperda* can occur at all stages of plant growth and cause relatively high yield losses to crop failure (Kumela et al., 2018; Baudron et al., 2019). This condition generally occurs in corn plantations planted in lowlands with a monoculture system accompanied by a row-per-tile planting model (Mutyambai et al., 2022).

This study aims to determine the characteristics of corn varieties and find the right interaction model between planting models and corn varieties to increase corn grain productivity. In addition, this study also aims to determine the effect of planting models and varieties on the population and level of damage to corn plants due to attacks by major corn pests and the population of natural enemies of weaver ants *O. smaragdina*. The results of this study are expected to be a reference or policy recommendation for farmers, extension workers, the private sector, the government, and other stakeholders.

2 Materials and methods

2.1 Research location and research design model

This research was conducted from June 2021 to January 2022 at a the farmer field located in the lowlands of Pa′bundukang village, South Bontonompo sub-district, Gowa Regency, South Sulawesi Province, Indonesia, located at 5.234783°S and 119.223958°E. This area has a dominant clay soil type, a small part of dusty clay at 4 meters above sea level. When the study was conducted, this area had an average rainfall with an intensity of 318.56 mm (Central Bureau of Statistics, 2022), average temperature 27.37\u00B0C, duration of sunlight: 6.13 h/day, and humidity 82.69% (Indonesian Agency for Meteorological, Climatological and Geophysics, 2022).

The experimental design used a Randomized Block Design Split Plot Model with 2 factors. The first factor in the main plot is the planting model, which consists of (1) a tile planting model (70 cm × 40 cm) and (2) a legowo planting model (2:1) (50 cm × 35 cm) × 90 cm. The second factor is the type of variety as a sub-plot consisting of 7 varieties: (1) Srikandi Kuning, (2) Pulut Uri, (3) Provit A1, (4) Anoman, (5) Srikandi Ungu, (6) Bisma, and (7) Sukmaraga. The number of treatment combinations is 14, each repeated 3 times. Treatment testing (1) Tile planting model + yellow Srikandi variety, (2) Tile planting model + Pulut Uri variety, (3) Tile planting model + Provit A1 variety, (4) Tile planting model + Anoman variety, (5) Tile planting model + Purple Srikandi variety, (6) Tile planting model + Bisma variety, (7) Tile planting model + Sukmaraga variety, (8) 2:1 legowo planting model + Yellow Srikandi variety, (9) 2:1 legowo planting model + Pulut Uri variety, (10) 2:1 legowo planting model + Provit A1 variety, (11) 2:1 legowo planting model + Anoman variety, (12) 2:1 legowo planting model + Srikandi Ungu variety, (13) 2:1 legowo planting model + Bisma variety, and (14) 2:1 legowo planting model + varieties Sukmaraga. Each treatment was planted on a plot measuring 3 m × 5 m with 2 seeds per planting hole. Fertilization was carried out using NPK compound fertilizer (15:15:15) with a dose of 300 $kg.ha^{-1}$. Fertilizer application was carried out on plants aged 15 and 30 days after planting using a ditch with a distance of 5 cm from the plant growth hole.

2.2 Data collection and observation

The parameters observed included plant height, leaf width, level of leaf damage, level of *S. frugiperda* population larvae, *O. smaragdina* weaver ant predator population, cob height, 50% flowering age, and seed yield. Observations of the parameters of the level of cob damage and seed yield were observed at the age of 105–115 days after planting. Observations of these agronomy parameters were carried out conventionally by following the guidelines for observing the morphology of corn plants (IBPGR, 2013). Observations of the *S. frugiperda* population larvae and the *O. smaragdina* population were calculated based on the average population of insect species on each plant in the same treatment plot. Observations of the level of leaf damage were calculated using the following formula (Fattah et al., 2020).

$$I = \frac{\sum_{i=0}^{z}\left(n1 \times v1\right)}{Z \times N} \times 100$$

I: Intensity of damage
n_i: the number of leaf with a v_i scale
N: Number of leaves observed.
Z: The higher v_i.
Scale value v_i:
0: no damage on leaves
1: leaf damage >0–20%
3: leaf damage >20–40%
5: leaf damage >40–60%
7: leaf damage >60–80%
9: leaf damage >80–100%

2.3 Data analysis

The research data were analyzed using Ms. Excell, Minitab V. 20, and R Studio V. 4.2.2 applications. All observation data related to agronomic performance, *S. frugiperda* population, *O. smaradigna* population, percentage of leaf damage, and percentage of cob damage were analyzed using factorial analysis of variance and LSD test at 0.05 probability. Correlation analysis using the pairwise Pearson method and biplot analysis of genotype ranking patterns based on 4 main data groups, namely *S. frugiperda* population, percentage of leaf damage, rate of cob damage, and seed yield.

3 Results and discussion

3.1 Physical characteristics of seven superior national corn varieties

The Srikandi Kuning variety has physical characteristics of weight of 1,000 seeds around 275 g, yellow seed color, semi-pearl seed shape, harvest age of 105–110 days, weight of 1,000 seeds around 275 g and resistance to corn stem borer (Table 1). The weight of 1,000 seeds is lower than the results of research by Sirappa and Nurdin (2010), the Srikandi Kuning variety has a weight of 1,000 seeds around 285.53 g and the number of rows per cob around 14.40 rows. While Pulut Uri has the characteristics of white seed color, the number of rows per cob is 14–16 rows, the weight of 1,000 seeds is 356 g, the harvest age is around 85 days, and is somewhat resistant to downy mildew disease (Jamidi et al., 2022).

Bisma variety has a harvest age of 96 days, the number of rows per cob is 14.13, the color of the seeds is yellow, the weight of 1,000 seeds is 307 g, and it is somewhat resistant to lodging. The Sukmaraga variety has a harvest age of 105–110 days, the number of rows per cob is 15.33, the color of the seeds is dark yellow, the weight of 1,000 seeds is 270, and it is adaptive to acidic soil. According to Etika et al. (2016) the weight of 1,000 seeds of the Srikandi Kuning variety is 200.89 g,

TABLE 1 Characteristics of seven varieties of food corn based on the description of corn varieties.

Varieties	Harvest age (days)	Number of rows per cob (row)	Seed shape	Seed color	Weight of 1,000 seeds (g)	Other advantages
Srikandi Kuning	105–110	14.87	Semi pearl	Modified hard/ yellow	275	Resistant to stem borers
Pulut Uri	85	14–16	Dent	White	356	Somewhat resistant to downy mildew
Provit A1	96	12–14	Semi pearl	White	318	Adaptive to dry land
Anoman-1	103	14–18	Horse tooth	White	320	Resistant to downy mildew
Srikandi Ungu	87	12–14	Mutiara	Purple	311,1	Resistant to downy mildew
Bisma	96	14.13	Mutiara	Yellow	307	Resistant to lodging
Sukmaraga	105–110	15.33	Semi pearl	Old yellow	270	Adaptive to acidic land

Source: Description of superior corn varieties (2016).

Bisma is 170.11 g, and the number of rows per cob of Srikandi Kuning is 14.33 rows and Bisma is 11.78 rows.

3.2 Agronomic performance of several varieties of food corn

The results showed a significant effect of planting model treatment on yields (6.63, $p \leq 0.01$) but did not significantly affect the agronomic performance of corn plants. Separately, differences in variety types significantly affected agronomic performance such as plant height (168.78–219.30 cm, $p \leq 0.001$), leaf area (6.60–7.85 cm, $p \leq 0.01$), flowering age (45.33–49.00 dap, $p \leq 0.01$), and cob height (83.42–119.32 cm, $p \leq 0.01$) (Table 1). Factors that affect plant performance and yield are variety and its interaction with the growing environment. According to Uberti et al. (2023) state that some varieties can only grow well and produce high yields in a supportive environment. Morphological traits are essential in achieving optimum seed yield (Xu et al., 2024). Furthermore, Dias et al. (2019) stated that differences significantly influence variations in agronomic performance of corn plants in varieties and distance between plants.

In plant height plant performance, the highest value was in Sukmaraga (219.30 cm), and the lowest was in Srikandi Ungu (168.78 cm). The most expansive leaf area was Srikandi Kuning (7.85 cm), and the lowest was Srikandi Ungu (6.60 cm). The highest flowering age was Bisma (49 daps), and the lowest was Pulut Uri (45.33 daps). The highest cob position was in Bisma (124.08 cm), and the lowest was Srikandi Ungu (83.42 cm). The legowo 2:1 planting pattern gave a higher yield (7.89 t ha^{-1}) compared to the farmer's planting model (5.38 t ha^{-1}) (Table 1). Plant and cob height and cob ratio affect changes in plant seed yield (Liu et al., 2022). A plant height of around 240–300 cm can optimize harvest yields and avoid the risk of lodging (Qin et al., 2016). The ability of the quantity and quality of plant variety production results from plant breeding, including the selection of plant characters with smaller leaf angles and large leaf orientation values (Liu et al., 2022; Zhao et al., 2022).

Plant arrangement with a 2:1 legowo planting pattern can avoid the effects of the canopy structure of corn varieties with wide leaf angles on reducing sunlight intensity at the bottom of the canopy. The vast planting distance between every two rows of plants (90–100 cm) is expected to increase light penetration to the base of the plant stem in each row. This study showed a significant increase in production using the 2:1 legowo planting pattern of 46% from the tile planting pattern (Table 2). An increase in plant population of 57.8% has the potential to increase seed yields by 11.2% (Shao et al., 2024). Using the

TABLE 2 Effect of plant spacing and maize varieties on some agriculture performance, and seed yield of maize.

Plant spacing	Plant height (cm)	Leaf width (cm)	Tasseling age (dap)	Cob height position (cm)	Seed yield (th^{-1})
Farmers	191.87 a	7.48 a	47.86 a	98.88 a	5.38 b
Legowo 2:1	201.21 a	7.12 a	47.48 a	112.64 a	7.89 a
Mean	196.54	7.30	47.67	105.76	6.63
LSD	16.14	0.78	0.54	13.93	0.41
Maize varieties					
Srikandi Kuning	207.25 ab	7.85 a	48.00 abc	119.32 ab	6.80 a
Pulut Uri	177.63 de	6.85 bc	45.33 d	88.78 c	6.20 a
Provit A1	188.52 cd	7.68 ab	47.00 c	99.87 bc	6.08 a
Anoman	196.42 bc	7.45 abc	47.33 bc	110.58 ab	7.20 a
Srikandi Ungu	168.78 e	6.60 c	48.33 ab	83.42 c	6.68 a
Bisma	217.90 a	7.20 abc	49.00 a	124.08 a	7.30 a
Sukmaraga	219.30 a	7.48 ab	48.67 a	114.25 ab	6.18 a
Mean	198.02	7.27	47.76	105.79	6.63
LSD	17.34	0.87	1.10	20.14	2.24
Significance level					
Plant spacing	NS	NS	NS	NS	**
Maize varieties	***	**	***	**	NS
Plant spacing × maize varieties	NS	NS	NS	NS	NS

Means followed by a different letter (s) in a column differ significantly from the LSD test at 0.05 probability. NS, Non significant. **Highly significant at $p \leq 0.01$. ***Highly significant at $p \leq 0.001$. Dap, day after planting.

right varieties with the right planting distance innovation is a practical strategy to increase corn production (Assefa et al., 2018; Liu et al., 2022). The upright plant type with a smaller leaf angle can potentially increase plant density, leaf orientation values, and optimum production results (Liu et al., 2021; Yang et al., 2021). This character increases radiation intensity in the lower canopy and increases light interception (Perez et al., 2019). The results of our study showed a significant effect of higher seed yields (7.89 t ha^{-1}) in the 2:1 legowo planting pattern compared to the Tegel planting pattern (5.38 t ha^{-1}) (Table 2). This result is influenced by the increase in population and the suppression of pest attacks on leaves and cobs. Suppression of the main pests of corn plants, such as *S. frugiperda*, significantly affects the final results of cultivation. The higher the suppression of the *S. frugiperda* pest population, the greater the potential yield can be obtained (De Groote et al., 2020).

3.3 Population level of *Spodoptera frugiperda*, percentage of leaf damage, and population level of *Oecophylla smaragdina*

The treatment of the planting model, variety, and combination of both significantly influenced the intensity of corn cob damage ($p \leq 0.01$). The variety treatment resulted in significant differences in the population level of *S. frugiperda larvae* (0.43–1.23, $p \leq 0.0001$), the population of red ants *O. smaragdina* (1.03–2.33, $p \leq 0.0001$), the intensity of corn leaf damage (12.32–25.23, $p \leq 0.0001$) and the intensity of cob damage (8.80–16.17, $p \leq 0.0001$) (Table 3). *S. frugiperda* is a migratory and colonial pest, causing severe damage to maize, rice, and other food crops (Nayyar et al., 2021; Rane et al., 2022; Yainna et al., 2022). *S. frugiperda* infestation and incidence and damage to plants are predominantly influenced by factors such as maize varieties (Santos et al., 2022), planting time (Mbaidiro et al., 2023; Tabu et al., 2024), and pesticide use (Briones Ochoa et al., 2023). Some maize varieties that are categorized as resistant to *S. frugiperda* show antixenosis and antibiosis resistance mechanisms (Pamidi et al., 2024). The level of leaf damage due to *S. frugiperda* attacks on plants is determined by the location and age of the plants. According to Liu et al. (2024) the young plants are preferred by *S. frugiperda* over old plants, and lowlands have higher levels of damage than highlands. Several countries in South Africa, such as Ethiopia, Kenya, and Zimbabwe, have higher levels of corn leaf damage due to *S. frugiperda* attacks found in lowlands (Kumela et al., 2018). Land with intensive weeding has lower *S. frugiperda* attacks than land with many weeds (Mutyambai et al., 2022).

Table 3 shows that the intensity of corn cob damage is lower in the 2:1 legowo treatment (11.58%) compared to the farmer's method (13.09%). The combination of pest control and specific planting distance management methods significantly reduces overall plant damage, especially cob damage, and can increase yields (Kusi et al., 2024).

The lowest *S. frugiperda* population was found in the Bisma variety (0.53 heads) and the highest in Sukmaraga (1.23 heads). The intensity of corn leaf damage due to *S. frugiperda* attacks was lowest in Bisma (12.32%) and the highest in Sukmaraga (25.23%). The intensity of cob damage was lowest in Bisma (8.80%) and the highest in Sukmaraga (15.03%) (Table 3). Several corn varieties can recover from *S. frugiperda* pest damage at certain levels of damage with environmental support, such as sufficient rainfall and appropriate soil moisture levels (Abang et al., 2024).

TABLE 3 Effect of planting model and maize varieties on pest population, predator population, leaf, and cob damage.

Planting model	Population of *S. frugiperda larvae* (individu)	*Oecophylla smaragdina* population (individu)	Leaf damage of *S.frugiperda* (%)
Farmers	0.64 a	1.59 a	21.26 a
Legowo 2:1	0.67 a	1.59 a	19.12 a
Mean	0.65	1.59	20.19
LSD	0.35	0.65	2.32
Maize varieties			
Srikandi Kuning	0.60 b	1.50 b	22.15 c
Pulut Uri	0.57 bc	1.53 b	24.12 b
Provit A1	0.57 bc	1.63 b	21.90 c
Anoman	0.63 b	1.60 b	14.97 e
Srikandi Ungu	0.53 bc	1.50 b	20.70 d
Bisma	0.43 c	2.33 a	12.32 f
Sukmaraga	1.23 a	1.03 c	25.23 a
Mean	0.65	1.58	20.19
LSD	0.19	0.24	0.73
Significance level			
Planting model	NS	NS	NS
Maize varieties	***	***	***
Planting model × maize varieties	NS	NS	NS

Means followed by a different letter(s) in a column differ significantly from the LSD test at 0.05 probability. NS, Non significant. **Highly significant at $p \leq 0.01$. ***Highly significant at $P \leq 0.001$.

This study showed a significant effect of the 2:1 legowo planting distance treatment with the farmer's planting method on reducing the percentage of cob damage (Table 3). The effects of plant damage due to *S. frugiperda* pests can be reduced by arranging plant spacing (Yeboah et al., 2021). In addition to arranging plant spacing, arranging plants using the intercropping method with several plants from the *Fabaceae* family is also known to reduce the incidence and severity of corn leaf damage due to *S. frugiperda* (Wu et al., 2022; Soujanya et al., 2024), but not with plants from the *Cucurbitaceae* family (Baudron et al., 2019). Corn plant damage due to *S. frugiperda* can also be suppressed by utilizing the role of natural enemies (Afandhi et al., 2022; Keerthi et al., 2023).

The highest population of red ant predators, *O. smaragdina*, was found in the Bisma variety (2.33 individuals) and the lowest in Sukmaraga (1.03 individuals) (Table 3). The *Formicidae* family of the Hymenoptera order is one of the natural enemies commonly found in corn fields (Perfecto, 1991). Most recently, there were 32 genera consisting of 47 species of ants that act as predators (Lutinski et al., 2024). Ecosystem management, including plant spacing and external input management, can affect the presence and population of weaver ants in cornfield ecosystems (del-Val et al., 2021). According to

Sholahuddin et al. (2023) the use of the legowo row planting system in rice cultivation can increase the population of natural enemies such as the tomcat beetle *Paederus* sp. and the spider *Tetragnatha* sp.

3.4 Forms and symptoms of damage caused by *Spodoptera frugiperda*, and the form and behavior of *Oecophylla smaragdina*

S. frugiperda larvae are generally light brown in instar (Figure 1b) and attack plants on the top leaves in the vegetative phase (1c). According to Sumaryati et al. (2023) the *S. frugiperda* instar III larvae are light brown. *S. frugiperda* larvae attack corn plants from the vegetative to generative phases and attack in the vegetative phase that begins at the top of the plant (Figure 1c). According to Adi Pratama et al. (2020) the *S. frugiperda* larvae attack corn plants from the vegetative to generative phases and can cause leaf damage of around 60%. Furthermore, it is said that *S. frugiperda* larvae attack corn plants on the tops and appear to have holes, and usually, larval feces are present on the leaves.

The weaver ant *O. smaragdina* is one of the most effective predators in preying on various pests, including *S. prugiperda* pests on corn plants. These weaver ants have live on perennial plants such as soursop plants (Figure 2a) and rambutan plants (Figure 2b). According to Masram et al. (2023) the weaver ants *O. smaragdina*, from young insects or nymphs to adults, are reddish black or reddish brown in color and make their nests from fresh leaves at the top *O. smaragdina* ants are often found on plants that have broad and dense canopies such as plants from the *Annonaceae* group. Weaver ants *O. smaragdina* make nests by rolling up the leaves of the plants they use as their homes (Figure 2b).

Weaver ants search for food on annual plants such as corn around their habitat (Figure 2c). According to Ratri et al. (2017) the weaver ants *O. smaragdina* are insects that are very active in searching for food on various types of plants around their habitat and are pretty effective as predators or pest controllers because they can prey on numerous types of larvae and nymphs of green ladybug pests, leaf-eating caterpillars, and fruit-eating insects.

3.5 Effect of treatment interaction on the percentage of cob damage

Based on the field observations, the level of cob damage indicates an interaction between the planting model treatment and the type of variety. Some varieties, such as Bisma, Anoman, Srikandi Kuning, Pulut Uri, Sukmaraga, and Srikandi Ungu, showed a greater level of cob damage in the use of the tile planting pattern used by farmers compared to the use of the 2:1 legowo planting pattern (Figure 3). In contrast, only the Provit A variety showed more significant cob damage in the 2:1 legowo planting pattern (Figure 3). This indicates that of the varieties tested, only the Provit-A1 variety is not recommended for use in the 2:1 legowo planting model. These results align with other observation variables, including leaf damage and increased seed production in the 2:1 legowo planting pattern (Table 2). The interaction

FIGURE 1
Legowo corn plant model 2:1 **(a)** *S. frugiperda* larvae on corn leaves **(b)** and symptoms of *S. frugiperda* attack in the vegetative phase.

FIGURE 2
Predator *O. smaragdina* nests on soursop leaves **(a)** or rambutan leaves **(b)**, and *O. smaragdina* looking for food on annual plants such as corn **(c)**.

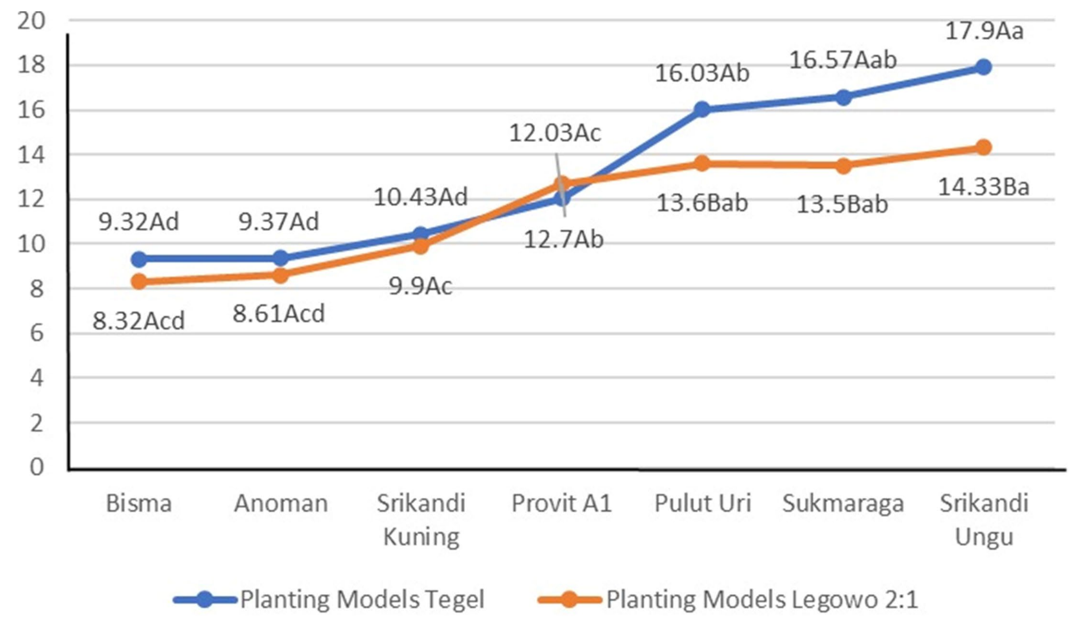

FIGURE 3
Interaction graph of treatments on corn cob damage observations. The average value followed by different letters indicates a significant difference in the 5% BNT follow-up test, Capital Letters: notation of significant differences in the treatment of planting distance patterns Ordinary Letters: notation of significant differences in the treatment between varieties.

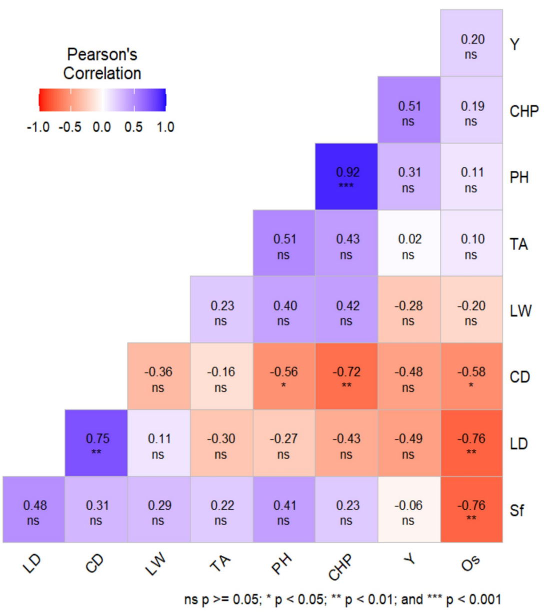

FIGURE 4
Korelasi Pearson variabel pengamatan pada perlakuan pola jarak tanam petani dan legowo 2:1. LD, leaf damage; CD, cob damage; LW, leaf width; TA, tasseling age; PH, plant height; CHP, cob height position; Y, yield; Sf, *S. frugiperda*; Os, *O. smaragdina*.

between the treatment of planting models and varieties is thought to occur due to differences in the phenotype of the varieties tested, including morphological characters, response to the environment, and tolerance to extreme environmental conditions. Germplasm resources with resistant varieties greatly support the development of corn varieties resistant to *S. frugiperda* have been widely developed (Chiriboga Morales et al., 2021; Yao et al., 2023). In this study, the Bisma variety is a good variety for optimizing production that is correlated with suppressing leaf and cob damage due to *S. frugiperda* attacks due to the presence of resistant genes. The resistance properties of this variety have a mechanism for accumulating 33-kD tyrosine protease when responding to *S. frugiperda* larvae feeding (Pechan et al., 2000). In addition, the development of resistant varieties also includes resistance genes found in transgenic Bt corn. In particular, there have been many research results on unique corn resources, such as commercially grown transgenic fresh corn (Crubelati-Mulati et al., 2014; de Oliveira et al., 2018). Several insect-resistant variety resources have been extensively studied, but insect-resistant genes and insect-resistant proteins have not been comprehensively analyzed.

3.6 Correlation analysis of observation variables in treating planting models and corn varieties

Correlation analysis showed that the population variable of weaver ants (*O. smaragdina*) was negatively correlated with the population of *S. frugiperda* (r = −0.76, p = 0.01), the scale of leaf damage (r = −0.76, p = 0.01) and the scale of corn cob damage (r = −0.58, p = 0.05). The observation variable of cob position was negatively correlated with the scale of corn cob damage (r = −0.72, p = 0.01) and positively correlated with plant height (r = 0.92, p = 0.001). The plant height variable was negatively correlated with the scale of corn cob damage (r = −0.56, p = 0.05). The scale of leaf damage was positively correlated with the scale of cob damage (r = 0.75, p = 0.01) (Figure 4).

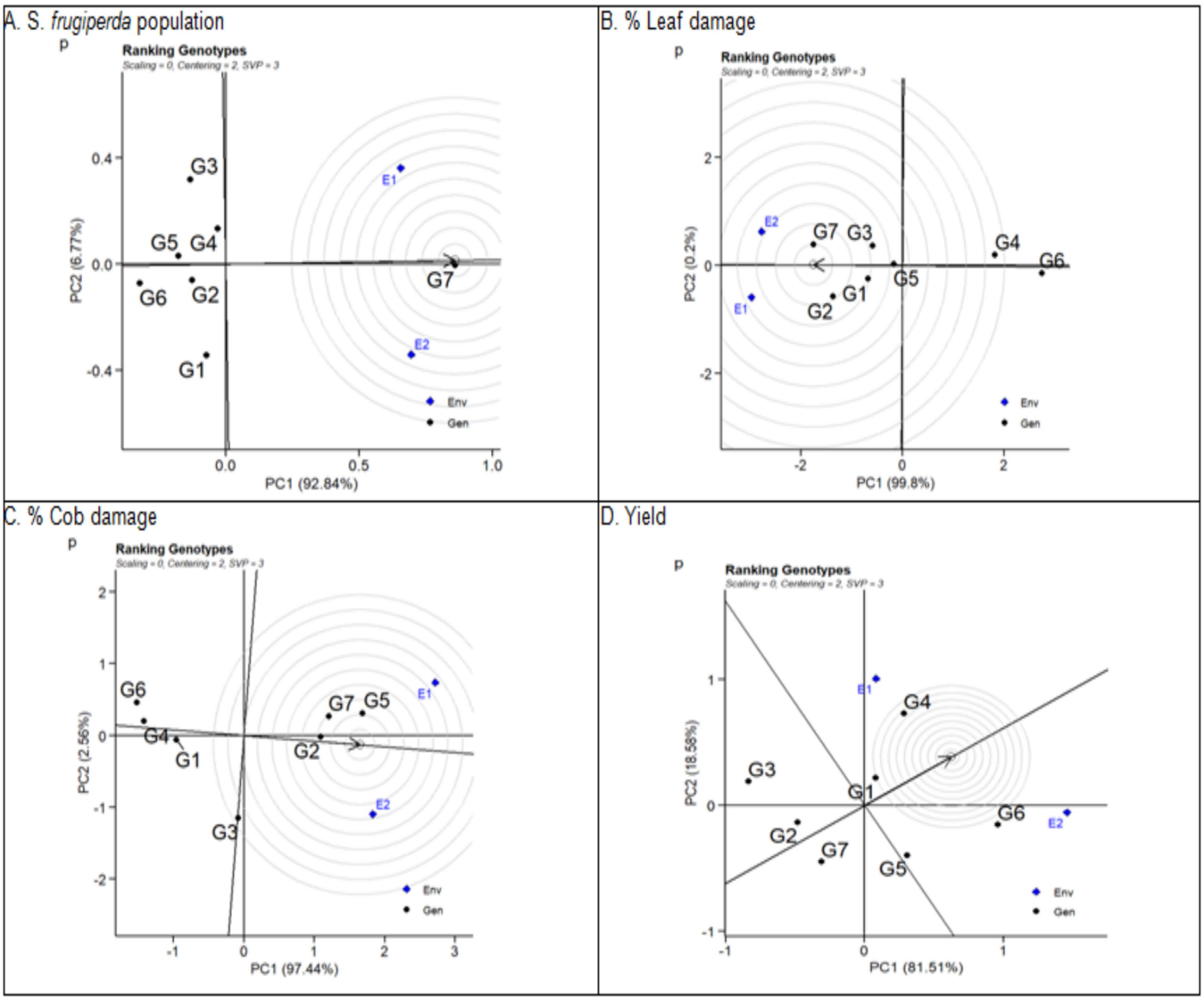

FIGURE 5
Ranking variety analysis (G1: Srikandi kuning, G2: Pulut Uri, G3: Provit A1, G4: Anoman, G5: Srikandi Ungu, G6: Bisma, G7: Sukmaraga) in two planting models (E1: Farmer model, E2: Legowo 2:1 model). **(A)** S. frugiperda population, **(B)** Leaf damage, **(C)** Cob damage, **(D)** Yield.

The relationship between the population of weaver ants *O. smaragdina* and the population of pests *S. frugiperda* and corn leaf damage is negatively correlated, as shown in Figure 4 with $r = -0.76$, $p = 0.01$ (population of *S. frugiperda*) and $r = -0.76$, $p = 0.01$ (damage to corn leaves). This is in accordance with Karmawati and Wikardi (2020) when the population of weaver *ants O. smaragdina* is 1 per plant, the level of damage to cashew shoots is 14%, while when the population of weaver ants *O. smaragdina* is 2 per plant, the level of damage to cashew shoots becomes 9%. Weaver ants *O. smaragdina* are insects that like food that contains more protein than carbohydrates. According to Rezki et al. (2023) the weaver ants, in their food selection behavior, prefer beetle larvae (60.21%) compared to sugar feed which only reaches 32.45%. Furthermore, of the three types of feed for *O. smaragdina* weaver ants, tested chicken, sugar, and bread, the most commonly chosen by weaver ants as their food is chicken (Hasan et al., 2021). This proves that *O. smaragdina* weaver ants prefer food with a lot of protein over food with carbohydrates.

3.7 Biplot analysis: ranking genotype

Biplot analysis aims to conduct selection based on the suitability of the seven varieties used with the planting method treatment used. The most ideal variety based on the observed parameters is the one that is located closer to the coordinates of the small circle with an arrow pointing to it. The results of the analysis show that to achieve optimal harvest results, the Bisma variety (G6) is more ideal when planted with a 2:1 legowo planting pattern, and Anoman (G4) is more ideal when planted with a tile planting pattern (Figure 5D). If both varieties are planted with the proper method (Bisma in a 2:1 legowo pattern and Anoman in a tile pattern). There is a chance for both varieties to experience a lower FAW pest population density and a lower percentage of leaf and cob damage (Figures 5A–C).

The *S. frugiperda* pest population positively correlates with the intensity of leaf and cob attacks. The higher the *S. frugiperda* population, the greater the chance of increasing attack intensity. According to Apriani et al. (2021) the a population of *S. frugiperda* of 4.47 per plant can cause damage to around 64.97%. The same thing was expressed by

Dian and Wanta (2022) the lower the population of *S. frugiperda*, the lower the intensity of attacks; in this case, when the population of *S. frugiperda* was 12.40, the intensity of attacks caused reached 18.85% and when the population was 4.20, the intensity of attacks on the leaves became 9.88%. The population of *S. frugiperda* is negatively correlated with seed yields in corn. In other words, the higher the population of *S. frugiperda*, the lower the seed yield. According to Megasari and Khoiri (2021) that if the population of *S. frugiperda* reaches 0.2 per plant, it can result in a 5% decrease in seed yield, and at a population of 0.8 per plant, it can result in a 20% decrease in seed yield.

The coordinate points of the varieties in the middle (moderate) of the yield plot are G1 (Srikandi Kuning) and G5 (Srikandi Ungu) (Figure 5D). The coordinates of these two varieties are far outside the centroid of the *S. frugiperda* population plot (Figure 5A), and very close to the centroid of the percent damage to leaves (Figure 5B) and cobs (Figure 5C). These varieties can still be planted with the Legowo 2:1 (G5) and tegel (G1) planting patterns. Still, it is necessary to control *S. frugiperda* pests from the start because they can cause a high percentage of damage to these two varieties, even in low populations. This is indicated by the high rate of leaf and cob damage (Figures 5C,D) even though the *S. frugiperda* population is not significant (Figure 5A).

4 Conclusion

The use of planting models and types of plant varieties affect the performance and production of corn seeds. Planting with the 2:1 legowo planting model is better for the Anoman, Srikandi Kuning, Provit A1, Pulut Uri, Sukmaraga and Srikandi Ungu varieties. Varieties treatment gave a significant difference in the *S. frugiperda* population variable. The lowest *S. frugiperda* population was found in the Bisma variety and the highest in Sukmaraga. The intensity of corn leaf damage due to *S. frugiperda* attacks was lowest in the Bisma variety and the highest in the Sukmaraga variety. The population of weaver ants *O. smaragdina* was negatively correlated with the level of leaf damage, the level of damage. Varieties treatment gave a significant difference in the *O. smaragdina* red ant population variable. Based on the data from this study, the 2:1 legowo planting model is recommended for use by farmers or other stakeholders in the field. Likewise, the Bisma variety and the weaver ant predator *O. smaragdina* can be recommended for use by farmers to overcome the level of *S. frugiperda* armyworm attacks on corn.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

AF: Resources, Writing – review & editing, Writing – original draft, Conceptualization, Methodology, Supervision, Investigation. IW: Investigation, Supervision, Validation, Writing – review & editing, Conceptualization, Writing – original draft. MY: Writing – review & editing, Methodology, Writing – original draft, Investigation, Supervision, Resources, Conceptualization, Validation. SM: Conceptualization, Writing – original draft, Methodology, Supervision, Validation, Writing – review & editing. MN: Supervision, Conceptualization, Writing – review & editing, Writing – original draft, Validation. SurS: Writing – review & editing, Conceptualization, Writing – original draft, Supervision, Visualization, Resources, Methodology, Validation, Investigation. MH: Writing – original draft, Methodology, Visualization, Investigation, Writing – review & editing. EN: Methodology, Data curation, Writing – review & editing, Writing – original draft, Visualization, Resources. II: Writing – original draft, Visualization, Writing – review & editing, Investigation, Validation. HH: Writing – original draft, Visualization, Writing – review & editing, Validation, Supervision. SyaS: Conceptualization, Supervision, Methodology, Writing – review & editing, Writing – original draft. PP: Writing – original draft, Conceptualization, Validation, Writing – review & editing, Supervision. SusS: Writing – review & editing, Supervision, Writing – original draft, Conceptualization. YN: Writing – original draft, Resources, Writing – review & editing, Investigation, Validation, Conceptualization. MS: Writing – original draft, Conceptualization, Supervision, Writing – review & editing, Validation. DH: Supervision, Resources, Writing – review & editing, Writing – original draft, Conceptualization, Methodology, Investigation, Validation. MA: Conceptualization, Validation, Supervision, Writing – review & editing, Writing – original draft. WW: Validation, Writing – review & editing, Writing – original draft, Conceptualization. NN: Supervision, Writing – review & editing, Writing – original draft, Conceptualization. WD: Writing – original draft, Writing – review & editing, Investigation, Visualization, Validation. AS: Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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