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IMPACT OF CULTIVATION TECHNOLOGY PACKAGE ON INSECT PEST INCIDENCE IN FOUR CAYENNE PEPPER HYBRID CULTIVARS

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ABSTRACT

The yield of cayenne pepper can be enhanced using hybrid cultivars combined with suitable cultivation technology packages. However, differences in cultivar traits, fertilizer dosage, and fertilizer application methods may affect pest incidence and damage intensity, affecting resistance among hybrid cultivars. This study aimed to evaluate the effects of four cultivation technology packages (TP-I, TP-II, TP-III, TP-IV) on pest incidence in four cayenne pepper hybrid cultivars. A Split Plot Design arranged in a Randomized Complete Block Design was used, with four cultivation technology packages (TP-I, TP-II, TP-III, and TP-IV) as the main plots and four hybrid cultivars (‘UNIB CHR17’, ‘Lado F1’, ‘Rimbun F1a’, and ‘Krisna F1’) as subplots. Results showed that the lowest population density of *Spodoptera exigua* occurred under TP-IV combined with the cultivar ‘Lado F1’. No significant differences were observed in the populations of *Bemisia tabaci*, *Thrips parvispinus*, *Bactrocera dorsalis*, or *Helicoverpa armigera* across technology packages or cultivars. Technology packages did not affect the intensity of indirect pest attacks, but did influence direct pest damage. TP-IV and TP-II reduced *B. dorsalis* attack intensity, while TP-II, TP-III, and TP-IV resulted in comparably lower *H. armigera* attack intensity. Among cultivars, ‘Lado F1’ and ‘Krisna F1’ showed lower indirect pest attack intensities (40.77% and 41.01%), while no cultivar differences were observed for direct pest attacks. TP-IV in combination with the cultivar ‘Lado F1’ is recommended to minimize pest incidence in cayenne pepper cultivation.

Keywords: Chili; cultivation technology package; hybrid cultivars; insect pests; pest incidence

ABSTRAK

Hasil pengeluaran cili padi dapat dipertingkatkan melalui penggunaan kultivar hibrid yang digabungkan dengan pakej teknologi penanaman yang sesuai. Namun demikian, perbezaan sifat kultivar, kadar baja, dan kaedah aplikasi baja boleh mempengaruhi kejadian perosak serta tahap kerosakan, sekali gus memberi kesan terhadap ketahanan antara kultivar hibrid. Kajian ini dijalankan bagi menilai kesan empat pakej teknologi penanaman (TP-I, TP-II, TP-III, TP-

IV) terhadap kejadian perosak pada empat kultivar hibrid cili padi. Reka bentuk Split Plot yang disusun dalam Reka Bentuk Blok Lengkap Secara Rawak telah digunakan, dengan empat pakej teknologi penanaman (TP-I, TP-II, TP-III, dan TP-IV) sebagai petak utama dan empat kultivar hibrid ('UNIB CHR17', 'Lado F1', 'Rimbun F1a', dan 'Krisna F1') sebagai subplot. Hasil menunjukkan bahawa kepadatan populasi *S. exigua* paling rendah diperoleh pada TP-IV apabila digabungkan dengan kultivar 'Lado F1'. Tiada perbezaan signifikan didapati dalam populasi *Bemisia tabaci, Thrips parvispinus, Bactrocera dorsalis*, atau *Helicoverpa armigera* merentasi pakej teknologi atau kultivar. Pakej teknologi tidak mempengaruhi intensiti serangan perosak tidak langsung, tetapi memberi kesan kepada kerosakan perosak secara langsung. TP-IV dan TP-II berjaya mengurangkan intensiti serangan *B. dorsalis*, manakala TP-II, TP-III, dan TP-IV menghasilkan intensiti serangan H. armigera yang lebih rendah. Dalam kalangan kultivar, 'Lado F1' dan 'Krisna F1' menunjukkan intensiti serangan perosak tidak langsung yang lebih rendah (masing-masing 40.77% dan 41.01%), manakala tiada perbezaan antara kultivar bagi serangan perosak secara langsung. TP-IV yang digabungkan dengan kultivar 'Lado F1' disyorkan untuk meminimumkan kejadian perosak dalam penanaman cili padi.

Kata Kunci: Cili; pakej teknologi penanaman; kultivar hibrid; perosak serangga; kejadian perosak

INTRODUCTION

Cayenne pepper is an important vegetable crop in Indonesia, serving as a local and export commodity (Puspitasari et al. 2022). Cayenne pepper possesses high nutritional and economic value, utilized as a spice or raw material in various food, beverage, cosmetic, and pharmaceutical industries (Duranova et al. 2022). Cayenne pepper exhibits excellent development prospects due to its high economic value. The Ministry of Agriculture's Directorate General of Horticulture of Indonesia (Dirjen Hortikultura & Badan Pusat Statistik 2019) reported an average cayenne pepper productivity of around 9.10 tons/ha, relatively low compared to the potential yield ranging from 12 to 20 tons/ha (Soetiarso & Setiawati 2010). Despite this, the potential yield of cayenne pepper plants can be achieved through the use of superior cultivars and the application of appropriate cultivation technology packages.

In the last decade, the productivity of cayenne pepper, like other horticultural crops, has declined due to increased attacks by plant pests triggered by climate change impacts (Moekasan et al. 2012; Saqib et al. 2022). Pest attacks could result in yield losses of approximately 30% - 100% (Suprapti et al. 2022). According to Sahetapy et al. (2019), the average pest attack level on chili plants, particularly by the fruit fly (*B. dorsalis*), can reach 41-49%. Important pests on chili plants include *T. parvispinus*, *B. tabaci*, *S. exigua*, and *B. dorsalis*. Plant parts most affected by pests are young leaves, causing damage and resulting in abnormal changes in shape and color (Meilin 2014).

Efforts to reduce the risk of losses due to pest attacks involve managing pest populations, including the use of pest-resistant cultivars and appropriate cultivation technology packages. Arifin et al. (2020) showed that implementing recommended cultivation technology package could increase cayenne pepper plant productivity. Employing cultivation technology package involving biofertilizers and pesticides reduced aphids and fruit flies attack (Suci et al. 2019). Information on the types of pests and the level of pest attacks on cayenne pepper plants is crucial to understand to justify the effectiveness of cultivation technology packages and cultivars to improve cayenne pepper plant productivity. The objective of this study was to evaluate the effects of different cultivation technology packages on pest incidence in four cayenne pepper hybrid cultivars.

MATERIALS AND METHOD

Sampling Sites and Duration

This research was conducted in a farmer farm of Bukit Peninjauan 2 Village, Sub-district of Sukaraja, District of Seluma, Bengkulu Province, and the Agricultural Quarantine Station Laboratory Bengkulu, Indonesia from November 2020 to March 2021.

Experimental Design

The research employed a Split-Plot Design (SPD), where the main plots were arranged in a Randomized Complete Block Design (RCBD) with three replications. The main plots included four cayenne pepper cultivation technology packages (TP-I, TP-II, TP-III, and TP-IV) (Table 1), and the subplots consisted of cayenne pepper hybrid cultivars (‘UNIB CHR17’, ‘Lado F1’, ‘Rimbun F1a’, and ‘Krisna F1’). ‘UNIB CHR17’ is our newly developed and registered hybrid cultivar, and ‘Lado F1’, ‘Rimbun F1a’, and ‘Krisna F1’ are commercial hybrid cultivars available in the marketplace commonly grown by vegetable farmers. This design consisted of 48 experimental plots, each of which was a ten-meter planting bed with twin row, 50 cm apart.

Table 1. Description of the technology packages as the main plot treatments

Technology	**Technology Package (TP)**			
	TP-I	**TP-II**	**TP-III**	**TP-IV**
Plant spacing				
Between rows	50 cm	50 cm	50 cm	50 cm
Within row	40 cm	40 cm	50 cm	50 cm
Dolomite	2 ton/ha	2 ton/ha	2 ton/ha	2 ton/ha
Manure				
Type	Cattle	Cattle	Chicken	Chicken
Rate	20 ton/ha	20 ton/ha	20 ton/ha	20 ton/ha
Fertilizer				
Urea	400 kg/ha	300 kg/ha	400 kg/ha	300 kg/ha
SP-36	400 kg/ha	300 kg/ha	400 kg/ha	300 kg/ha
KCl	150 kg/ha	150 kg/ha	150 kg/ha	150 kg/ha
Method of application	Broadcast	Broadcast	Fertigation*)	Fertigation*)

*Fertilizers were dissolved in water and drenched at 200 mL per plant weekly for 10 weeks

Experimental Procedure

To initiate seed germination, seeds underwent a brief immersion in warm water (50°C) for 2 minutes. Subsequently, these seeds were meticulously sown in designated seed trays filled with a mix media of top soil and cow manure (1:1, v/v). The seedlings were maintained in the nursery for five weeks. Every week, the seedlings were fertigated with NPK solution with the rate of 2 g/L, following the procedure of Herison et al. (2014).

In land preparation, an initial step involved the meticulous removal of existing vegetation and residual plant materials. This was succeeded by diligent soil cultivation utilizing a hoe. The creation of beds measuring 1m x 10m followed this process, strategically executed one month prior to the actual planting. After the application of manure, the beds were covered by plastic mulch following the practices of the standard commercial cayenne pepper grower. Transplantation took place when the seedlings reached the age of 35 days. The distances between plantings were judiciously adjusted in adherence to the specifications outlined in each distinct cultivation technology package. To optimize conditions, plastic mulch was systematically applied to the beds.

The initial fertilization included the application of 20 ton/ha cattle manure or chicken manure (20 ton/ha). Subsequently, urea, SP-36 phosphate fertilizer, and KCl were applied according to the precise specifications stipulated by each designated cultivation technology package. The comprehensive maintenance regimen involved essential practices such as staking, irrigation, pruning, fertilization, weeding, watering, and the vigilant management of plant pests and diseases following Herison et al. (2017). Pest and diseases control strategies involved periodic applications of insecticides, acaricides, and fungicides in a preventive manner every other week. Harvesting was initiated when chili plants met predetermined criteria, specifically marked by a minimum of 50% of chili fruits exhibiting a vibrant red hue Herison et al. (2023).

Sampling Method and Data Collection

For accurate assessment, a systematic approach to random sampling was adopted involving as much as 10% of the plant population within each plot. The most end plants in each plot were not included in sampling randomization.

Pest incidence parameters included pest population, pest species identification, and the intensity of pest attacks. The pest population was quantified based on the number of pests observed during the assessments, corresponding to each type of pest present in each sampled plant within the treatment plots. Observations on pest population and characteristics were conducted at the plant age of 4, 5, 6, 7, 8, 9, and 10 weeks after transplanting (WAT). The identification of pest types was carried out by assessing the symptoms of infestation and the characteristics of pests during each observation period. Pest samples were collected and identified visually on their morphological features both in the field and in the laboratory using a stereo microscope and cross-referring to the insect identification book of Castner (2001) and Borror et al. (1992).

The intensity of chili pest attacks was evaluated four weeks after planting and subsequently at one-week intervals, examining the symptoms of infestation in each observed sample cluster. It was essential to note that indirect pests were those whose attacks did not directly affect the productivity or yield of chili plants. The observation of pest attack intensity employed a 4-level scale, where the severity of infestation was categorized into distinct levels (Table 2). This meticulous process ensures a comprehensive understanding of the dynamics of pest incidence, contributing valuable insights into the potential impacts on chili plant cultivation.

Table 2. Plant damage scale on cayenne pepper (Indirect Pest) (Toepfer et al. 2021)

Scale	The level of plant damage (Percent of attacked leaves)	Category
0	0%	No damage
1	0%>-≤25%	Very low damage
2	25%>-≤50%	Low damage
3	50%>-≤75%	Medium high damage
4	75%>-≤100%	High damage

Data Analysis
Pest population was determined based on the number of pests found during each observation, according to the specific pest species present on each sample plant within the treatment plots. Observations of pest population and characteristics were conducted at 4, 5, 6, 7, 8, 9, and 10 weeks after transplanting (WAT). Pest individuals found on the sample plants were recorded. Specimens collected during each observation were stored in sample bottles and labeled accordingly. The intensity of indirect pest attacks (Indirect Pest) on chili plants was calculated using the formula used by Nurhajijah et al. (2024).

$$I = \sum \frac{(n\ x\ v)}{Z\ x\ N}\ x\ 100\%$$

where I, n, v, Z and N was pest attack intensity (%), number of plants with the same category value of plant damage, scale value for each category (0, 1, 2, 3, 4), the highest category, and total number of observed plants, respectively. Direct pests are pests whose attacks directly impact the productivity or yield of chili plants. The intensity of direct pest attacks (Direct Pest) was calculated using the following formula used by Nurhajijah et al. (2024).

$$P = \frac{a}{(a+b)} \times 100\%$$

where P, a and b were the level of damage or percent of yield reduction, number of plant or fruit damage, and number of healthy plant or fruit, respectively. Data of pest incidence parameter were analyzed descriptively and statistically. ANOVA was applied and main comparisons were conducted by the Tukey's Honestly Significant Difference (HSD) test at α=5%.

RESULTS

Pests Incidence
The pest incidence in this study revealed three species of pests that did not directly impact the cayenne pepper yield (Indirect Pest), namely *S. exigua*, *T. parvispinus*, and *B. tabaci,* (Figure 1, 2, and 3, respectively). Attacks by those three species of insect pest occurred from the vegetative phase to the generative phase, affecting the leaves of cayenne pepper plants. Pest attacks on the leaves of cayenne pepper plants might result in disruptions to the plant's photosynthesis process due to the abnormality of the leaves which was potentially decreased the productivity of cayenne pepper plants.

During the generative phase, *Helicoverpa armigera* and *Bactrocera dorsalis* (Figures 4 and 5, respectively) attacked cayenne pepper fruits, causing perforation and internal rot, respectively, thereby reducing yield. *H. armigera* larvae bore into and feed within the fruit, whereas *B. dorsalis* females oviposit inside the fruit, and the resulting larvae feed internally and cause rot. Accordingly, both species are classified as direct pests.

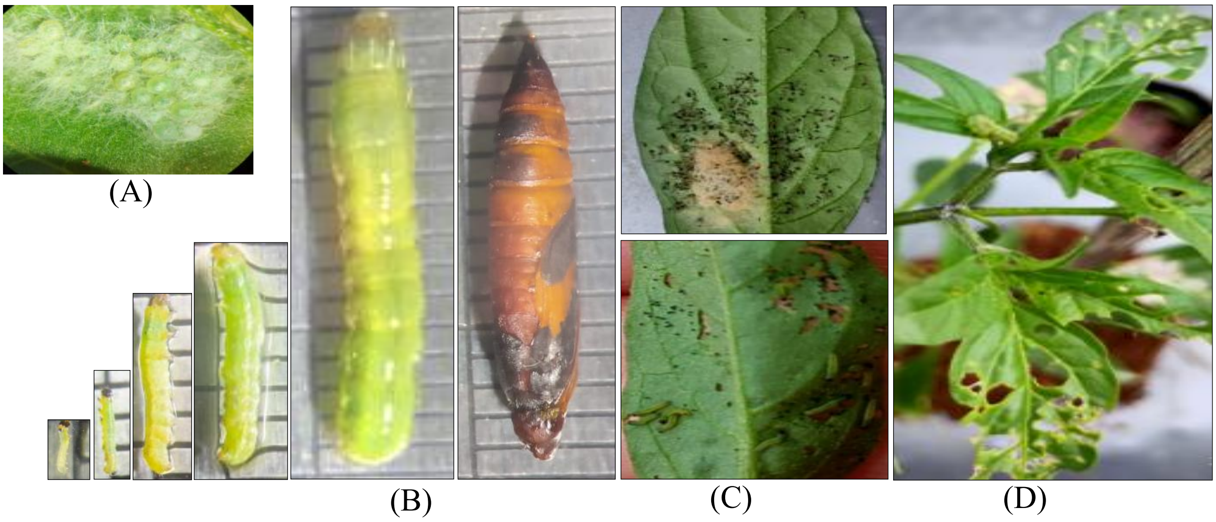

Figure 1. Samples of *S. exigua* collected from the cayenne pepper field. (A) magnified image of the eggs, (B) larval development from the first through fifth instars to the pupal stage, (C) neonate larvae (top) and leaf damage caused by first- and second-instar larvae (bottom), and (D) leaf damage characteristic caused by fourth- and fifth-instar larvae

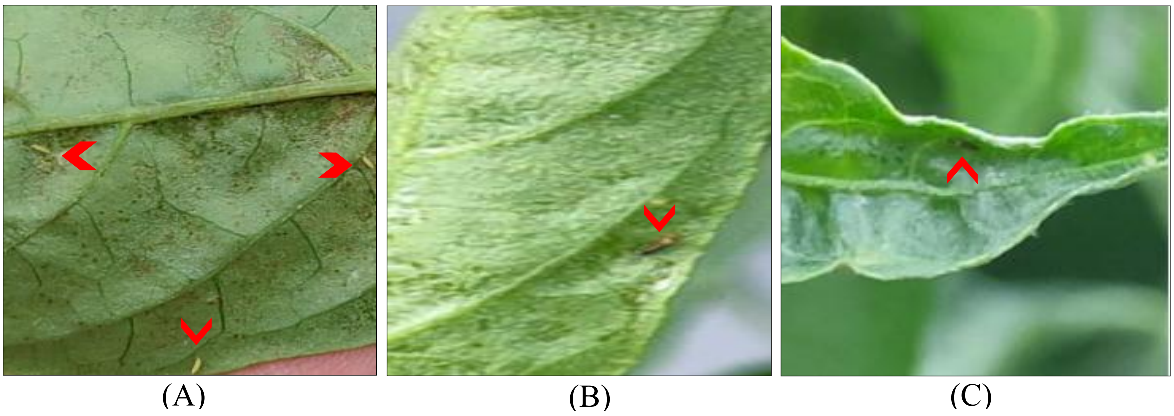

Figure 2. Larvae (A) and imago (B) of *T. Parvispinus,* and (C) symptoms of feeding damage on cayenne pepper leaves

Figure 3. Imago stage of *B. tabaci* (A)*,* and (B) symptoms of feeding damage on cayenne pepper leaves

(A) (B) (C)

Figure 4. *Helicoverpa armigera* observed in the cayenne pepper field: (A) morphology, (B) larval feeding on a young fruit, and (C) feeding damage characterized by perforated fruit

(A) (B) (C)

Figure 5. (A) Morphology of *Bactrocera* sp., (B) infested young cayenne pepper fruits, and (C) internal fruit rot caused by larval feeding

Pest Population Density

Pest population density is an indicator of population resistance to pest attack intensity. High pest population density indicates that the plant environment is suitable for the life cycle of the pest itself. The higher the incidence of pest populations, the higher the intensity of plant damage in a cayenne pepper plot. The average population density on four cultivation technology packages combined with four cultivars of cayenne pepper showed that the highest average pest population was *T. parvispinus*. The highest average population of *T. parvispinus* was 12.70 in the fifth observation 8 WAT (Figure 6). Damage to cayenne pepper plants caused by *T. parvispinus* was characterized by changes in color, shape, and size of cayenne pepper leaves. Leaves affected by *T. parvispinus* turned copper brown, curled, and wrinkled.

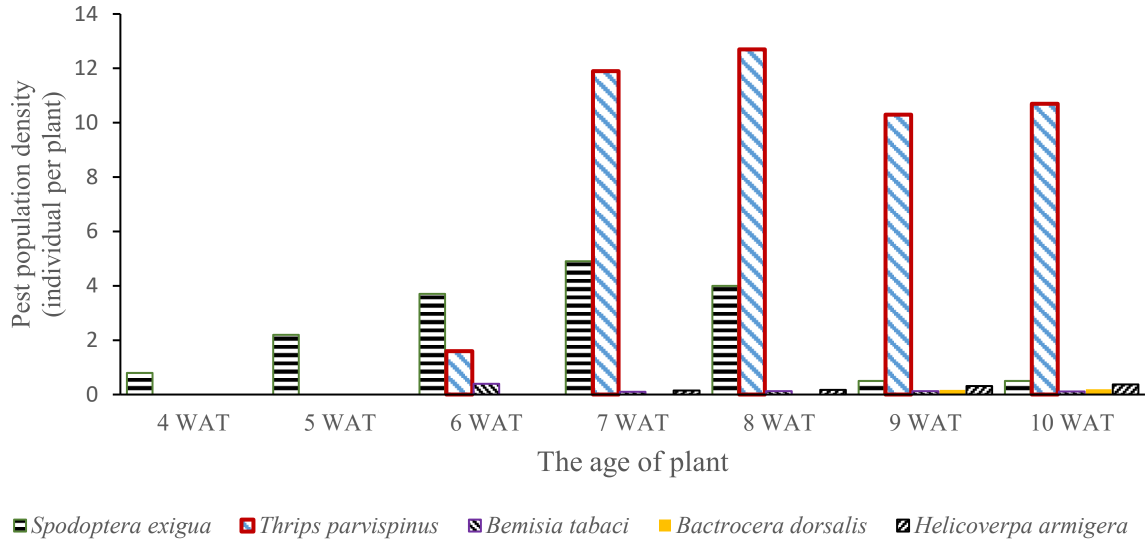

Figure 6. The average pest population density over all the treatment combinations

The highest population of *S. exigua* in the generative phase occurred when cayenne pepper plants were 7 WAT, with the highest average population being 4.90 individuals at 9 WAT. The population of *S. exigua* decreased by the time the chili plants reached 10 weeks old. Attacks by *S. exigua* were characterized by leaves becoming perforated, and the intensity of damage to cayenne pepper leaves could reach 50%.

The population density of *B. tabaci* were observed at 6 WAT and were the highest (0.4 individual per plant) during the observation period, and decreased at 7 WAT, then increased steadily and decreased again at 10 WAT. Morphologically, some plants in the study area were affected by yellow leaf curl virus disease, indicating the infestation of *B. tabaci*. Population density of direct pests was considered relatively low. The population of *H. armigera* increased 7 WAT when the plants entered the generative phase. *Helicoverpa armigera* attacks occurred when the cayenne pepper was still green and continued until they ripened. Generally, attacks by fruit fly (*B. dorsalis*) occurred in ripe cayenne pepper fruits, but sometimes they also attacked newly growing fruits.

The Impact of Cultivation Technology Package and Cultivar on Pest Population

The results of the analysis of variance indicated either cultivation technology package or cultivar factor alone as the main factors did not significantly influence the population density of observed pest (*S. exigua*, *T. parvispinus*, *B. tabaci*, *H. armigera*, and *B. dorsalis*). The interaction of both factors also did not significantly affect the population density of all pest, except on *S. exigua*. A significant interaction between the factors of cayenne pepper cultivar and cultivation technology package was evidence on the population of *S. exigua* in cayenne pepper plants, by the significance value of 0.03 (Table 3).

The data observed on the incidence of important pest populations in cayenne pepper plants have coefficients of variation ranging from 18.54% to 60.79%. The lowest coefficient of variation was observed in *T. parvispinus*, while the highest was in the average population of *B. tabaci* (Table 3). High coefficient of variation indicated the magnitude of unstructured variation among experimental units. This finding may be due to the behavior of *B. tabaci* which easily dispersed sporadically and flown by the wind. The weed population surrounding the experimental plots which differ between the inner and the outer plots may also contribute to the high coefficient of variation.

Table 3. Summary of the results of the analysis of variance on the pest populations density

Cayenne Pepper Pest	***P* Value**			**CV (%)**
	TP	**V**	**TP x V**	
Spodoptera exigua	0.16 ns	0.29 ns	0.03 *	31.63
Thrips parvispinus	0.21 ns	0.66 ns	0.17 ns	18.54
Bemisia tabaci	0.32 ns	0.97 ns	0.38 ns	60.79
Bactrocera dorsalis	0.14 ns	0.76 ns	0.80 ns	29.31
Helicoverpa armigera	0.27 ns	0.59 ns	0.50 ns	47.12

Note: * = significant (*P≤5%*), ns = non-significant (*P>5%*), TP= cultivation technology package, V = cultivars, TP x V= interaction factor, CV = coefficient of variation

The interaction between cultivation technology package and cayenne pepper hybrid cultivars was observed in suppressing the population density of *S. exigua*, although the average population density was categorized low in most treatment combination (*<5%*). In cultivation technology package TP-I, the use of cultivar 'Krisna F1' resulted in the lowest *S. exigua* population density among cultivars evaluated. In TP-II, the most suitable cultivar to suppress *S. exigua* population density was 'Lado F1'. Meanwhile, in TP-III, either 'Lado F1' or 'Krisna F1' exhibited the lowest *S. exigua* population density. Whereas when we use cultivation technology package TP-IV, all cultivars performed similarly in suppressing *S. exigua* population density. It seems likely that the use of TP-IV or TP-III suppressed *S. exigua* population density higher than TP-I or TP-II. With regard to the cultivars, when we use cultivar 'UNIB CHR17', 'Lado F1' or 'Rimbun F1a', TP-IV showed the least *S. exigua* population density among cultivation technology packages evaluated. However, when we use cultivar 'Krisna F1', TP-I suppress *S. exigua* population density higher than the other cultivation technology packages (Table 4).

For cayenne pepper cultivation, it seems advisable to avoid the use of cow manure fertilizer because the population of *S. exigua* pests was high with this cultivation technology package treatment. For hybrid of 'UNIB CHR17', 'Lado F1', and 'Rimbun F1', the most effective method to suppress the population of *S. exigua* pests was to use cultivation technology package IV (TP-IV), which included a planting distance of 50 cm x 50 cm, chicken manure fertilizer at a rate of 20 tons/ha, and inorganic fertilizer applied through fertigation at a concentration level of mix fertilizer (urea 9.23 g, SP-36 9.23 g, and KCl 5.46) diluted into 2 liters solution, with a weekly application of 200 ml per plant). Meanwhile, for cultivar 'Krisna F1', the most effective method to suppress the population of *S. exigua* pests was to use cultivation technology package I (TP-I) with a planting distance of 50 cm x 40 cm, cow manure fertilizer at a dosage of 20 tons/ha, and inorganic fertilizer at a dosage of 400 kg urea, 400 kg SP-36, and 150 kg KCl per hectare applied through broadcasting around the base of the plants (Table 4).

Table 4. The effect of interaction between cultivation technology package factors and hybrid cultivars of cayenne pepper on the population density of *S. exigua*

Hybrid	**Cultivation technology package**							
	TP-I		**TP-II**		**TP-III**		**TP-IV**	
'UNIB CHR17'	4.12 (A)	ab	3.32 (AB)	ab	3.43 (AB)	a	2.46 (B)	a
'Lado F1'	5.17 (A)	a	2.58 (B)	b	2.04 (B)	b	1.77 (B)	a
'Rimbun F1a'	3.57 (B)	ab	4.80 (A)	a	3.19 (BC)	ab	2.42 (C)	a
'Krisna F1'	2.17 (B)	b	3.30 (A)	ab	2.42 (AB)	b	2.42 (AB)	a

Note: Numbers in the same row followed by upper-case letter, or in the same column followed by lower-case letter were not significantly different according to HSD α=5%.

Pest Attack Intensity

The intensity of pest attacks, with no direct impact on yield (Indirect Pest), in cayenne pepper inflicted by *S. exigua* exceeded 50% damage levels from 8 WAT. The highest intensity of *S. exigua* pest attacks reached 56.56% in the 10th WAT. By the 6th WAT, the cayenne pepper plants were subjected to *T. parvispinus* attacks, with an average intensity of 8.44%, and *B. tabaci* attacks, with an average intensity of 2.50%. The average intensity of *T. parvispinus* attacks in this study peaked at the 10th WAT, reaching 17.71%. The intensity of *T. parvispinus* attacks did not show a significant increase at the 8th WAT. The pest *B. tabaci* reached its peak attack intensity at the 10th WAT, with a value of 16.35% (Figure 7). The high intensity of these indirect pest attacks was attributed to the high population density of pests in the cayenne pepper plants.

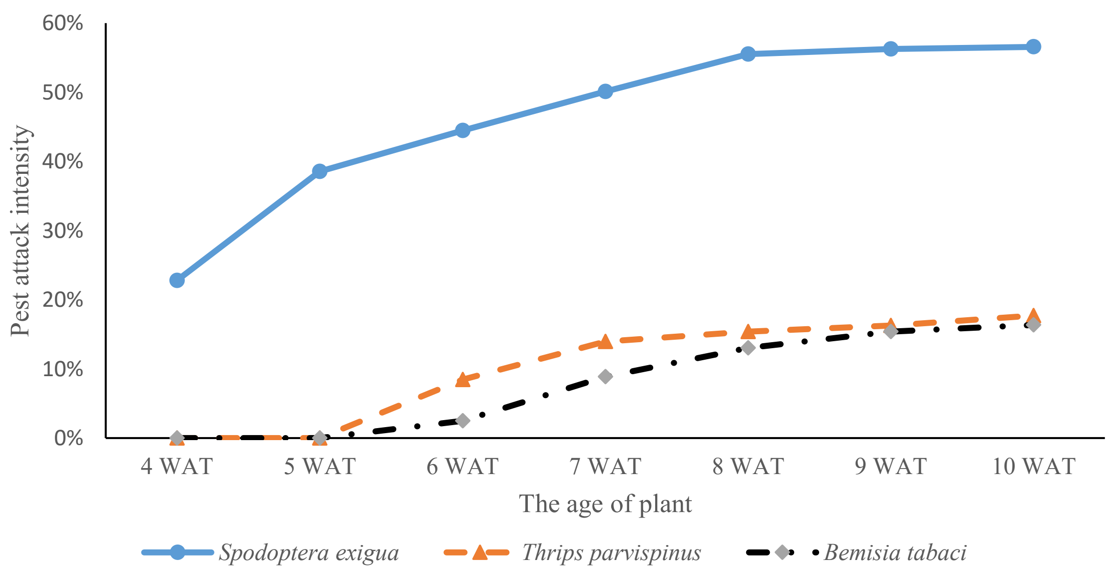

Figure 7. Graph of the average intensity of indirect pest attacks

The results of the ANOVA indicate that cultivation technology packages (TP) did not significantly influence the attack intensity of the indirect pests *S. exigua*, *T. parvispinus*, or *B. tabaci*. However, it did significantly affect attacks by the direct pest *B. dorsalis* ($p < 0.05$), indicating that certain technology combinations were more effective at suppressing fruit fly incidence. In contrast, TP had no significant effect on attack intensity by *H. armigera*. Cultivar effects (V) significant influence solely for pest attack intensity by *S. exigua* ($P<0.01$), demonstrating that genotype-specific characteristics played a greater role than cultivation technology in determining susceptibility to this indirect pest. No significant influence of TP × V interactions were detected on the pest attack intensity by any pest species ($P>0.05$), suggesting that cultivar responses to the cultivation technology packages were consistent and that no cultivar exhibited a differential response to specific TP combinations. There was a significant effect of the cultivation technology package in suppressing the intensity of direct pest attacks by *B. dorsalis* (fruit fly) and *H. armigera*. Coefficients of variation ranged from moderate to high (12.86%–161.02%), particularly for the direct pests, reflecting substantial variability in pest pressure across experimental units (Table 5).

Table 5. Summary of the results of the analysis of variance on the average intensity of pest attacks on cayenne pepper

Variables	**P-value**			**CV (%)**
	TP	**V**	**TP x V**	
Indirect pest				
Spodoptera exigua	0.41 ns	0.00**	0.66 ns	19.62
Thrips parvispinus	0.94 ns	0.38 ns	0.07 ns	12.86
Bemisia tabaci	0.09 ns	0.31 ns	0.68 ns	39.89
Direct pest				
Bactrocera dorsalis	0.03 *	0.86 ns	0.70 ns	77.72
Helicoverpa armigera	0.05 *	0.72 ns	0.98 ns	161.02

Note: * = significant ($P\leq5\%$), ns = non-significant ($P>5\%$), TP= cultivation technology package, V = cultivars, TP x V= interaction factor, CV = coefficient of variation

Across the cultivation technology packages, the intensities of indirect attacks by *S. exigua*, *T. parvispinus*, and *B. tabaci* remained similar, with no clear differences among TP-I, TP-II, TP-III, and TP-IV. In contrast, variation among cultivars was more apparent for *S. exigua*. 'UNIB CHR17' and 'Rimbun F1a' showed higher levels of *S. exigua* attack, while 'Lado F1' and 'Krisna F1' suffered comparatively lower intensities (40.77% and 41.01%, respectively). For *T. parvispinus* and *B. tabaci*, all cultivars experienced comparable levels of attack, with no noticeable differences among them (Table 6).

Table 6. The effect of cultivation technology package and cultivar factors on the average intensity of indirect pest attacks on cayenne pepper

Treatment	**Indirect Pest Intensity (%)**					
	Spodotera exigua		***Thrips parvispinus***		***Bemisia tabaci***	
Cultivation Technology Package						
TP-I	48.75	a	12.63	a	2.49	a
TP-II	46.84	a	12.29	a	1.92	a
TP-III	50.53	a	12.77	a	1.43	a
TP-IV	39.16	a	12.84	a	2.30	a
Cayenne Pepper Hybrid						
'UNIB CHR17'	54.28	a	12.98	a	1.90	a
'Lado F1	40.77	b	13.12	a	1.88	a
'Rimbun F1a'	49.22	a	12.22	a	1.93	a
'Krisna F1	41.01	b	12.22	a	2.43	a

Note: Numbers in the same column followed by lower-case letter were not significantly different according to HSD α=5%.

The intensity of pest attacks with a direct impact on yield (Direct Pest) in cayenne pepper reached its highest average at the 8th WAT (8.63%), with fruit fly (*B. dorsalis*). Meanwhile, *H. armigera* exhibited the highest intensity at 10 WAT, reaching 1.40% (Figure 8). The low intensity of direct pest, below 10%, was significantly influenced by environmental factors specific to the research location.

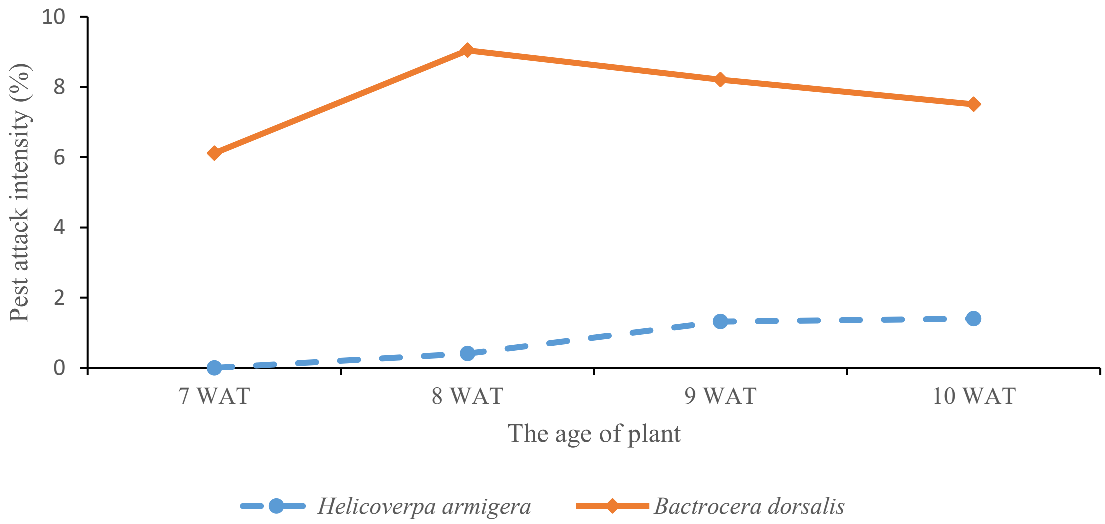

Figure 8. Graph of the dynamic of direct pest attacks intensity

Cultivation technology package significantly influenced direct pest attack intensity. Differences among cultivation technology packages were observed in direct pest intensity. For *B. dorsalis*, TP-II and TP-IV showed lower attack intensity compared to TP-III or TP-I. Whereas, for *H. armigera*, TP-II, TP-III, and TP-IV demonstrated lower levels of attack intensity than TP-I did. On the contrary, all hybrid cultivars exhibited similar levels of direct pest attack, with no detectable differences among them (Table 7).

Table 7. The effect of cultivation technology package and cultivar factors on the average intensity of direct pest attacks on cayenne pepper

Treatment	Direct Pest intensity (%)			
	Bactrocera dorsalis		***Helicoverpa armigera***	
<u>Cultivation Technology Package</u>				
TP-I	7.62	ab	2.03	a
TP-II	5.22	b	0.29	b
TP-III	10.00	a	0.38	b
TP-IV	4.88	b	0.45	b
<u>Cayenne Pepper Hybrid</u>				
'UNIB CHR17'	6.03	a	0.68	a
'Lado F1	6.55	a	0.52	a
'Rimbun F1a'	7.45	a	0.86	a
'Krisna F1	7.69	a	1.09	a

Note: Numbers in the same column followed by lower-case letter were not significantly different according to HSD α=5%.

DISCUSSION

The findings of this study explain how important to understand the dynamic of pest incidence cayenne pepper cultivation in the field. Different pest species influence cayenne pepper yield through both direct and indirect pathways. Understanding these relationships is essential for developing effective pest management strategies that can support high productivity and fruit quality.

The indirect pests identified were *S. exigua, T. parvispinus,* and *B. tabaci* did not directly reduce yield, yet their presence should be cautioned. These pests attack leaves from the vegetative through the generative growth stages, disrupting photosynthesis due to leaf deformation. If untreated, these physiological disruptions may eventually affect plant productivity. Similar results were reported by Anggraini et al. (2018), who found that high indirect pest populations significantly reduced chili yield. Thrips infestation has also been shown to decrease pepper production (Intarti et al. 2020), reinforcing the need for integrated pest management approaches (Smith et al. 2023). Likewise, *B. tabaci* disturbs plant physiological processes and serves as a vector for yellow leaf curl viral diseases (Liu et al. 2013), emphasizing the importance of managing indirect pest pressure (Jones et al. 2022; Patel et al. 2024).

The evaluation of hybrid responses under different cultivation technology packages demonstrates that pest dynamics are influenced by both genetics and cultivation practices. This aligns with Oerke (2006), who emphasized the importance of combining genetic resistance and agronomic strategies in sustainable pest management. A primary finding of this study was the significant interaction between cultivation technology packages and hybrids on *S. exigua* population dynamics. High populations of *S. exigua* in this study likely resulted from rapid spread and high egg abundance. Similar patterns were reported by Sembiring and Prasetya (2021), who noted that higher pest density increases damage intensity (Shivalingaswamy et al. 2022).

Although most combinations resulted in population densities below 5%, differences among hybrids indicate varying resistance levels. For example, 'Krisna F1' performed best under TP-I, whereas 'Lado F1' showed better suppression under TP-II. The TP-III and TP-IV produced similar outcomes across cultivars, suggesting that management practices in these systems contributed more to pest control than cultivar traits alone. The interaction between technology package and cultivar affecting *S. exigua* provides additional insight into how pest pressure can be influenced by genotype-specific responses (Letourneau et al. 2021). This supports the concept that plant traits, environment, and management strategies interact to shape pest outcomes.

At the generative stage, two direct pests, *B. dorsalis* and *H. armigera* were identified as having an observable effect on fruit yield. These pests damage fruits by boring holes or causing rot, which reduces both marketable yield and fruit quality. Although the observed infestation level of *B. dorsalis* or *H. armigera* was low (*<10%*), controlling this pest below its economic threshold is recommended to prevent economic loss (Rajput et al. 2018; Sahetapy et al. 2019). Recent study supports the importance of monitoring and targeted control for these pests in pepper cultivation (Chen et al. 2024; Li et al. 2023; Wang et al. 2023).

Understanding these interactions enables refinement of management strategies and supports the development of precision agriculture approaches (Bai et al. 2020). As precision tools continue to advance, opportunities emerge to fine-tune pest control based on real-time data and cultivar-specific responses (Zaman 2023). Cultivar-specific responses were also evident. Hybrids such as 'UNIB CHR17,' 'Lado F1,' and 'Rimbun F1a' showed the lowest *S. exigua* populations under TP-IV, whereas 'Krisna F1' performed best under TP-I. These findings highlight the importance of matching hybrid traits with cultivation practices and support the need for resistance-focused breeding programs (Jaouannet et al. 2020). Variation in susceptibility to thrips and whiteflies further demonstrates the complexity of plant–insect interactions. Genomic research supports the role of plant genetics in resistance development (Bansal et al. 2021; Prabhaker et al. 2018). Integrating such knowledge into breeding programs will strengthen future cayenne pepper resistance.

The relationship between pest pressure and yield reduction reflects broader global challenges in food security. Reducing pest-induced yield loss is economically important, and sustainable pest management approaches provide measurable benefits (Pretty et al. 2018). The influence of cultivation technology on pest dynamics aligns with agroecological principles. Many studies highlight the value of sustainable farming systems for improving biodiversity and reducing pest pressure (Altieri & Nicholls 2020). The present findings support these principles and demonstrate their practical benefits for cayenne pepper production.

Low population density of indirect pests, *S. exigua, T. parvispinus*, and *B. tabaci* is a positive outcome for cultivation systems. Although *B. tabaci* can transmit viruses such as yellow leaf curl disease (Liu et al. 2013), the low population suggests that the cultivation packages were effective. Weed-free cultivation areas, particularly removal of *Ageratum conyzoides* (a known host of *B. tabaci*), contributed to suppression (Subagyo & Hidayat 2014). These outcomes align with IPM principles emphasizing cultural control (Barzman et al. 2015). Similarly, low attack intensity of direct pests—*H. armigera* and *B. dorsalis*—are encouraging because both species are capable of major yield loss (Andiko et al. 2023; Budiyani et al. 2020; Moekasan et al. 2012). *Helicoverpa armigera* causes perforated fruit, and fruit fly results in symptoms of rotten fruit, abnormal development fruit, and premature fruit drop before reaching the desired maturity (Dhillon et al. 2005). The low intensity of these direct pest attacks is probably due to the low population density of adult pests. In high fruit fly populations, the intensity of attacks can reach 100% (Sahetapy et al. 2019). Their suppression indicates that the cultivation technology packages used in this study were effective in reducing economic loss. This suggests that the cultivation practices implemented supported crop resilience and minimized yield loss risk.

Although this study provides valuable insights, further research is needed. Additional work should examine long-term pest dynamics, seasonal patterns, and potential shifts in resistance. A broader ecological understanding of pest–crop interactions will support more targeted and sustainable pest management solutions. Our study has demonstrated that combining cultivar selection with appropriate cultivation technology can effectively manage pest pressure in cayenne pepper production. Understanding genotype-specific responses and aligning them with agronomic practices helps minimize yield loss and supports sustainable crop management.

CONCLUSION

The lowest population density of *S. exigua* occured in TP-IV (50 cm × 50 cm spacing; urea, SP-36, and KCl applied at 300, 300, and 150 kg ha^{-1}, respectively, through fertigation) combined with the cultivar 'Lado F1'. Cultivation technology package or cultivar did not influence the population density of *B. tabaci*, *T. parvispinus*, *B. dorsalis*, or *H. armigera*. Technology packages did not affect the intensity of indirect pest attacks, but influenced direct pest infestation. TP-IV and TP-II reduced *B. dorsalis* attack intensity, while TP-II, TP-III, and TP-IV resulted in comparably lower *H. armigera* attack intensity. Among cultivars, 'Lado F1' and 'Krisna F1' showed lower indirect pest attack intensities (40.77% and 41.01%), while no cultivar differences were observed for direct pest attacks. Based on these findings, TP-IV in combination with the cultivar 'Lado F1' is recommended to minimize pest incidence in cayenne pepper cultivation.

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Conflict of Interest
The authors declare no conflict of interest.

Ethics Declarations
No ethical issue is required for this research

Credit Authorship Contribution Statement
Catur Herison (CH),: Set up the experiment, plant maintenance, plant growth and yield data collection, data analysis, manuscript writing. Ryansyah Putra (RP): pest incidence data collection, data analysis, manuscript writing. Sempurna Br Ginting (SPG): insect identification, manuscript proofreading. Dwinardi Apriyanto (DA): manuscript proofreading.

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