BIODIVERSITAS
Volume 24, Number 2, February 2023
Pages: 1303-1312

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240273

The false alarm of experimentally companion plants to the cabbage pests with their ecological effects

AGUNG SIH KURNIANTO[1,♥], LUHUR SEPTIADI[2], NANANG TRI HARYADI[1], WILDAN MUHLISON[1], IRWANTO SUCIPTO[1], NILASARI DEWI[1], AHMAD ILHAM TANZIL[1], AYU LESTARI[1], NUR LAILA MAGVIRA[1] ROSE NOVITA SARI HANDOKO[3,4]

[1]Program of Agrotechnology, Faculty of Agriculture, Universitas Jember. Jl. Kalimantan No. 37, Tegalboto, Jember 68121, East Java, Indonesia. Tel./fax.: +62-331-330224, ♥email: agung.sih.kurnianto@unej.ac.id

[2]Department of Biology, Faculty of Science, Chulalongkorn University. 254 Phaya Thai Rd, Wang Mai, Pathum Wan, Bangkok 10330, Thailand

[3]Program of Agrotechnology, Faculty of Agriculture, Universitas Islam Malang. Jl. Mayjen Haryono No. 193, Malang 65144, East Java, Indonesia

[4]Department of Plant Pathology, National Chung Hsing University. 145 Xingda Rd., College of Agriculture and Natural Resource, Taichung 40227, Taiwan

Manuscript received: 5 October 2022. Revision accepted: 21 February 2023.

Abstract. *Kurnianto AS, Septiadi L, Haryadi NT, Muhlison W, Sucipto I, Dewi N, Tanzil AI, Lestari A, Magvira NL, Handoko RNS. 2023. The false alarm of experimentally companion plants to the cabbage pests with their ecological effects. Biodiversitas 24: 1303-1312.* Jember is one of the important horticulture producers in Indonesia. Companion Plants (CP) are promising for effective pest control. This study aims to analyze the abundance of cabbage pests across several local CP and the theoretical ecological interactions between pests and plants. We conducted an experiment with several local CP: Ground Peanut (*Arachis hypogaea*), Tomato (*Solanum lycopersicum*), Welsh Onion (*Allium fistulosum*), and Shallot (*Allium cepa*) to Cabbage (*Brassica oleracea* var. *capitata*) and examining the abundance of cabbage pests (*Plutella* sp. and *Crocidolomia* sp.). The results showed that Arachis hypogaea performed as suitable as a CP for cabbage, whereas the other plants (*Allium* spp.) contradicting attracted more pests. The similarity index based on cabbage pests and abundance clearly demonstrated that *A. fistulosum* was most similar to the control. PCA shows *Plutella* sp. was abundantly seen throughout weeks 1-4, and *Crocidolomia* sp. was seen in abundance during weeks 5 and 6. The patterns between pests' abundance, attack area, and damage intensity showed a similar trend for both *Plutella* sp. and *Crocidolomia* sp. In the future, it is essential to evaluate the use of *Allium* groups as CP for cabbage and VOC interactions between plants and pests.

Keywords: *Crocidolomia* sp., ecological effect, Jember, *Plutella* sp., VOCs

INTRODUCTION

Concerns about the impact of pesticides on non-target organisms continue to drive advancements in environmentally friendly pest management (Dara 2019). One alternative is to increase crop diversity, called intercropping (Mancini 2013). Intercropping, a traditional technique for increasing yield by utilizing resources that would otherwise not be utilized by a single crop, has been used by farmers for decades to conserve agroecosystem diversity (Brooker et al. 2015), including protection of plants against pests (Moreno and Racelis 2015). Using a companion plant (CP) is one of the intercropping techniques. CP is a plant that accompanies the main crop and can synergistically support its defense against pests. CP can be harvested, and it can increase farmers' economic gain. This will increase the willingness of farmers to apply CP to their land because they do not need to provide space to grow plants that do not have an economic impact, such as refugia plants in general (Parker et al. 2013; Sarkar et al. 2018).

There are various reasons for using CP with crops to reduce pest attacks. First, CP is more attractive to pests and drags pests away from the crop (Sarkar et al. 2018). Then, by emitting Volatile Organic Compounds (VOCs), CP can directly repel pests or mask the odor of crops as host targets (Parker et al. 2013). Recently, CP has been successfully used as "trap-crops" and "intercrops", and this function has been described as a "push-pull strategy" (Kim et al. 2012; Lee et al. 2014). Several references have demonstrated its effectiveness in reducing spotted stem-borer (*Chilo partellus*) attacks on maize (*Zea mays*) in Zambia (Ekoja et al. 2015). Therefore, the CP may be an effective and eco-friendly tool for pest management (Ben-Issa et al. 2017). Researchers suggest that companion plants are used as intercrops in corn agroecosystems. This strategy makes corn more unattractive and unsuitable for pests (push), and companion plants can also lure pests away (pull). Therefore, instead of spraying synthetic chemicals, an 'attractant' effect can be produced by trapping plants and a 'repellent' effect with CP (Kłyś et al. 2017; Schlaeger et al. 2018). In Indonesia, CP is applied to avoid pests on Sago (Zuhro et al. 2020), Albizia (Rahayu et al. 2021), and Cassava (Nurkomar et al. 2021). In advancements in eco-friendly pest management, studies examining the effects of CP and its ecological effects on pests are critical to supporting sustainable pest management.

Jember is a district in Indonesia that produces various horticultural commodities. As a lowland, cabbage is a suitable commodity for the microclimate and various biophysical factors in Jember. Its production continues to increase in line with intensive agricultural patterns (Jember Regency Government 2022). However, behind the high production comes the threat of ecosystem imbalance and production collapse due to pest explosions in the future. A study oriented to alternative management approaches and the transformation of Integrated Pest Management models is essential. This study experimented with several local companion plants and cabbage as the main crop. Cabbage is used because it is an economic commodity with a long history of pest attacks (Gautam et al. 2018). The people's demand for new cabbage strains made pests more varied and adaptive (Franzke et al. 2011; Gautam et al. 2018; Parajuli and Paudel 2019). This study aims to analyze the abundance of cabbage pests and damage to cabbage as the effect of several local companion plants. This study also describes the theoretical ecological interactions between pests, cabbage, and CP, with a case study in Jember, Indonesia.

MATERIALS AND METHODS

Study area

The study took place in an agricultural area in Kemiri Village, Panti District, Jember Regency, East Java, Indonesia (-8.616667 S, 113.5767 E) in March-August, 2022. The land is an agricultural area located 150 meters from a human settlement and is bordered by neighboring rice fields, irrigation, and hedgerows. There has been no information on cabbage cultivation in these locations in the recent five years from 2022. The soil type is inceptisol, the temperature ranges from 23 to 31ºC, and the annual rainfall ranges from 1969 to 3394 mm/year. The dry season occurs from 8 October to 24 November (1.5 months), and the rainy season is from 16 June to 25 August (2.3 months) (Jember Regency Government 2022), all of which are suitable for cabbage cultivation (Saren et al. 2016).

Experimental design

A 10,000 m^2 space is prepared for the experiment. Cabbage (*Brassica oleracea* var. *capitata*) is interplanted with companion plants alternately, according to Figure 1. The spacing between the cabbage and companion plants is 0.4 meters, while the next row's treatments are 0.3 meters apart. To avoid the effects between treatments and control, a 3 meter distance was given. This treatment was repeated four times. Randomized Block Design (RBD) was prepared based on repetition by Microsoft Excel, in which each block plot has a 2 m^2 area (see figure 1).

Have volatile compounds or brightly colored flowers. The treatment groups include: Control (cabbage only; P1); Ground Peanut (*Arachis hypogaea*) + cabbage (P2); Tomato (*Solanum lycopersicum*) + cabbage (P3); Welsh Onion (*Allium fistulosum*) + cabbage (P4); and Shallot (*Allium cepa*) + cabbage (P5). Each treatment uses a single plant (14 days after sowing) to be applied in the plot.

NPK Phonska© (nitrogen, phosphorus, and potassium) was used as the basic fertilizer for cabbage cultivation. All plants were initially sowed in polybags and then transferred to the field seven days later. Daily, all weeds were cleared. In this experiment, only two main cabbage pests were observed: *Plutella* sp. and *Crocidolomia* sp. (Prabaningrum and Moekasan 2021). *Plutella* sp. has a cylindrical shape and is smaller at the head and abdomen. The color is yellowish green with a paler head. The larvae generally make silk webs on leaves. *Crocidolomia* sp. has a lateral-symmetric body shape. The color is light brownish green with yellowish-white stripes along its body on the upper side and black spots on the two sides (Gautam et al. 2018; Prabaningrum and Moekasan 2021).

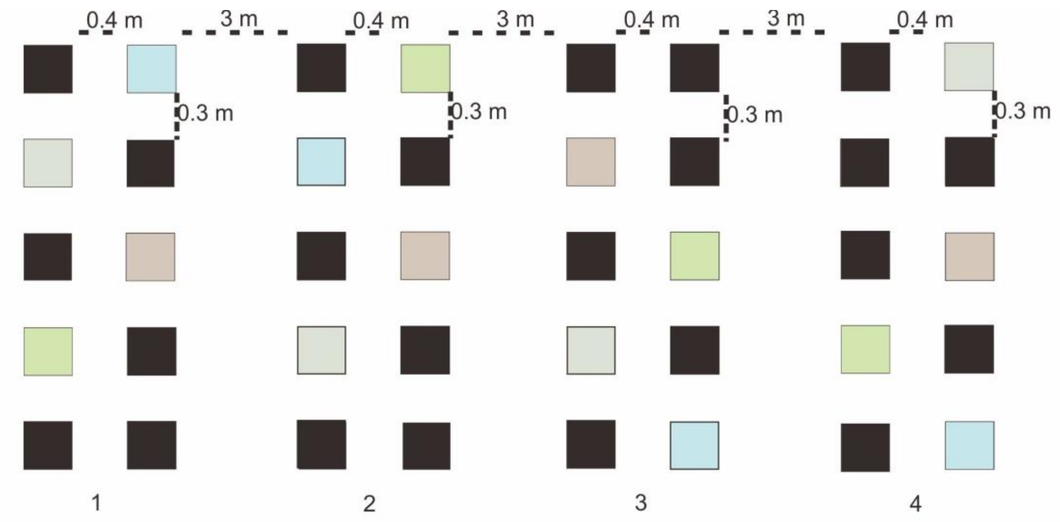

Figure 1. Experimental plot on 5 types of treatment and 4 repetition group. Colors key as follows: black and black = P1 (cabbage + cabbage, as control); black and red = P2 (cabbage + ground peanut); black and green = P3 (cabbage + tomato); black and blue = P4 (cabbage + welsh onion); black and grey = P5 (cabbage + shallot)

Observation and data analysis

For 6 weeks (code=M1-M6), daily observations, pest identification, and counting were conducted on the cabbage plants. The number of pests and the extent of damage caused by cabbage pests is also recorded in order to determine the scale of leaf damage (0: no damage; 1: 1%-25% damage; 2: 26%-50%; 3: 51%-75%; 4: 76%-100%). A total of 12 of the same leaves were observed. Damage caused by *Plutella* sp. has a rounded edge that starts from the center towards the edge of the leaf, and there are silk webs around it. *Crocidolomia* sp. damages the edge of the leaf with sharp jagged marks. The pests' abundance and damage to companion plants were not observed. Microsoft Excel was used to compile the data (McCullough and Wilson 2005). The results for pest abundance were presented as mean abundance (with standard deviation), whereas attack area and damage intensity were presented as relative percentages. The data visualization was done in RStudio v.3.4.1 (Team 2018) using the ggplot2 R-packages (Wickham 2008). Over a 6-week period, fluctuations in the total abundance of cabbage pests were observed. The data were analyzed using hierarchical clustering of Bray-Curtis similarity on PAST3 software (Hammer et al. 2001) to evaluate the clustering similarity between treatment groups. Statistics analysis provided with SPSS 16.0. The Shapiro-Wilk normality test was provided to determine the type of data distribution with a small sample population, and then the Friedman non-parametric test was used to illustrate the significance of the interaction between treatments (Mishra et al. 2019). Principal Component Analysis (PCA) on PAST3 software was used to group cabbage pests seen during the observation period. For PCA analysis, weekly pest data were used, which were arranged based on two groups of species. To investigate attack patterns and competition, we examined the fluctuations in total abundance, attack area, and damage intensity for each cabbage pest species (*Plutella* sp. and *Crocidolomia* sp.) over a 6-week period. The attack area was calculated using the formula as follows (Suprapti et al. 2022):

$$AA = \frac{\sum na}{N} 100\%$$

Where: AA is attack area, na is a number of observed pests, and N is a number of observed leaves. The attack intensity was determined using the formula as follow:

$$AI = \frac{\sum (ns \times v)}{Z \times N} 100\%$$

Where: AI is attack intensity, ns is a number of damaged leaves in each attack, v is the scale value of each attack category, Z is the highest set scale value, and N is a number of observed leaves. The set scale values include: Scale 0 (no leaf damage was observed), Scale 1 (1-25% damage to the observed leaves), Scale 2: (26-50% damage to the observed leaves), Scale 3 (51-75% damage to the observed leaves), and Scale 4 (76-100% damage to the observed leaves).

RESULTS AND DISCUSSION

Fluctutation in abundance of cabbage pests

Cabbage pests' abundance fluctuated during weeks 3 and 5 (Figure 2). However, the P1 (without a companion plant) exhibited a similar trend. Surprisingly, the abundance in P1 is lower than the majority of the treatment groups (P2, P3, P4, P5) that used various companion plants for 6 weeks of observations, contradicting the previous records that companion plants may repel cabbage pests. Surprisingly, the P2 (Ground Peanut) had the lowest abundance.

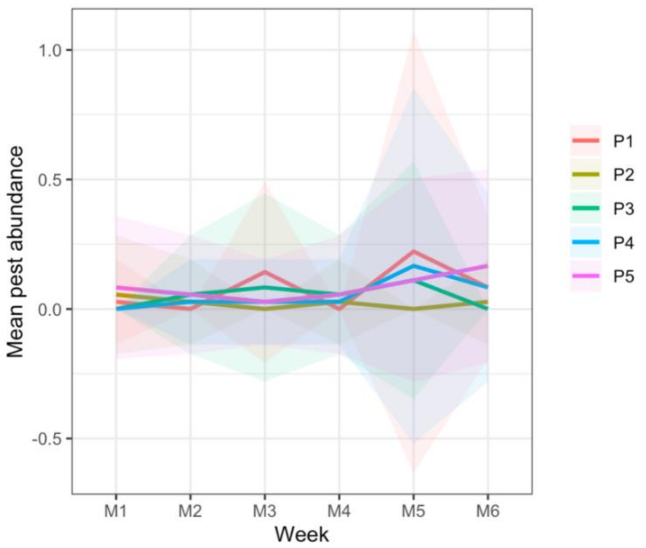

Figure 2. The mean of abundance and its standard deviation (transparent area) of cabbage pests throughout 6 weeks periods (M1-M6), across several treatment groups (see Materials and Methods for the details of abbreviations)

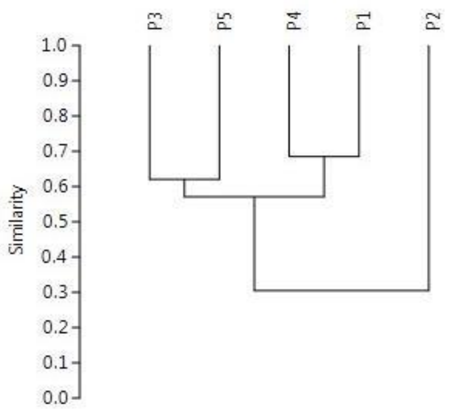

Figure 3. Bray-curtis similarity of cabbage pests abundance across several treatment groups (see Materials and Methods for the details of abbreviations)

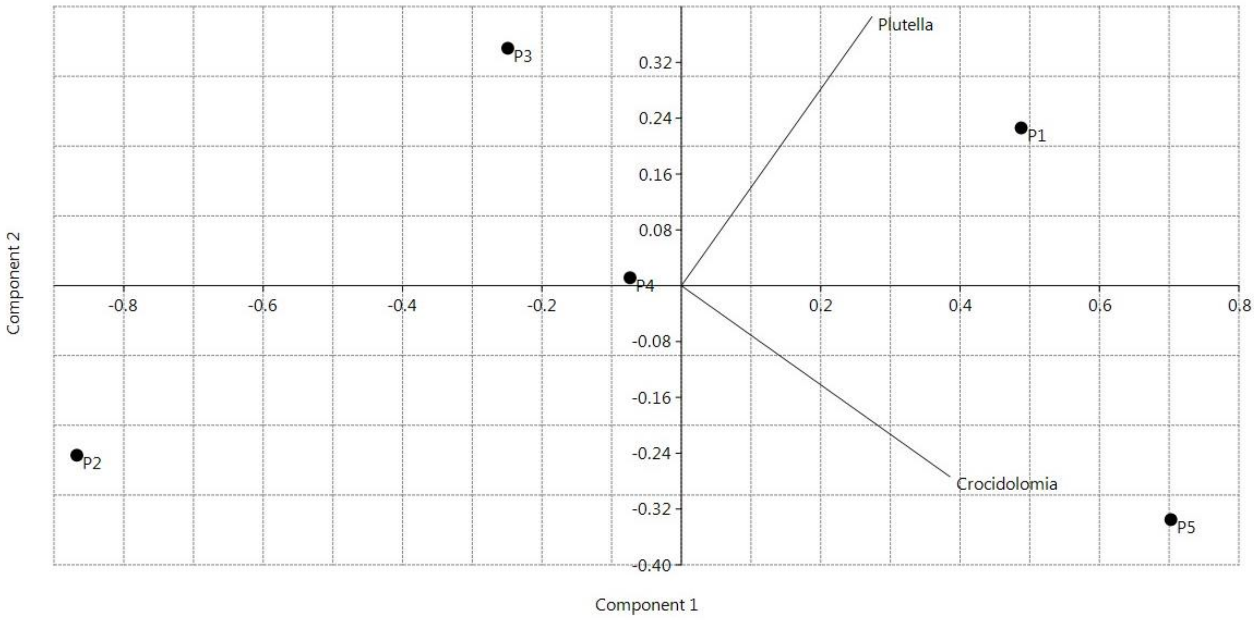

Figure 4. PCA graph showed clustering of *Plutella* sp. and *Crocidolomia* sp. preferences to the treatments (see Materials and Methods for the details of abbreviations)

The similarity index based on cabbage pests and abundance (Figure 3) clearly demonstrated that P4 was most similar to P1, and P3 was most similar to P5. Welsh Onion (P4) is similar to the control and shows that this treatment is less effective as a CP. With a relatively small difference in the similarity scale, the tomato (P3) and shallot (P5) treatments also have low effectiveness. Again, P2 had the lowest total abundance of cabbage pests compared to the others, so it has the lowest similarity index compared to the others. This evidence shows that its effectiveness is higher than other treatments.

PCA ordination graph based on treatment groups and observation periods clearly demonstrated the clustering of two major cabbage pest species (Figure 4). Variation values shown: PC1: 82.091% and PC2: 17.909%. Interestingly, P2 was the most suitable companion plant compared to other treatments due to the lack of grouping in the PCA graph and the lowest cabbage pest's abundance. *Plutella* sp. prefers P1, while *Crocidolomia* sp. prefers treatment P5.

Cabbage pest's abundance and damages

Friedman non-parametric test showed insignificant results with treatment variables and the number of pests, both on *Crocidolomia* sp. and *Plutella* sp (Asymp.Sig: 0.331 and 0.846, respectively). However, this quantitative analysis has yet to provide a clear picture of pest fluctuations in this research. The patterns between cabbage pests' abundance, attack area, and damage intensity showed a similar trend for both *Plutella* sp. and *Crocidolomia* sp. *Plutella* sp. abundance decreased in P5 over M1-M3, which correlates with the attacked area and damage intensity. Additionally, there was an increase in the abundance of *Crocidolomia* sp. between M3-M6, which also correlates with the attacked area and damage intensity. *Plutella* sp. in P4 only appeared during M4, reached its peak in weeks M5, and decreased during M6, which correlates with the attacked area and damage intensity. In addition, *Plutella* sp. was relatively increasing during overall periods (M1-M6), which correlates with the attacked area and damage intensity. Similarly, using Welsh Onion as a companion plant for cabbage had no discernible effect on resistance to *Crocidolomia* sp.

Plutella sp. in P3 showed a different trend, with an emergence during (M3) and re-emergence during M5, although not high as previously, which correlates with the attacked area and damage intensity. Similarly, *Crocidolomia* sp. showed an emergence during M2 and re-emergence during M5, which also correlates with the attacked area and damage intensity.

Due to the absence of *Plutella* sp. in P2, there was no damage to the cabbage. *Crocidolomia* sp., on the other hand, showed no increase in abundance, just emergence in M1 and re-emerging in weeks M4, which correlates with attacked area and intensity of the damage. Using Ground peanuts as a companion plant for cabbage has an effect on both *Plutella* sp. and *Crocidolomia* sp. abundance. Ground Peanut is a plant that shows the best results among the four other types of plants. However, the research results that are very interesting to discuss are the *Allium* genus disservice which shows a greater severity of damage intensity than other plants.

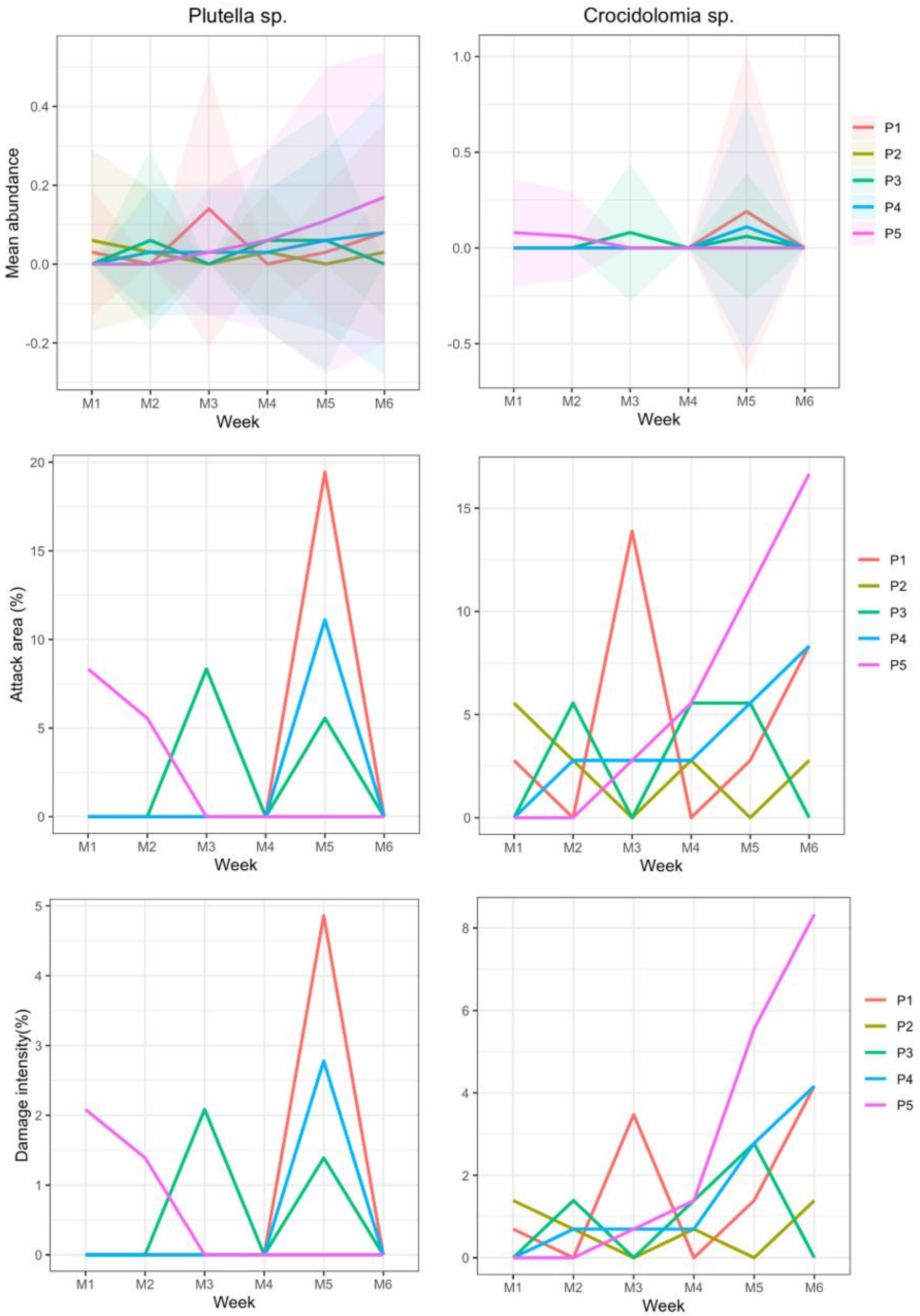

Figure 5. Fluctuations of pest abundance with standard deviation (transparent area), attack area, and damage intensity of cabbage pests across several treatment groups over 6 weeks observation periods (see Materials and Methods for the details of abbreviations)

Discussion

The highest abundance pattern in cabbage pests was observed during week 5, with P5 being the most abundant, followed by P4, P3, and P2, P1. It demonstrated that Tomatoes, Welsh Onion, and Shallot do not possess repellent properties against cabbage pests, which contradicts previous findings (Ikeura et al. 2012). It may be argued that using Shallots as a companion plant for cabbage had no noticeable impact on the abundance of *Crocidolomia* sp. Additionally, Shallots may be attacked by pests, and their presence may contribute to an increase in the abundance of *Crocidolomia* sp., despite the fact that the extract is known to cause pest mortality. The nitrifying ability of ground peanut (Sintia et al. 2021) could attract natural enemies (Cortesero et al. 2000). It is noteworthy that Ground Peanut is a nitrogen-fixing plant that, along with other Fabaceae, forms symbiotic relationships with *Rhizobium* sp. bacteria to fix nitrogen in the air, promote remediation processes (Ullah et al. 2019), enrich the soil with nutrients thereby preventing desertification (Ramos et al. 2019), and suppress weeds (Samedani et al. 2015; Supriyadi et al. 2017). However, the exact chemical substance and biochemical impact of ground peanuts on cabbage pests are not fully understood. Tomatoes as companion plants for cabbage had an unknown effect on the abundance of *Plutella* sp. and *Crocidolomia* sp., however, their flowers and fruit were known to attract more natural enemies of pests (Li et al. 2018; Ciceoi et al. 2021).

Attack pattern differences are likely caused by the speed differences of each pest in responding to the VOCs released by these plants. In control, *Crocidolomia* sp. faster to reach its population peak in M3, compared to *Plutella* sp. in the fifth week. However, it is suspected that the population of *Crocidolomia* sp. can continue to increase after the sixth week. It is challenging to determine which VOCs influence and attract the preferences of these two pests without in-depth research. However, PCA results showed that *Plutella* sp. were more attracted to the control, whereas they were generally more attracted to the cabbage VOCs. On the other hand, *Crocidolomia* sp., who attacked at the crest of the two waves, showed their interest in Shallot. In a study using these two types of pests, Welsh Onion and Shallot are also known as food plants besides Brassicae (Hidrayani and Martinius 2014).

The findings of this study reveal interesting facts, demonstrating a difference between the utilization of companion plants known to have a refugia effect, e.g., *Allium* sp. (Welsh Onion and Shallot in this research). Previously, it was considered that *Allium* sp., both Shallots and Welsh Onions, were well-known for their ability to boost the yield of Romaine lettuce (*Lactuca sativa* var. *longifolia*) (Kapoulas et al. 2017), Canola and Barley (Sarkar et al. 2018). Supposedly, *Allium* sp. has volatile compounds that are able to repel pests or, in this case, keep away from the main crop. When the habitat contains volatile repellents, this will obscure the location of the host plant and force the pest to change its target orientation. These effects were also observed in mustard aphids (*Lipaphis erysimi*) in mustard (*Brassica napus*) cultivation with onions (*Allium cepa*) and garlic (*Allium sativum*) at various ratios (Sarker et al. 1970).

Additionally, it contains volatile organic compounds (VOCs) such as dimethyl disulfide. This content is known to be able to resist several species of pests on plants, which has also been studied by several authors (Potts and Gunadi 1991; Amarawardana et al. 2007; Mutiga et al. 2010; Liu et al. 2014). The content of dimethyl disulfide is present in a high percentage portion (94%) and is thought to be the reason for *Allium*'s ability to repel pests (Debra and Misheck 2014). These compounds are products of alkyl sulfate, which is well known to have potential pest-protective properties during storage. In addition, the family Liliaceae is generally capable of producing various volatile allelochemicals that are used to control pests. The odor of these plants plays an important role in the behavioral change and reproduction of pests (Bagiu et al. 2012; Ben-Issa et al. 2017). Although it is highly probable that the impacts of these substances have a similar influence on cabbage growing, this was not demonstrated in our results.

The underlying factors that influenced these findings were probably due to competition and volatile cues, which ended up attracting more pests. The insect's preference for the dimensions of vision is much smaller than that of smell. Parasitoid insects can detect their prospective hosts' presence from hundreds of meters to several kilometers away and lay their eggs precisely, even if they are hidden in earthen burrows or wood. Chemical substances produced by plants that are detectable by insects have a substantial effect on navigation and attack precision (Conboy et al. 2020). According to the evidence presented in this study, there is a high possibility that the odor of substances emitted by *Allium* sp. has an effect on the presence of the major cabbage pests. The high abundance of *Plutella* sp. in the M1 and *Crocidolomia* sp. in the M3, which ended up increasing, demonstrated that *Allium* sp. may attract these cabbage pests. The more severe the damage to cabbage, the more plant chemicals are released, and the pest receives attention (Baudry et al. 2021). The odor produced by companion plant substances should attract more predatory insects or parasitoids that are capable of suppressing pest populations (Conboy et al. 2020).

To prevent and repel pests, the compounds emitted by plants must either have a direct effect on the pests or attract predators and pest parasitoids earlier to the pests. It reported that companion plants utilized in this study exhibited volatile organic compounds (Table 1). Certain companion plants may act as insect repellants. On the other side, this chemical is complex and may attract attacks to other plants. In general, the response of predators and parasitoids to cabbage pests is faster than the response time of pests to locate the source of the odor. According to this study, cabbage pests were able to respond more quickly. Just as insects use chemical signals released by plants as a source of information, plants can detect and use chemical signals to communicate with their habitat (Ueda et al. 2012; Xu and Turlings 2018). Plant interactions below-ground or above-ground without physical contact can be defined as allelopathy, which can be further defined as direct or indirect competition, or the beneficial effects of one plant on another plant through the release of chemical components into the environment (Dahiya et al. 2017). Allelopathy has advantages and disadvantages in plant interactions. Several authors have demonstrated the negative effects of allelopathy in agroecosystems in inhibiting seed germination, as well as root and shoot growth, but the ecological role of allelopathy in agroecosystems is generally beneficial for plant survival (Hunter and Menges 2002; Trezzi et al. 2016).

Table 1. Literatures reporting the volatile organic compounds (VOCs) contained on several companion plants utilized in this study

Volatile compounds	Cabbage	Ground peanut	Tomatoes	Shallots	Welsh onions	Sources
Glucosinolates (GSL)	+	-	-	-	-	Choi et al. (2014)
Acetic acid	+	-	-	-	-	Veromann et al. (2013)
Hydroperoxide	-	+	+	-	-	Orozco-Cardenas and Ryan (1999); Puppo et al. (2013)
Carbonyl, ethanol, Ester, acetate	+	-	-	-	-	Banerjee et al. (2014); Li et al. (2016); Lamy et al. (2018)
Propil sulfide and disulfide	+	+	-	+	+	Edmands et al. (2013); Wang et al. (2019)
Allicin	-	-	-	+	+	Kusano et al. (2016); Nohara et al. (2021)
Dimethyl disulfide	-	-	-	+	+	Potts and Gunadi (1991); Amarawardana et al. (2007); Liu et al. (2014); Charoenchai et al. (2018); Baudry et al. (2021)

Note: +: present; -: absent

Plants can interpret information based on VOCs and use them to adapt to changes in morphology and physiology. These mechanisms are based on the ability of plants to exchange gases with each other. Plants emit a mixture of VOCs that have specific biological functions, whether in plant-insect, plant-pathogenic, or plant-to-plant relationships (Cui et al. 2018; Takahashi et al. 2021). However, this mechanism is poorly understood. Plants can respond with various perceptions of the given stimulus. Activation of various metabolic pathways explains many plant responses as a result of this communication, including the release of VOCs (Ninkovic et al. 2021), gene expression (Trdá et al. 2014), synthesis of phenolic components (Cappellari et al. 2017), synthesis of inhibitory proteins (Tyagi et al. 2018), and nectar production (Li and Blande 2017). Interestingly, the term push-pull in an Integrated Pest Management (IPM) concept is described very differently in this research. *Allium*, which is described as being able to give a 'push' effect, turns out to be a plant that attracts pests and also has a negative impact on the main crop. Push-pull strategies provide elements of different pest management tactics (Bhattacharyya 2017).

The function of the push component in a push-pull strategy is to make protected resources difficult to find, unattractive, or unsuitable for pests. This is obtained by using a stimulus that has an effect on the avoidance behavior of natural enemies and the negative influence of host location and host acceptance (feeding and reproduction). These stimuli may play a role over long or short distances and, ultimately, have an impact on pests that are denied or prevented from accessing the main crop. Stimuli at long range can represent the first line of defense, capable of preventing or reducing attacks. Stimuli over a short distance can be a very powerful tool in preventing specific pest behavior. In the ‘pull’ component of the “push-pull” strategy, attractive stimuli can be used to divert pests from protected areas to trap plants. This stimulus is obtained at a long distance. However, stimuli with short distances can be useful for capturing and trapping pests in a specific place and concentrating on a massive population, and preventing them from approaching the main commodity (Kim et al. 2012).

CP can release certain volatiles that can attract natural enemies. These volatiles can impact the movements of these natural enemies and lead them to find their prey or host habitat (Ben-Issa et al. 2017; Salamanca et al. 2018; Dardouri et al. 2019). One of the author's studies has shown that ladybirds (*Coccinella septempunctata*) are attracted to the smell of Beret (*Berberis vulgaris)* and Camomile (*Tripleurospermum inodorum*) extracts (Schaller and Nentwig 2000). The same VOCs may also be used, both between herbivores and natural enemies, to find their food (Dardouri et al. 2019).

Onions and other plants used in this research are aromatic plants that have great potential to produce VOCs to affect the cabbage habitat. Aromatic plants have been used as CPs to increase the abundance of natural enemies. The author notes that in the Pear Orchard agroecosystem, several aromatic plants are used: Savory (*S. hortensis*), Ageratum (*A. houstonianum*), and Basil (*O. basilicum*), to increase the activity of *C. septempunctata* and reduce the incidence of *Aphis citricola*. The interesting result is that the intercropping system with aromatic plants contributes to the earlier emergence of natural enemies and the shorter presence of pests (Song et al. 2012). Various other aromatic plants (*Mentha canadensis, A. houstonianum, T. Patula,* and *O. basilicum*) have been used on Orchard Apples, increasing their predator abundance and species richness during the flowering period of these aromatic plants (Song et al. 2012). The presence and attack of *Plutella* sp. in the early weeks demonstrate that this insect is able to discover food crops faster than other potential pests. This attack was able to reach its peak in week 3. However, when *Crocidolomia* sp. began to appear in week 2, the abundance of *Plutella* sp. declined at the end of the observation. This may be due to competing intensely for access to resources and space in cabbage.

Our results showed a surprising fact that bridges a gap in our understanding of the effect of companion plants on cabbage pests. Studies on the preference of cabbage pests need to consider the responsible volatile content, type of companion plant, and plant spacing to understand its interaction. The results of this research indicate the preferences, suitability, and resistance of certain pests to plant species. The use of CP combined with intercropping remains a promising alternative method. We show that the failure of *Allium* sp. to attract natural enemies faster than pests is an avenue for further research. There are many schemes used to extend this approach. As several authors point out that the choice of CP has different impacts, and there is no guarantee of success in all cases (Parolin et al. 2012; Moreno and Racelis 2015). Of course, many factors influence the system design using CP. For example, both types, arrangement, density, and distance between CP and the main plant (Ben-Issa et al. 2017). Likewise, time is the most effective part of the use of CP, as well as the presence of adjacent planting locations in conventional agricultural areas. CP should not be a home for pests, and CP needs to reach the right phenological phase so that it can provide protection and food sources for natural enemies (Dib et al. 2017; Li and Blande 2017). We conclude that many factors can lead to the success of the CP strategy for cabbage crops. For good long-term results, this strategy must be combined with other alternative approaches, taking into account the influence of other conventional areas around it.

In conclusion, according to abundance and observation periods, ground peanut (*Arachis hypogea*) shows promising results as a suitable companion plant for cabbage by repelling cabbage pests. Despite being regarded as a suitable companion plant for cabbage pests, some crops (*Allium* spp.) had contradicting results in which they attracted more cabbage pests and, as a result, caused more damage to the cabbage. In the future, research regarding VOCs on Ground peanuts and their effects on the cabbage insect pest has the potential to be carried out. Then, research regarding the use of the *Allium* group in companion plant studies needs to be evaluated for its effectiveness.

ACKNOWLEDGEMENTS

We express our gratitude to Mr. Yusnan, May Tricia Ar Rohmah, and Tani Jaya II farmers group who have assisted in the field. We thank the University of Jember, Indonesia for the internal grant to support this research (contract no. 6354/UN25.3.1/LT/2022).

REFERENCES

Amarawardana L, Bandara P, Kumar V, Pettersson J, Ninkovic V, Glinwood R. 2007. Olfactory response of *Myzus persicae* (Homoptera: Aphididae) to volatiles from leek and chive: Potential for intercropping with sweet pepper. Acta Agric Scand Sect B Soil Plant Sci 57 (1): 87-91. DOI: 10.1080/09064710500487721.

Bagiu RV, Vlaicu B, Butnariu M. 2012. Chemical composition and in Vitro antifungal activity screening of the *Allium ursinum* L. (Liliaceae). Intl J Mol Sci 13 (2): 1426-1436. DOI: 10.3390/ijms13021426.

Banerjee A, Variyar PS, Chatterjee S, Sharma A. 2014. Effect of post harvest radiation processing and storage on the volatile oil composition and glucosinolate profile of cabbage. Food Chem 151: 22-30. DOI: 10.1016/j.foodchem.2013.11.055.

Baudry X, Doury G, Couty A, Fourdrain Y, van Havermaet R, Lateur M, Ameline A. 2021. Antagonist effects of the leek *Allium porrum* as a companion plant on aphid host plant colonization. Sci Rep 11 (1): 1-9. DOI: 10.1038/s41598-021-83580-8.

Ben-Issa R, Gomez L, Gautier H. 2017. Companion plants for aphid pest management. Insects 8 (4): 1-19. DOI: 10.3390/insects8040112.

Bhattacharyya M. 2017. The push-pull strategy: A new approach to the eco-friendly method of pest management in agriculture. J Entomol Zool Stud 5 (3): 604-607.

Brooker RW, Bennett AE, Cong WF, Daniell TJ, George TS, Hallett PD, Hawes C, Iannetta PPM, Jones HG, Karley AJ. 2015. Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytol 206 (1): 107-117. DOI: 10.1111/nph.13132.

Cappellari LR, Chiappero J, Santoro MV, Giordano W, Banchio E. 2017. Inducing phenolic production and volatile organic compounds emission by inoculating *Mentha piperita* with plant growth-promoting rhizobacteria. Sci Hortic 220: 193-198. DOI: 10.1016/j.scienta.2017.04.002.

Charoenchai L, Luprasong C, Meksuriyen D. 2018. Characterization of some organosulfur compounds in Shallot Bulbs. Thai J Pharm Sci 42: 93-97.

Choi SH, Park S, Lim YP, Kim SJ, Park JT, An G. 2014. Metabolite profiles of glucosinolates in cabbage varieties (*Brassica oleracea* var. capitata) by season, color, and tissue position. Hortic Environ Biotechnol 55 (3): 237-247. DOI: 10.1007/s13580-014-0009-6.

Ciceoi R, Iordachescu M, Udriste AA, Badulescu LA. 2021. Insight on solanaceous resitance against tomato leafminer (*Tuta absoluta*), with emphasis on chemical compounds useful in integrated pest management. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 49 (4): 2-15. DOI: 10.15835/nbha49412543.

Conboy NJA, McDaniel T, George D, Ormerod A, Edwards M, Donohoe P, Gatehouse AMR, Tosh CR. 2020. Volatile organic compounds as insect repellents and plant elicitors: An Integrated Pest Management (IPM) strategy for glasshouse whitefly (*Trialeurodes vaporariorum*). J Chem Ecol 46 (11-12): 1090-1104. DOI: 10.1007/s10886-020-01229-8.

Cortesero AM, Stapel JO, Lewis WJ. 2000. Understanding and manipulating plant attributes to enhance biological control. Biol Control 17 (1): 35-49. DOI: 10.1006/bcon.1999.0777.

Cui S, Ling P, Zhu H, Keener HM. 2018. Plant pest detection using an artificial nose system: A review. Sensors 18 (2): 1-18. DOI: 10.3390/s18020378.

Dahiya S, Kumar S, Khedwal RS, Ram SJ. 2017. Allelopathy for weed management. J Pharm and Phytochem 2017: 832-837. DOI: 10.1007/978-3-319-96397-6_16.

Dara SK. 2019. The new integrated pest management paradigm for the modern age. J Integr Pest Manag 1 (10): 1-9. DOI: 10.1093/jipm/pmz010.

Dardouri T, Gomez L, Schoeny A, Costagliola G, Gautier H. 2019. Behavioural response of green peach aphid *Myzus persicae* (Sulzer) to volatiles from different rosemary (*Rosmarinus officinalis* L.) clones. Agric For Entomol 21 (3): 336-345. DOI: 10.1111/afe.12336.

Debra KR, Misheck D. 2014. Onion (*Allium cepa*) and garlic (*Allium sativum*) as pest control intercrops in cabbage based intercrop systems in Zimbabwe. IOSR J Agric Vet Sci 7 (2): 13-17. DOI: 10.9790/2380-07221317.

Dib H, Sauphanor B, Capowiez Y. 2017. Report on the life history traits of the generalist predator *Forficula auricularia* (Dermaptera: Forficulidae) in organic apple orchards in southeastern France. Can Entomol 149 (1): 56-72. DOI: 10.4039/tce.2016.41.

Edmands WMB, Gooderham NJ, Holmes E, Mitchell SC. 2013. S-methyl-l-cysteine sulphoxide: The Cinderella phytochemical? Toxicol Res 2 (1): 11-22. DOI: 10.1039/c2tx20030a.

Ekoja EE, Pitan OR, Olaosebikan FT. 2015. Variations in stem borer infestation and damage in three maize (*Zea mays* variations in stem borer infestation and damage in three maize (*Zea mays* L.) types in Southern Guinea Savanna and rainforest zones of Nigeria. Agric For Fish 4 (6): 284-290. DOI: 10.11648/j.aff.20150406.18.

Franzke A, Lysak MA, Al-Shehbaz IA, Koch MA, Mummenhoff K. 2011. Cabbage family affairs: The evolutionary history of Brassicaceae. Trends Plant Sci 16 (2): 108-116. DOI: 10.1016/j.tplants.2010.11.005.

Gautam MP, Patel SV, Singh H, Kumar S, Kumar V, Singh G, Singh SN. 2018. Diamondback moth, *Plutella xylostella* (Linnaeus) (Insecta: Lepidoptera: Plutellidae) a major insect of cabbage in India: A review. J Entomol Zool Stud 6 (4): 1394-1399.

Hammer Ø, Harper DAT, Ryan PD. 2001. Past: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol Electron 4 (1): 1-9.

Hidrayani H, Martinius M. 2014. Diversity of nuclear polyhedrosis viruses on Lepidopteran pests on Cruciferae in West Sumatera, Indonesia. Intl J Adv Sci Eng Inf Technol 4 (3): 134. DOI: 10.18517/ijaseit.4.3.385.

Hunter ME, Menges ES. 2002. Allelopathic effects and root distribution of *Ceratiola ericoides* (Empetraceae) on seven rosemary scrub species. Am J Bot 89 (7): 1113-1118. DOI: 10.3732/ajb.89.7.1113.

Ikeura H, Kobayashi F, Hayata Y. 2012. Repellent effects of volatile extracts from herb plants against larvae of pieris rapae (*Crucivora boisduval*). J Agric Sci 5: 145-148. DOI: 10.5539/jas.v4n5p145.

Jember Regency Government. 2022. Harvested Area, Average Production and Total Production of Vegetables by Type 2018. https: //jemberkab.bps.go.id/statictable/2020/11/11/241/luas-panen-rata---rata-produksi-dan-total-produksi-sayur---sayuran-menurut-jenis-sayuran-2018.html.

Kapoulas N, Koukounaras A, Ilić ZS. 2017. Nutritional quality of lettuce and onion as companion plants from organic and conventional production in north Greece. Sci Hortic 219: 310-318. DOI: 10.1016/j.scienta.2017.03.027.

Kim SH, Fowler JW, Shunk DL, Pfund ME. 2012. Improving the push-pull strategy in a serial supply chain by a hybrid push-pull control with multiple pulling points. Intl J Prod Res 50 (19): 5651-5668. DOI: 10.1080/00207543.2012.656332.

Kłyś M, Malejky N, Nowak-Chmura M. 2017. The repellent effect of plants and their active substances against the beetle storage pests. J Stored Prod Res 74: 66-77. DOI: 10.1016/j.jspr.2017.10.006.

Kusano M, Kobayashi M, Iizuka Y, Fukushima A, Saito K. 2016. Unbiased profiling of volatile organic compounds in the headspace of *Allium* plants using an in-tube extraction device. BMC Res Notes 9 (1): 1-12. DOI: 10.1186/s13104-016-1942-5.

Lamy F, Dugravot S, Cortesero AM, Chaminade V, Faloya V, Poinsot D. 2018. One more step toward a push-pull strategy combining both a trap crop and plant volatile organic compounds against the cabbage root fly *Delia radicum*. Environ Sci Pollut Res 25 (30): 29868-29879. DOI: 10.1007/s11356-017-9483-6.

Li T, Blande JD. 2017. How common is within-plant signaling via volatiles? Plant Signal Behav 12 (8): e1347743. DOI: 10.1080/15592324.2017.1347743.

Li T, Blande JD, Holopainen JK. 2016. Atmospheric transformation of plant volatiles disrupts host plant finding. Sci Rep 6: 1-10. DOI: 10.1038/srep33851.

Li X, Garvey M, Kaplan I, Li B, Carrillo J. 2018. Domestication of tomato has reduced the attraction of herbivore natural enemies to pest-damaged plants. Agric For Entomol 20 (3): 390-401. DOI: 10.1111/afe.12271.

Liu XC, Lu XN, Liu QZ, Liu ZL. 2014. Evaluation of insecticidal activity of the essential oil of *Allium chinense* G. Don and its major constituents against *Liposcelis bostrychophila* Badonnel. J Asia Pac Entomol 17 (4): 853-856. DOI: 10.1016/j.aspen.2014.08.007.

Mancini L. 2013. Conventional, organic and polycultural farming practices: Material intensity of Italian crops and foodstuffs. Resources 2 (4): 628-650. DOI: 10.3390/resources2040628.

McCullough BD, Wilson B. 2005. On the accuracy of statistical procedures in Microsoft Excel 2003. Comput Stat Data Anal 49 (4): 1244-1252. DOI: 10.1016/j.csda.2004.06.016.

Mishra P, Singh U, Pandey CM. 2019. Application of student's t-test, analysis of variance, and covariance. Ann Card Anaesth 22 (4): 407-411. DOI: 10.4103/aca.ACA.

Moreno CR, Racelis AE. 2015. Attraction, repellence, and predation: Role of companion plants in regulating *Myzus persicae* (Sulzer) (Hemiptera: Aphidae) in organic kale systems of South Texas. Southwest Entomol 40 (1): 1-14. DOI: 10.3958/059.040.0101.

Mutiga SK, Gohole LS, Auma EO. 2010. Effects of integrating companion cropping and nitrogen application on the performance and infestation of collards by *Brevicoryne brassicae*. Entomol Exp Appl 134 (3): 234-244. DOI: 10.1111/j.1570-7458.2009.00952.x.

Ninkovic V, Markovic D, Rensing M. 2021. Plant volatiles as cues and signals in plant communication. Plant Cell Environ 44 (4): 1030-1043. DOI: 10.1111/pce.13910.

Nohara T, Fujiwara Y, El-Aasr M, Ikeda T, Ono M, Nakano D, Kinjo J. 2021. Thiolane-type sulfides from garlic, onion, and Welsh onion. J Nat Med 75 (4): 741-751. DOI: 10.1007/s11418-021-01533-x.

Nurkomar I, Trisnawati DW, Aisyah SN. 2021. Pest insects in cassava plantations intercrop with different plants at Gunungkidul, Yogyakarta, Indonesia. Serangga 26 (1): 1-12.

Orozco-Cardenas M, Ryan CA. 1999. Hydrogen peroxide is generated systemically in plant leaves by wounding and systemin via the octadecanoid pathway. Proc Natl Acad Sci U S A 96 (11): 6553-6557. DOI: 10.1073/pnas.96.11.6553.

Parajuli S, Paudel S. 2019. Eco-friendly management of diamondback moth (*Plutella xylostell*a L.) of cabbage (*Brassica oleracea* var. capitata) in Nepal. Intl J Appl Sci Biotechnol 7 (3): 304-308. DOI: 10.3126/ijasbt.v7i3.25701.

Parker JE, Snyder WE, Rodriguez-Saona, Hamilton GC, Cesar. 2013. Companion planting and insect pest control. In: Soloneski S (eds). Weed Pest Control-Conventional New Challenges. IntechOpen, United Kingdom.

Parolin P, Bresch C, Desneux N, Brun R, Bout A, Boll R, Poncet C, Antipolis F-S. 2012. Secondary plants used in biological control : A review. Intl J Pest Manag 58 (2): 91-100. DOI: 10.1080/09670874.2012.659229.

Potts Mj, Gunadi N. 1991. The influence of intercropping with *Allium* on some insect populations in potato (*Solatium tuberosum*). Ann Appl Biol 119 (1): 207-213. DOI: 10.1111/j.1744-7348.1991.tb04859.x.

Prabaningrum L, Moekasan TK. 2021. Use of light trap for controlling cabbage pests 752: 012027. DOI: 10.1088/1755-1315/752/1/012027.

Puppo A, Pauly N, Boscari A, Mandon K, Brouquisse R. 2013. Hydrogen peroxide and nitric oxide: Key regulators of the legume - *Rhizobium* and mycorrhizal symbioses. Antioxid Redox Signal 18 (16): 2202-2219. DOI: 10.1089/ars.2012.5136.

Rahayu S, Triyogo A, Widyastuti SM, Musyafa', Ardianyah F. 2021. Pests and diseases on *Falcataria moluccana* trees in agroforestry systems with pineapple in East Java, Indonesia. Biodiversitas 22 (5): 2779-2788. DOI: 10.13057/biodiv/d220541.

Ramos SJ, Gastauer M, Mitre SK, Caldeira CF, Silva JR, Neto AEF, Oliveira G, Filho PWMS, Siqueura JO. 2019. Plant growth and nutrient use efficiency of two native Fabaceae species for mineland revegetation in the Eastern Amazon plant growth and nutrient use efficiency of two native Fabaceae species for mineland revegetation in the Eastern Amazon. For Res 7: 1-8. DOI: 10.1007/s11676-019-01004-w.

Salamanca J, Souza B, Rodriguez-Saona C. 2018. Cascading effects of combining synthetic herbivore-induced plant volatiles with companion plants to manipulate natural enemies in an agro-ecosystem. Pest Manag Sci 74 (9): 2133-2145. DOI: 10.1002/ps.4910.

Samedani B, Juraimi AS, Rafii MY, Sheikh ASA, Anwar MP, Anuar AR. 2015. Effect of cover crops on weed suppression in oil palm plantation. Intl J Agric Biol 17 (2): 251-260.

Saren S, Mishra A, Das D, Dey P. 2016. Soil test based fertilizer recommendation for targeted yield of french bean (*Phaseolus vulgaris*) under rice-french bean cropping system. Intl J Bio-resour Stress Manag 7 (5): 1128-1130. DOI: 10.23910/ijbsm/2016.7.5.1536.

Sarkar SC, Wang E, Wu S, Lei Z. 2018. Application of trap cropping as companion plants for the management of agricultural pests: A review. Insects 9 (4): 128. DOI: 10.3390/insects9040128.

Sarker P, Rahman M, Das B. 1970. Effect of intercropping with mustard with onion and garlic on aphid population and yield. J Bio-Sci 15: 35-40. DOI: 10.3329/jbs.v15i0.2200.

Schaller M, Nentwig W. 2000. Olfactory orientation of the seven-spot ladybird beetle, *Coccinella septempunctata* (Coleoptera: Coccinellidae): Attraction of adults to plants and conspecific females. Eur J Entomol 97 (2): 155-159. DOI: 10.14411/eje.2000.029.

Schlaeger S, Pickett JA, Birkett MA. 2018. Prospects for management of whitefly using plant semiochemicals, compared with related pests. Pest Manag Sci 74 (11): 2405-2411. DOI: 10.1002/ps.5058.

Sintia M, Rahman MM, Khanom A, Huq MA, Ali MY, Rauf M, Banu NA, Biswas SK, Azad MAK. 2021. Differential response of the nitrifying microbes and net nitrification rates (NNRs) between different cereal and legume crop soils with chemical fertilization. Arab J Geosci 14 (18): 1857. DOI: 10.1007/s12517-021-08250-5.

Song B, Zhang J, Wiggins NL, Yao Y, Tang G, Sang X. 2012. Intercropping with aromatic plants decreases herbivore abundance, species richness, and shifts arthropod community trophic structure. Environ Entomol 41 (4): 872-879. DOI: 10.1603/EN12053.

Suprapti E, Budiyono A, Dewi TSK, Daryanti, Wiyono, Hermawan D. 2022. Inventory of pests and intensity of fruit fly attacks (*Bactrocera dorsalis*) on curly red chili plants (*Capsicum Annum* L.) in Sido Luhur Farmer Group of Cabeyan Village. Jurnal Ilmiah Agrineca 2: 75-87. DOI: 10.36728/afp.v22i2.1936.

Supriyadi S, Sudaryanto R, Hadisudarmo P, Safrudin A. 2017. Management of legume as land cover crop and empty bunch for the nitrogen efficiency in inceptisols at oil-palm plantation. Sains Tanah 13 (2): 51-59. DOI: 10.15608/stjssa.v13i2.264.

Takahashi Y, Shiojiri K, Yamawo A. 2021. Aboveground plant-to-plant communication reduces root nodule symbiosis and soil nutrient

concentrations. Sci Rep 11 (1): 1-6. DOI: 10.1038/s41598-021-92123-0.
Team RC. 2018. R: A Language and Environment for Statistical Computing. R Found Stat Comput Vienna, Austria. www.r-project.org/.
Trdá L, Fernandez O, Boutrot F, Héloir MC, Kelloniemi J, Daire X, Adrian M, Clément C, Zipfel C, Dorey S, Poinssot B. 2014. The grapevine flagellin receptor VvFLS2 differentially recognizes flagellin-derived epitopes from the endophytic growth-promoting bacterium *Burkholderia phytofirmans* and plant pathogenic bacteria. New Phytol 201 (4): 1371-1384. DOI: 10.1111/nph.12592.
Trezzi MM, Vidal RA, Junior AAB, von Hertwig BH, da Silva SFAP. 2016. Allelopathy: Driving mechanisms governing its activity in agriculture. J Plant Interact 11 (1): 53-60. DOI: 10.1080/17429145.2016.1159342.
Tyagi S, Mulla SI, Lee KJ, Chae JC, Shukla P. 2018. VOCs-mediated hormonal signaling and crosstalk with plant growth promoting microbes. Crit Rev Biotechnol 38 (8): 1277-1296. DOI: 10.1080/07388551.2018.1472551.
Ueda H, Kikuta Y, Matsuda K. 2012. Plant communication. Plant Signal Behav 7 (2): 222-226. DOI: 10.4161/psb.18765.
Ullah MI, Altaf N, Afzal M, Arshad M, Mehmood N, Riaz M, Majeed S, Ali S, Abdullah A. 2019. Effects of entomopathogenic fungi on the biology of *Spodoptera litura* (Lepidoptera: Noctuidae) and its reduviid predator, *Rhynocoris marginatus* (Heteroptera: Reduviidae). Intl J Insect Sci 11: 117954331986711. DOI: 10.1177/1179543319867116.
Veromann E, Toome M, Kännaste A, Kaasik R, Copolovici L, Flink J, Kovács G, Narits L, Luik A, Niinemets Ü. 2013. Effects of nitrogen fertilization on insect pests, their parasitoids, plant diseases and volatile organic compounds in *Brassica napus*. Crop Prot 43: 79-88. DOI: 10.1016/j.cropro.2012.09.001.
Wang A, Luca A, Edelenbos M. 2019. Emission of volatile organic compounds from yellow onion (*Allium cepa* L.) bulbs during storage. J Food Sci Technol 56 (6): 2940-2948. DOI: 10.1007/s13197-019-03764-z.
Wickham H. 2008. ggplot2: Elganta Graphics for Data Analysis. Springer, US.
Xu H, Turlings TCJ. 2018. Plant volatiles as mate-finding cues for insects. Trends Plant Sci 23 (2): 100-111. DOI: 10.1016/j.tplants.2017.11.004.
Zuhro F, Zuhro F, Djoefrie MHB. 2020. Optimizing sago land utilization by intercropping with eggplants, A study at Tanjung Peranap Village, Meranti Island, Riau, Indonesia. J Trop Crop Sci 7 (1): 1-6. DOI: 10.29244/jtcs.7.01.1-6.