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Population dynamics of *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) and its populations on different planting dates and host plant species

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ABSTRACT

The greenhouse whitefly (GWF), *Trialeurodes vaporariorum* (Westwood), is a cosmopolitan pest of horticultural crops. The study purpose was to assess the GWF adult population dynamics on potato and its populations on different planting dates and different host plant species. A survey was conducted to determine the GWF population on potato and its associated abiotic factors from January to December 2019. Four crop species, common bean (*Phaseolus vulgaris*), tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), and chili (*Capsicum annum*) were planted in two field experiments with different planting dates (7 April and 10 July). The results showed that during high rainfall, the GWF densities were very low. However, as the rainfall declined, the population increased and reached its peak in August. Again, when the rain started in September, the population drastically dropped and continuously declined as the rainfall increased until the year-end. The rainfall rate negatively correlates with the GWF population, but there was no significant correlation between temperature and the insect population. Populations of GWF adult, egg, and nymph were significantly higher in planting date 2 than in planting date 1. On both planting dates, the GWF populations on common bean were significantly higher than those on the other host plants. Hence common bean is the potential to be used as a trap crop in potato or chili plantations. Further studies are necessary to develop efficient and effective ways of utilizing bean as a trap crop.

1. Introduction

The greenhouse whitefly (GWF), *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), is a cosmopolitan pest that has caused economic losses to horticultural crops in greenhouses. The GWF is polyphagous insect feeding on 128 plant species belonging to 48 families in Crete (Roditakis, 1990). The pest has also been reported inflicting serious damages to field-grown crops, including strawberry (*Fragaria* × *Annanassa* L.) (Bi et al., 2002), pepper (*Capsicum annum* L.) (Velásquez-Valle, 2020), tomato (*Lycopersicum esculentum* Mill), green bean (*Phaseolus vulgaris* L.) (Lourenção et al., 2008) and potato (*Solanum tuberosum* L. (Lourenção et al., 2008; Nasruddin and Mound, 2016). In South Sulawesi Province of Indonesia, the pest has been reported infesting potato, green bean, chili, and tomato.

Potato is an important horticultural crop in Indonesia. It is cultivated in highland areas (over 1000 m above sea level) and thousands of smallholding farmers are dependent on this crop for their livelihood. Recently, the GWF was found causing serious damage on potato and threatening the sustainability of crop production in South Sulawesi Province, Indonesia (Nasruddin and Mound, 2016).

The GWF causes direct damage to plants by sucking the plant sap inflicting distortion of buds, leaves, and premature defoliation. Indirect damage occurs when the whitefly transmits plant viruses (McKee et al., 2007). The GWF has been reported transmitting the species *Potato Yellow Vein Virus* (PYVV) (Franco-Lara et al., 2013; Salazar et al., 2000), *Tomato Infectious Chlorosis Virus* (TICV), *Beet Pseudo Yellows Virus* (BPYV), and *Strawberry Pallidosis Associated Virus* (SPaV), and *Tomato Chlorosis Virus* (ToCV) (Duffus et al., 1996; Wintermantel and Wisler, 2006). These viruses belong to Genus: *Crinivirus*, Family: *Closteroviridae* (Wisler et al., 1997). Other than *Criniviruses*, the GWF can also transmit *Torradovirus* (*Secoviridae*) (Navas-Castillo et al., 2011). Plant viruses transmitted by the GWF have yet to be found in this region. Indirect damage to a plant also occurs when the whitefly produces honeydew on which sooty mould fungi grow. The sooty mould reduces the amount of light reaching the plant leaves, so it reduces the photosynthesis efficiency and it also contaminates crop products (Johnson et al., 1992; Liu et al., 1993).

The greenhouse whitefly population is affected by both biotic and abiotic factors of the environment. The biotic factors include plant host species and natural enemies. For example, cucumber plants were

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the most preferred by the greenhouse whitefly adults, followed by tomato, strawberry, lima bean, and pepper (Niu et al., 2014). Several natural enemies of the greenhouse whitefly have been reported, including predators such as *Adalia bipunctata* L. (Coleoptera: Coccinellidae) and *Crhysopa phyllochroma* Wesmael (Neuroptera: Chrysopidae) (Perić et al., 2009); parasitoid, such as *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) (Kos et al., 2009); and entomopathogens such as *Lecanicillium muscarium* R. Zare & W. Gams (Hypocreales: Cordycipitaceae) and *Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales: Cordycipitaceae) (Hamdi et al., 2012). While, the abiotic factors regulating the whitefly population include temperature, relative humidity, and rainfall. Temperature and relative humidity are positively correlated with the population development of the whitefly, while rainfall negatively affects the whitefly population (Leite et al., 2005).

To control the GWF, local potato growers mainly use insecticides with high application frequencies, 2–3 times a week. This practice has the potential of impacting consumers' health and the environment. Therefore, alternative control measures of GWF, such as the use of resistant crops, trap crops, and appropriate planting times, should be developed. To achieve these goals, it is imperative to understand the pest population dynamics and ecological factors influencing them and insect's preference on different host species. Therefore, the objective of the current study was to evaluate the effects of planting time and plant host species on GWF populations. The results are useful to determine the appropriate planting time to help plants escape from high GWF population pressure throughout the season and the potential crop species that can be used as a trap crop.

2. Materials and methods

2.1. Study site

Studies were conducted in potato growers' fields in Malino, Gowa Regency, South Sulawesi Province of Indonesia (5° 14′S, 119° 56′E) situated about 1700 m above the sea level with a land slop range from 5 to 40%. The average monthly temperature of the study site was 27 °C, ranging from 25 to 33 °C in 2019 (AccuWeather, 2020) and the average monthly rainfall was 221 mm, ranging from 0 to 470 mm. The average annual rainfall is 1409 mm, ranging from 244 to 3678 mm. Most potatoes are planted during the period of May (the end of the rainy season) to July (the beginning of the dry season) and generally, there is only one planting season per year in the study site.

2.2. Effect of the abiotic factors on the GWF population dynamics

A survey was conducted to determine the GWF populations in Malino area. From April to December, five potato fields with a size of at least 0.5 ha were selected randomly in every 500 m along the regency main road. However, during the high rainfalls (January–March), since no potato plantations were available in the field, GWF populations were observed on volunteer potato plants left from the previous season. In each location, twenty potato plants were randomly selected following a W sampling pattern. On each plant, four fully developed young compound leaves were observed for whitefly adult counts. The leaves were carefully turning and all GWF adults found were counted. The samplings were carried out once in two weeks from Jan to Dec 2019.

2.3. The GWF populations on different host species planted on different dates

Four different host species of the GWF, chili (*C. annum*), Tomato (*L. esculentum*), potato (*S. tuberosum*), and common bean (*P. vulgaris*) were planted on 7 April (Planting date 1) and 10 July (Planting date 2). The treatments were arranged in a split-plot design employed in a complete randomized block design with four replications. The main plots were the planting times and the sub-plots were the plant species. Each replication consisted of a plot of eight rows wide and ten meters long. In each plot, two rows of each of the plant species were planted, so there were eight plant rows randomly placed in the plot. The planting space used was 75 cm between rows and 50 cm between plants within a row. One week before planting, an organic fertilizer (chicken manure) was applied to the soil with a rate of two tons per ha, and on the day after, NPK (Phonska 15: 15: 15) and urea fertilizers (Urea 46) (Petrokinia Gresik) were applied at 150 kg/ha and 50 kg/ha, respectively. On the thirtieth day after planting, NPK fertilizer was again applied at a rate of 100 kg/ha. Plants were irrigated and sprayed with fungicide as needed, but no insecticide was used in this experiment.

The populations of the greenhouse whitefly were monitored weekly for eight weeks, starting from two weeks after the plant emergence. In each plot, five plants of each plant species were randomly selected for whitefly counts. On each plant, four fully developed young upper compound leaves were observed for whitefly counts. The leaves were slowly turning and all GWF adults found on the abaxial surface of the leaves were counted. For egg and nymph counts, four upper leaves and four middle leaves, respectively, were picked and place in zip-lock bags

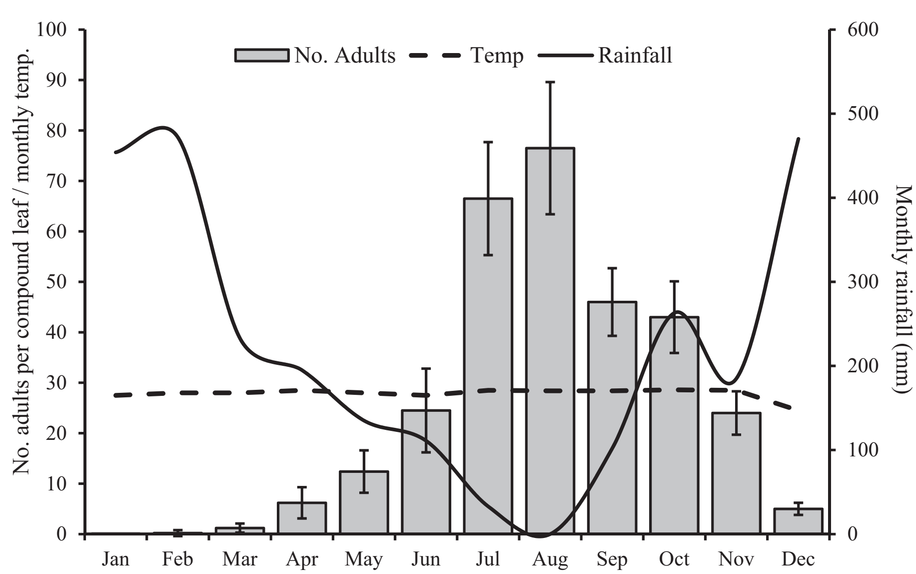

Fig. 1. Influence of the average monthly rainfall (mm) and monthly temperature (°C) on the greenhouse whitefly (*T. vaporariorum*) (GWF) adult population. Monthly rainfall data was provided by the Climatology Station, Maros, South Sulawesi.

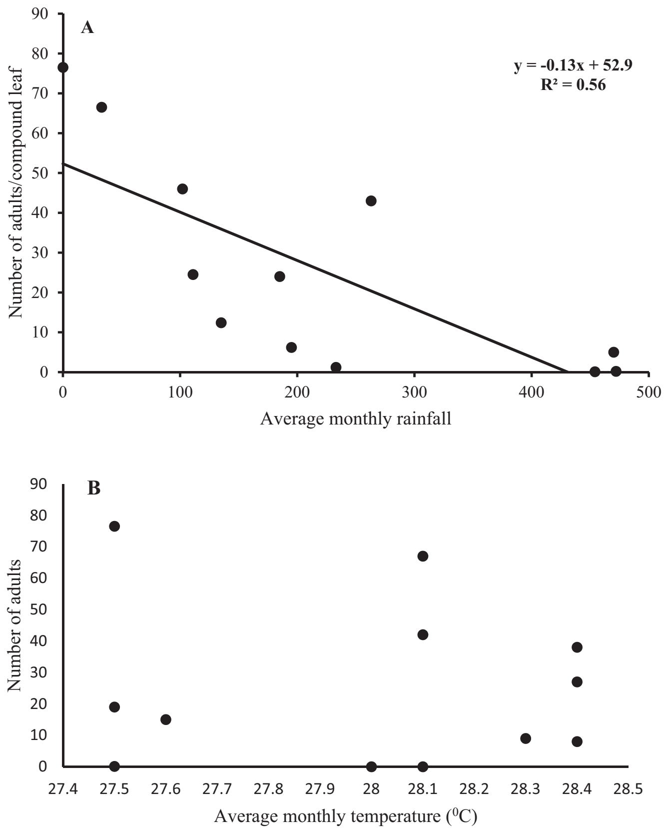

Fig. 2. Relationship between the average monthly rainfall rate (A) and temperature (B) and the number of greenhouse whitefly (*T. vaporariorum*) (GWF) adults per compound leaf.

and then brought to our laboratory for counting under a dissecting microscope (200×). The numbers of eggs and nymphs per1 cm^2 of abaxial leaf surface were determined.

2.4. Data analysis

Count data of GWF adults, nymphs, and eggs were transformed using a log (x + 1) to normalize the data and then separately subjected to an analysis of variance (ANOVA) ($P = 0.05$). Means were separated using a Tukey's test ($P = 0.05$). Linear regression analysis was performed to determine the relationship between rainfall rate or temperature and the greenhouse whitefly populations (SPSS Statistics 27.0.1.0).

3. Results

3.1. Effect of abiotic factors on the GWF population

During the survey, the average monthly rainfall was 221.1 mm, ranging from 0 to 472 mm and the average monthly temperature is 27.9, ranging from 24.5 to 28.6 °C. The number of greenhouse whitefly adults per compound potato leaf and the associated climatic data (Fig. 1). During the peak of the rainfall, Jan (454 mm) and Feb (472 mm), the average number of GWF adults per leaf was very low, 0.05 to 0.2 adults per compound leaf, respectively. After that, as the rainfall continuously dropped and young plants were available in the field, the populations steadily increased and a significant jump occurred from June to July and reached its peak in August (76.5 individuals per compound leaf) when the rainfall was 0 mm for that month. As the rainfall started to increase in September, the GFW adult population dropped significantly and then the population continuously decreased till the end of the year. The number of the GWF adults was significantly negatively correlated with the rainfall rate ($y = -0.13x + 52.9$; $r^2 = 0.56$; $P < 0.05$). However, temperature did not significantly correlate with the whitefly population ($r^2 = 0.07$; $P \geq 0.05$) (Fig. 2).

3.2. The GWF populations on different host species planted on different dates

For 7 April planting date (Planting date 1), on the first three observation dates (8 May, 15 May, and 22 May), the numbers of the GWF adults per compound leaf were very low and there were no significant differences among the host species treatments. However, starting from the fourth observation (29 May) till the end of the study (26 Jun), there were significant differences in numbers of the GWF adults in the treatments. Populations of *T. vaporariorum* on common bean were consistently significantly higher than on the other treatments throughout the study (Table 1), followed by its populations on tomato. In general, the whitefly populations on chili and potato were not significantly different from each other but significantly lower than those populations on tomato and bean. There was a general trend that the whitefly populations on all host species consistently increased throughout the study period. For the first three observations, the number of eggs (Table 2) was very low and no significant differences were detected among the host treatments. However, for the rest of the survey, the average numbers of the GWF eggs were significantly higher on bean in comparison with the other treatments. This was followed by the egg populations on tomato and the lowest whitefly egg populations were found on chili and potato, which were not significantly different each other. Similarly, during the first three observations, the numbers of nymphs were so low that no significant differences existed among the treatments (Table 3). However, in the following observations, the numbers of nymphs found on bean were constantly higher than the nymph numbers on the other hosts.

For July planting date (planting date 2), in each observation date, plant species had significant effects on the average number of GWF adults per compound leaf (Table 4). Common bean had significantly higher numbers of greenhouse whitefly adults than did the other host species during the field experiment, followed by tomato. Whitefly populations on chili and potato were not significantly different from each other but significantly lower than the population on tomato and bean. In general, whitefly populations steadily increased on all treatments from the first observation (4 Aug) but then dropped in the last observation (22 Sep). Similar trends were also observed for the numbers of eggs and nymphs per compound leaf (Tables 5 and 6).

Table 1
Mean numbers (±SE) the greenhouse whitefly (*T. vaporariorum*) (GWF) adults per compound leaf on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for April planting time.

Host plant	Mean number of GWF adults per compound leaf (±SE)							
	8 May	15 May	22 May	29 May	5 Jun	12 Jun	19 Jun	26 Jun
Chili	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.10 ± 0.07^{ns}	0.20 ± 0.09^{b}	0.10 ± 0.06^{c}	0.40 ± 0.11^{c}	0.60 ± 0.13^{c}	1.70 ± 0.22^{c}
Potato	0.20 ± 0.09^{ns}	0.00 ± 0.00^{ns}	0.15 ± 0.08^{ns}	0.30 ± 0.14^{b}	0.75 ± 0.14^{b}	0.25 ± 0.12^{c}	0.55 ± 0.09^{c}	3.05 ± 0.30^{c}
Tomato	0.20 ± 0.09^{ns}	0.10 ± 0.04^{ns}	0.15 ± 0.16^{ns}	0.85 ± 0.18^{b}	1.35 ± 0.28^{b}	1.25 ± 0.17^{b}	3.35 ± 0.60^{b}	7.75 ± 1.48^{b}
Bean	0.10 ± 0.06^{ns}	0.15 ± 0.08^{ns}	0.30 ± 0.10^{ns}	3.10 ± 0.32^{a}	4.10 ± 0.46^{a}	4.80 ± 0.29^{a}	10.85 ± 1.04^{a}	17.30 ± 0.79^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 2
Mean numbers (±SE) of greenhouse whitefly (*T. vaporariorum*) (GWF) eggs on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for April planting time.

Host plant	Mean number of GWF eggs per compound leaf (±SE)							
	8 May	15 May	22 May	29 May	5 Jun	12 Jun	19 Jun	26 Jun
Chili	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.00 ± 0.00^{b}	0.10 ± 0.06^{b}	0.20 ± 0.09^{b}	1.45 ± 0.22^{b}	2.60 ± 0.33^{c}	4.90 ± 0.38^{c}
Potato	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.55 ± 0.15^{b}	1.15 ± 0.18^{b}	2.15 ± 0.21^{c}	6.40 ± 0.54^{c}
Tomato	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.10 ± 0.06^{b}	0.25 ± 0.09^{b}	0.75 ± 0.20^{b}	3.00 ± 0.25^{b}	8.05 ± 0.44^{b}	23.05 ± 1.06^{b}
Bean	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	1.30 ± 0.16^{a}	3.55 ± 0.32^{a}	6.70 ± 0.81^{a}	16.85 ± 1.13^{a}	26.80 ± 1.41^{a}	39.60 ± 1.79^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 3
Mean numbers (±SE) of greenhouse whitefly (*T. vaporariorum*) (GWF) nymphs on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for April planting time.

Host plant	Mean number of GWF nymphs per compound leaf (±SE)							
	8 May	15 May	22 May	29 May	5 Jun	12 Jun	19 Jun	26 Jun
Chili	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.10 ± 0.04^{b}	0.10 ± 0.06^{b}	0.45 ± 0.15^{b}	0.55 ± 0.15^{c}	1.25 ± 0.25^{c}
Potato	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.00 ± 0.00^{b}	0.10 ± 0.06^{b}	1.10 ± 0.23^{b}	2.15 ± 0.29^{b}	3.10 ± 0.27^{c}
Tomato	0.00 ± 0.00^{ns}	0.00 ± 0.00^{ns}	0.10 ± 0.04^{ns}	0.10 ± 0.04^{b}	0.15 ± 0.08^{b}	1.00 ± 0.00^{b}	4.05 ± 0.32^{b}	8.15 ± 0.65^{b}
Bean	0.00 ± 0.00^{ns}	0.10 ± 0.06^{ns}	0.10 ± 0.04^{ns}	1.85 ± 0.31^{a}	1.65 ± 0.25^{a}	7.85 ± 0.50^{a}	14.35 ± 0.94^{a}	21.55 ± 1.17^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 4
Mean numbers (±SE) of the greenhouse whitefly (*T. vaporariorum*) (GWF) adults per compound leaf on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for July planting time.

Host plant	Mean number of GWF adults per compound leaf (±SE)							
	4 Aug	11 Aug	18 Aug	25 Aug	1 Sep	8 Sep	15 Sep	22 Sep
Chili	0.65 ± 0.16^{c}	0.55 ± 0.15^{c}	1.50 ± 0.21^{c}	1.75 ± 0.23^{c}	2.35 ± 0.26^{c}	2.75 ± 0.38^{c}	6.55 ± 0.90^{c}	1.70 ± 0.31^{c}
Potato	0.55 ± 0.13^{c}	1.15 ± 0.18^{c}	2.20 ± 0.34^{c}	2.20 ± 0.42^{c}	3.10 ± 0.37^{c}	4.45 ± 0.47^{c}	5.60 ± 0.51^{c}	1.80 ± 0.33^{c}
Tomato	1.65 ± 0.25^{b}	6.40 ± 0.56^{b}	6.25 ± 0.46^{b}	9.35 ± 0.48^{b}	15.90 ± 0.84^{b}	21.15 ± 1.18^{b}	34.70 ± 1.17^{b}	18.20 ± 1.09^{b}
Bean	7.35 ± 0.32^{a}	16.4 ± 1.51^{a}	30.05 ± 2.58^{a}	48.50 ± 9.73^{a}	60.70 ± 5.28^{a}	76.15 ± 6.91^{a}	84.4 ± 4.91^{a}	35.45 ± 3.08^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 5
Mean numbers (±SE) of the greenhouse whitefly (*T. vaporariorum*) (GWF) eggs per compound leaf on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for July planting time.

Host plant	Mean number of GWF eggs per compound leaf (±SE)							
	4 Aug	11 Aug	18 Aug	25 Aug	1 Sep	8 Sep	15 Sep	22 Sep
Chili	0.10 ± 0.07^{b}	0.75 ± 0.24^{b}	1.10 ± 0.19^{c}	1.85 ± 0.24^{c}	2.90 ± 0.36^{c}	5.05 ± 0.42^{c}	4.10 ± 0.43^{c}	8.05 ± 0.49^{c}
Potato	0.60 ± 0.19^{b}	1.15 ± 0.22^{b}	2.10 ± 0.33^{c}	3.20 ± 0.37^{c}	4.10 ± 0.34^{c}	4.00 ± 1.34^{c}	6.05 ± 0.37^{c}	11.15 ± 0.51^{c}
Tomato	0.50 ± 0.17^{b}	1.00 ± 0.19^{b}	4.20 ± 0.36^{b}	6.10 ± 0.28^{b}	13.10 ± 0.64^{b}	16.50 ± 1.15^{b}	22.40 ± 0.99^{b}	32.25 ± 1.07^{b}
Bean	2.45 ± 0.11^{a}	1.95 ± 0.17^{a}	8.95 ± 0.50^{a}	14.90 ± 0.93^{a}	27.80 ± 1.29^{a}	24.80 ± 1.30^{a}	44.55 ± 2.89^{a}	69.20 ± 7.02^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

Table 6
Mean numbers (±SE) the greenhouse whitefly (*T. vaporariorum*) (GWF) nymphs per compound leaf on four species of plant hosts, chili (*C. annum*), potato (*S. tuberosum*), tomato (*L. esculentum*), and common bean (*P. vulgaris*) for July planting time.

Host plant	Mean number of GWF nymphs per compound leaf (±SE)							
	4 Aug	11 Aug	18 Aug	25 Aug	1 Sep	8 Sep	15 Sep	22 Sep
Chili	0.30 ± 0.12^{b}	0.40 ± 0.15^{c}	2.10 ± 0.22^{b}	2.10 ± 0.16^{c}	4.80 ± 0.24^{c}	6.05 ± 0.39^{c}	12.15 ± 0.80^{c}	15.20 ± 0.81^{b}
Potato	0.40 ± 0.17^{b}	0.70 ± 0.18^{c}	4.25 ± 0.23^{b}	4.20 ± 0.22^{c}	3.90 ± 0.37^{c}	5.00 ± 0.26^{c}	14.05 ± 0.86^{c}	19.10 ± 0.97^{b}
Tomato	0.90 ± 0.18^{b}	3.25 ± 0.19^{b}	2.95 ± 0.15^{b}	10.00 ± 0.61^{b}	17.70 ± 1.07^{b}	32.45 ± 1.58^{b}	46.60 ± 1.87^{b}	39.75 ± 1.65^{a}
Bean	2.20 ± 0.17^{a}	5.90 ± 0.49^{a}	21.25 ± 1.10^{a}	35.40 ± 1.65^{a}	56.55 ± 4.02^{a}	76.50 ± 5.78^{a}	86.80 ± 5.60^{a}	43.55 ± 2.54^{a}

Means followed by the same letter are not significantly different ($P = 0.05$, Tukey's test).

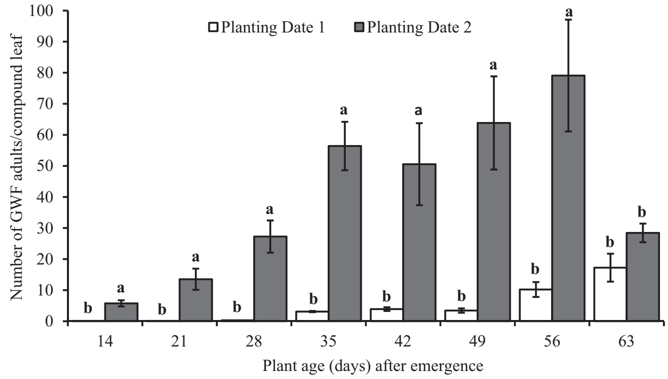

Fig. 3. Influence of planting date on the number of GWF adults per compound leaf on common bean. SE bars with different letters are significantly different within the same plant age (*t*-test, $P = 0.05$). Planting date 1, 7 April and planting date 2, 10 July.

The occurrence times and the population densities of *T. vaporariorum* on bean plants in the field are different between the planting dates (Fig. 3). For planting date 1, the GWF population was very low during the first three observations, 0.1, 0.1, and 0.3 adults per leaf, respectively, then it gradually increased and reached the peak, 17.24 adults/leaf, in the last observation (63 days after emergence). In contrast, in planting date 2, the GWF population density on bean was 7.35 in the first observation, then it gradually increased for the next two observations before it jumped up significantly in the fourth observation. For the next three observations, the population remained high and reached its peak (80 adults per leaf) in the seventh observation before it went down in the last observation. On each observation date (plant age), the average number of the GWF adults per compound leaf was significantly higher in planting date 2 than in planting date 1 (Fig. 3).

4. Discussion

The greenhouse whitefly is a new invasive pest in the Province of South Sulawesi, Indonesia, causing serious damage to field-grown potato plants (Nasruddin and Mound, 2016). This research is an effort to elucidate the GWF population dynamics and its preference for different plant species in the new environment. The GWF adults on potato plants were present in the field from January to December, with populations fluctuating following the rainfall rates (Fig. 1). During the peak of rainfall (January to February), potato crops were not present in the field, but GWF adults were found on volunteer potato plants from the previous planting season with a low population of 0.05 and 0.02 adults per compound leaf in January and February, respectively. As the rainfall decreased, the population started to build up in March and as the new crops became available, the population kept increasing until it reached the peak in August when the rainfall was 0 mm during the month. However, when the rain started in mid-September, the population dropped drastically and then it continuously declined till the end of the season. Our results also showed that there was a significant negative correlation between rainfall rate and the GWF population on potato plants (Fig. 2A). This is in agreement with the study results reported by Leite et al. (2005) that the whitefly population decreased following the high rainfall.

However, there was no significant correlation between the temperature and the whitefly population during the course of the study (Figs. 1 and 2B). This is contradictive with the finding of Arif et al. (2006) that temperature positively correlates to whitefly population growth. This is probably due to the temperature in the site of the current study did not fluctuate widely. The average monthly temperature was 27.5 °C, ranging from 24.5 to 28.5 °C during the study. Gamarra et al. (2020) reported that the optimal temperature for the GWF population growth is between 11.5 and 35.5 °C, and the fastest population growth occurs at 24 °C. Therefore, the temperature range in the research site was suitable for the whitefly growth throughout the year.

The greenhouse whitefly populations on the common bean were the highest and significantly different from those on the other host species in both planting date 1 and planting date 2. Similarly, Lourenção et al. (2008) reported that green bean was among the most preferred hosts of the GWF. For planting date 1, the average populations of the whitefly adult on bean were 6.0, 25.0, and 33.2 times higher than the populations on tomato, potato, and chili, respectively. Average egg populations on bean were about 4.7, 15.4 and 18.7 times higher than those found on tomato, potato, and chili, respectively. In contrast, nymphal populations on bean were about 5.7, 13.9, and 28.5 times higher than those found on tomato, potato, and chili, respectively. Therefore, of all tested crop species, bean was the most preferred host for feeding and egg-laying of the greenhouse whitefly.

Furthermore, when potato was planted in monoculture field set up, the GWF population was up to 84.81 per compound leaf (Fig. 1) and this is similar to the finding of Nasruddin and Mound (2016) that in potato monoculture, the GWF population on potato could reach 68.4 adults per compound leaf. However, when choices are available, the whitefly prefers bean over potato (Tables 1–6). The results suggested that bean has a promising potential to be used as a trap crop in chili or potato plantations because it was far more attractive to the GWF than were the chili and potato. Besides that, the common bean is not planted as a main crop in the study site. A crop trap is a crop that is used to attract pests to protect the main crop from the pest (Hokkanen, 1991). A crop trap is planted with the main crop to attract the pest and then the trap crop is sprayed with insecticide. This management tactic effectively suppresses the pest population and, at the same time, reduces the amount of insecticide used (Cavanagh et al., 2009; Javaid and Joshi, 1995; Lu et al., 2009).

Our results also indicated that planting dates affected the GWF adult populations. For each observation, the GWF population in planting date 2 was consistently significantly higher than the population in planting date 1 throughout the season (Fig. 3). Since the population levels and population development patterns were different between first and second planting dates for the same plant age, the differences are not attributable to the plant phenology but they are mainly affected by the rainfall rates. For the planting date 1, since the crops were planted at the end of the rainy season (4 April), the initial population of GWF adults was very low, 0.01 and the population peak was 17.24 adults per compound leaf at the end of the season. Whereas for planting date 2, crops were planted at the beginning of the dry season (10 July), the initial population was 7.35 and the population peak was 84.81 adults per leaf. The initial population is very important for the population build up during the season and thus, effective reduction of the initial population density is very important for the whitefly control (Ru-Mei et al., 1984). Therefore, planting date 1 could help plants escape from high whitefly populations, especially during the early stage of plant growth. This agrees with Mohamed (2012) reporting that cucumber plants planted early harbour significantly less *B. tabaci* than those on plants planted later because, during the early planting, the rainfall was high.

5. Conclusion

Population dynamics of the GWF adult were strongly affected by the rainfall rate with a significant negative correlation. The study results also indicated that appropriate planting time could be used to effectively control the GWF. Planting early (April) helped plants to escape the high whitefly population during the planting season. Besides that, of all tested crops species, bean was the most preferred host for feeding and egg-laying of the greenhouse whitefly. Hence it is the potential to be used as a trap crop in chili or potato plantations. Further studies, however, are necessary to find efficient and effective ways of applying bean as a trap crop.

Declaration of competing interest

The authors declare that they have no conflict of interest related to the submitted manuscript.

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