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Cotton aphid (*Aphis gossypii* Glover: *Aphididae*) influence associated to water hyacinth nutrient (*Pontederia crassipes* Mart.: Pontederiaceae) in lath house conditions in Great Rift Valley of Ethiopia

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Abstract

The cotton aphid, *Aphis gossypii* Glover is a polyphagous herbivore known worldwide. The aphid infestation could be considered as a challenge to crops, but an opportunity for alien invasive weed management. Hence, this study was initiated to investigate the potential of cotton aphid on the management of water hyacinth. Aphid-infested water hyacinth plants were used as a stock for rearing the aphid in a lath house at Ethiopian Sugar Corporation, Research and Development Center, Wonji. After rearing, randomly collected 30 aphids were placed onto water hyacinth plants cultivated under three nutrient levels. Aphid population, water hyacinth biomass and percent nitrogen and phosphorus were analyzed. The water hyacinth treated with a high nutrient level had the highest (295.0) mean aphids on apical leaves followed by the middle (178.3) and basal (104.7) leaves. The water hyacinth subjected to medium and no aphid treatment had the highest dry (44.3 g) biomass. However, when treated with a low nutrient level and aphids resulted in the lowest dry (31.9 g) biomass. Nitrogen and phosphorus concentrations were found high in the water hyacinth that received a high nutrient and no aphid treatment. The presence of the aphids reduced the biomass and nutrient concentration of the invasive weed. The findings of the current study revealed that the cotton aphid affected the water hyacinth in the lath house conditions in Ethiopia.

Keywords Biomass, Invasive, Natural enemy, Nutrient, Weed

Introduction

Alien invasive water hyacinth (Pontederiaceae: *Pontederia (=Eichhornia) crassipes* Mart.) is a free-floating macrophyte affecting freshwater bodies and becoming increasingly severe, especially in Africa (Tewabe 2015; Dechassa and Abate 2020; Karouach et al. 2022). This weed is one of a hundred of the world's worst invasive alien species distributed in more than 50 countries from its origin center, South America (GISD 2023). Water hyacinth reproduces primarily through vegetative propagation, though seeds may be a major source of re-infestation once the parent plants have died (Otieno et al. 2022).

Water hyacinth has been reported to cause many problems, primarily to the environment and socio-economic activities, in lakes, rivers, and many reservoirs

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around the world, particularly in Africa (Muche et al. 2020; Van Oijstaeijen et al. 2020; Karouach et al. 2022; Otieno et al. 2022). Water hyacinth was first introduced as an ornamental plant to the area surrounding Aba-Samuel Dam in Ethiopia's Central Rift Valley water bodies (Firehun et al. 2014). It was officially reported in Ethiopia for the first time in the second part of the twentieth century near Lake Koka and the Awash River (Stroud 1994). Since then, the coverage has increased and affected biodiversity, hydroelectric power generation, agricultural activities, transportation, fishing, and health condition (Firehun et al. 2014; Enyew et al. 2020; Damtie et al. 2022a).

The growth of water hyacinth is influenced by biotic and abiotic factors (Reddy and Sutton 1984; Damtie et al. 2022b; Otieno et al. 2022). The quantity of nutrients, the nature of a Lake, and the suitable climatic conditions of the area are among the causes of the weed's proliferation (Damtie et al. 2022b). Different control methods that include biological, manual, mechanical, as well as chemical control, are applicable with their own set of merits and demerits (Charudattan et al. 1995; Firehun and Yohannes 2009; García-de-Lomas et al. 2022). The long-term management of alien aquatic vegetation relies on the correct implementation of biological control using arthropods and pathogens for those species already in the country and the prevention of the introduction of other species (Hill and Coetzee 2017; Yigermal and Assefa 2019; Cerveira and de Carvalho 2019).

The most widely used biological control agents have been the weevils *Neochetina* spp., which are in use worldwide as classical biocontrol of the water hyacinth (Charudattan et al. 1995; Karouach et al. 2022). There are also other herbivore arthropods used to feed on this weed (Vogel and Oliver 1969; Cordo and DeLoach 1976; Coetzee et al. 2005; Sutton et al. 2016; Gupta and Yadav 2020). Successful post-release monitoring and evaluating the success or failure of the implementation of a biological control method should be a two-step process, focusing on short-term reduction in biomass and plant vigor and long-term goals by percent cover (Jones et al. 2018).

The sucking habits of herbivorous insects influence the growth parameters of water hyacinth, while under pressure in different environmental factors (Sacco et al. 2013; Tipping. et al. 2014; Miller et al. 2021; Coetzee et al. 2022). Aphis sp. was found feeding on water fern (*Salvinia cuculata*), water lettuce (*Pistia stratiotes*), and Curly Pondweed (*Potamogeton malaianus*) but not on water hyacinth (*Pontederia crassipes*), according to a survey of insect pests on noxious weeds conducted in Thailand in 1994 and 1995 (Siriworakul et al. 1997). However, report from Ethiopia indicated that the aphid has been found on water hyacinth in the Upper Awash River Basin (Stroud 1994).

This confirmed that *Aphis gossypii* Glover is a polyphagous aphid found worldwide that colonizes various types of plants when prone to food shortage (Deguine et al. 1999; Wang et al. 2016; Liu et al. 2017; Ma et al. 2019a). However, the *A. gossypii* genetic makeup and previous feeding experiences are determinants of host plant adaptation and damage (Ma et al. 2019b). Therefore, this study was targeted to evaluate the population density of *A. gossypii* and its impact on the water hyacinth plants under different nutrient levels in the lath house conditions.

Materials and methods

Cultivation of water hyacinth

Water hyacinth plants were collected from Camp 9 Water Reservoir, about 10 km Southeast of Wonji town. Following Kassu et al. (2022), four uniform-size water hyacinth plants with no visible disease symptoms and damages were selected and used for the experiment in plastic buckets contained in a lath house at Wonji. Each plastic bucket had a 15-L capacity, 16 cm height, and 40 cm width. Four water hyacinth plants, which had three to four leaves, were put in each plastic bucket containing water treated with nitrate (KNO_3) and phosphate (KH_2PO_4) sources (Bownes 2008) at different levels. The levels used were low (10 mg/l N, 0.18 mg/l P), medium (35 mg/l N, 1.68 mg/l P), and high (100 mg/l N, 3.0 mg/l P) as detected in the freshwater bodies of Ethiopia by Mekonnen et al. (2014) and Wondim (2016).

Rearing of *Aphis gossypii*

Test aphids were collected from Wonji town drainage system. Water hyacinths infested with aphids were selected and transported to the lath house at Ethiopian Sugar Corporation, Research and Development Center, Wonji. The collected aphids were reared for a month on water hyacinth containing three-fourths of its capacity in 15-L plastic buckets following Akey and Butler (1989) methods. After a month, aphids emerged in hundreds and were used for subsequent experiments (Sharma et al. 2017).

Treatments and experimental design

There were six treatments with aphids present or absent combined with the three nutrient levels mentioned above in the water hyacinth cultivation. The experimental design used was randomized complete block design with three replications and six treatments in the lath house conditions. In this experiment, there were four water hyacinth plants placed per bucket. Each plastic bucket with water hyacinth plants was kept in insect proof cage to prevent the entry and escape of the aphids. Following

Jayaweera et al. (2008), the experiment on the water hyacinth plants commenced after acclimatizing the test plants for a week. Just after the first-week replacement of the nutrient levels, 30 wingless aphids were released in the cages among the water hyacinth plants per bucket based on the combination, and the experiment was carried out from December 2020 to January 2021.

Data collection

Aphis gossypii population dynamics

The population of the aphid was counted on water hyacinth leaves from three different positions for seven round following Chau et al. (2005) and Araújo et al. (2019). The leaf positions were basal, middle, and apical parts by considering the front and back sides of the leaves. In aphid number determination, three leaves from each stage of water hyacinth plant leaves were randomly selected per bucket. The number of aphids per three leaves of the basal, middle, and apical leaves was counted after weekly nutrient treatment applications.

Water hyacinth biomass determination

Five sampled water hyacinth plants from every treatment were weighed for dry biomass determination at the end of the experiment (Sacco et al. 2013). The water hyacinth samples measured per treatment were sun-dried for three days before oven dried for 72 h at 65 ℃ in a soil laboratory at Ethiopian Sugar Corporation, Research and Development Center, Wonji, to remove the water from the water hyacinth (Jaiswal 2011; Damtie et al. 2022b).

Percent nitrogen of water hyacinth leaves

The percent nitrogen of the water hyacinth leaves was determined from randomly collected ten water hyacinth leaves, each from apical, middle, and basal parts at the end of the lath house experiment. Each leaf stage of the water hyacinth plant was oven dried for 24 h at 65 ℃. Nitrogen was determined by the Kjeldahl procedure of digestion, distillation, and titration (Bollard et al. 1962).

Percent phosphorus of water hyacinth leaves

Water hyacinth leaf sample collection method used for percent nitrogen determination were also applied for phosphorus. Determination of phosphorus carried out on the digest aliquot obtained through calcination or wet digestion. The phosphorus in the solution was determined colorimetrically by using molybdate and vanadate for color development. The reading was made at 460 nm wavelength using a spectrophotometer according to Konieczyński et al. (2007) and Tibbett et al. (2022).

Statistical analysis

All the data were checked for normality and equality of residual error variances to satisfy the assumptions of the ANOVA. Parametric and nonparametric tests were applied based on the nature of the data. Biomass and percent nitrogen data of the water hyacinth were fit to the normal distribution assumptions of ANOVA without any data transformation, while the others were not. Therefore, aphid population dynamics of the water hyacinth were tested using a negative binomial log link, while a square root transformation normalized water hyacinth phosphorus. Version 18 Genstat software package was used to compute the data. Descriptive statistics were used, and significant variable means were separated using Tukey's studentized range (HSD) at 5%.

Results

Aphid population dynamics on water hyacinth under different nutrient levels

Aphid population varied greatly on water hyacinth plants with different treatment levels (Table 1). Treatment and leaf position showed significant interaction ($F_{4, 16} = 2.97$, $p \leq 0.05$) on the aphid mean population. The mean aphid population found on the apical leaf of the water hyacinth plants that received the high nutrient level significantly differed from the mean aphid of the middle and basal leaves of water hyacinth that received medium and low water nutrient levels. There were no statistical differences in the mean aphid population between the apical and middle leaves of the water hyacinth plants that received a high nutrient level and the apical leaves of the water hyacinth plants that received a medium nutrient level (Table 1). The highest (295.0 per three leaves) and the lowest (3.3 per three leaves) mean aphid population

Table 1 Aphid population variation on the water hyacinth plants (per three leaves from each leaf stage) with different treatments (mean ± SE)

Treatment	Leaf	No of Aphid
AN2	Apical	295.0 ± 82.2a
	Middle	178.3 ± 41.7ab
	Basal	104.7 ± 44.6bc
AN1	Apical	149.7 ± 47.7ab
	Middle	89.0 ± 13.2bc
	Basal	55.0 ± 19.9 c
AN0	Apical	3.3 ± 0.7 d
	Middle	6.7 ± 3.2 d
	Basal	8.0 ± 2.1 d

In the treatment combinations, "A" refers to aphid, while "N" stands for nutrient (N0 = low, N1 = medium, N2 = high). Means sharing the same letters within the column are not significantly different from each other at the 5% level, Tukey's studentized range test (HSD) was counted from the apical leaf of the water hyacinth that received the high and low nutrient level, respectively (Fig. 1, Table 1).

Water hyacinth dry weight measurement

Dry weight of water hyacinth showed a significant discrepancy among the treatments ($F_{5, 12}=6.53$, $p=0$ 0.004). The water hyacinth treated with a combination of the medium nutrient level and no aphid were resulted in a higher mean dry weight (44.3 g per five plants) than when treated by aphid combined with low (31.9 g per five plants) or high (35.0 g per five plants) nutrient level, but not different from the other treatments (Table 2).

Table 2 Dry weight (g) (per five plants) of water hyacinth under different treatments (mean ± SE)

Treatment	Dry
A1N0	31.9 ± 1.65a
A1N2	35.0 ± 1.35ab
A0N0	37.6 ± 1.40abc
A1N1	39.6 ± 0.73abc
A0N2	41.2 ± 1.65bc
A0N1	44.3 ± 2.87c

In the treatment combinations, "A" refers to aphid (A0 = no aphid, A1 = aphid presence), while "N" stands for nutrient levels (N0 = low, N1 = medium, N2 = high). Means sharing the same letters within the columns are not significantly different from each other at the 5% level, Tukey's studentized range test (HSD)

Percent nitrogen of water hyacinth

Percent nitrogen was significantly ($F_{5, 48}=38.45$, $p<0.001$) affected only by the treatments, but neither by leaf stages nor by interaction of the leaf stages with treatments. The mean percent nitrogen recorded from the water hyacinth exposed to the high nutrient level with no aphid was higher than the water hyacinth that received low nutrient level with or without aphid and the medium nutrient level with aphid, but not different from the other treatments (Fig. 2A). The mean percent nitrogen recorded from apical leaf stage (3.43% N) was non-significantly greater than the other stages of the leaves (Fig. 2B).

Percent phosphorus of water hyacinth

The treatment was affected ($F_{5,48}=14.68$, $p<0.001$) the percent phosphorus similar to mentioned above in the percent nitrogen. The percent phosphorus recorded from the water hyacinth received high nutrient level with no aphid was higher than the water hyacinth that received low nutrient level with or without aphid and the medium nutrient level without aphid, but not different from the other treatments (Fig. 3A). Non- significantly greater (0.36% P) mean percent phosphorus was recorded on the apical leaf stage of the water hyacinth than the other stages (Fig. 3B).

Discussion

Water hyacinth biomass under different treatments

A higher water hyacinth biomass was detected in the treatment without aphid than the treatment with aphid. This finding is supported by Moran (2006) and Jones et al. (2018) reported that water hyacinth plants exposed to weevil herbivory demonstrated substantial reductions in total biomass compared to populations in the weevil exclusion treatments. The biomass of the water hyacinth was also affected by nutrient concentration beside the aphid. This is in line with the Heard and Winterton (2000) study, which found that the water hyacinth

Fig. 1 High *A. gossypii* density on apical leaf of the water hyacinth followed by middle and basal leaf, respectively

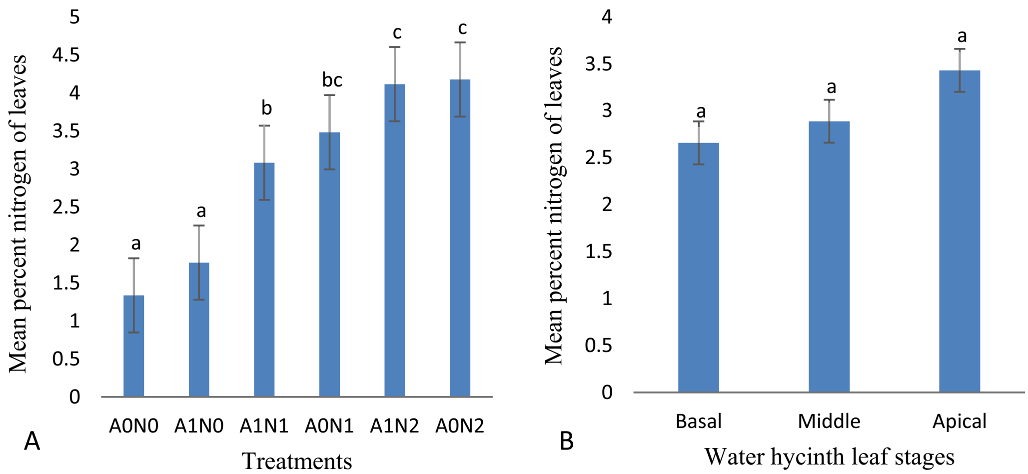

Fig. 2 Percent nitrogen across treatment combinations (A0 = no aphid, A1 = aphid presence, N0 = low nutrient, N1 = medium nutrient, N2 = high nutrient) (**A**) and water hyacinth leaves (**B**). Means sharing the same letter are not significantly different from each other at the 5% level, Tukey's studentized range test (HSD)

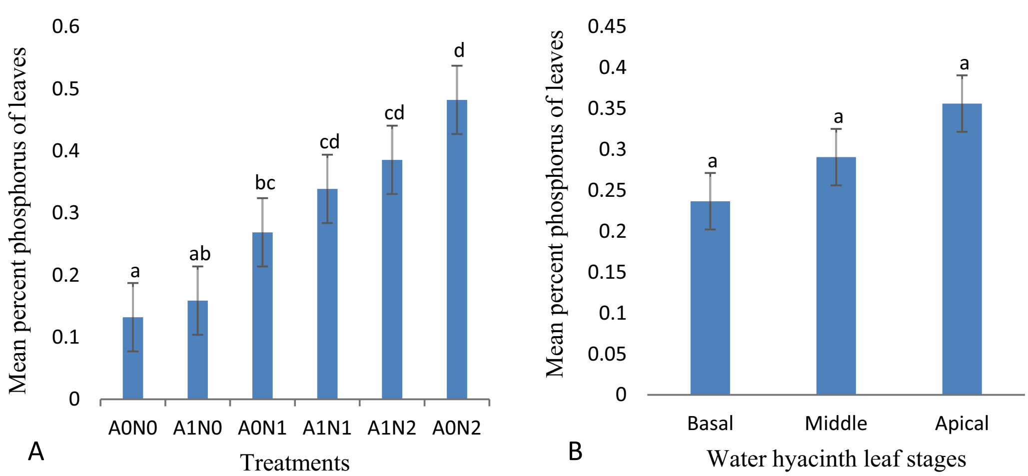

Fig. 3 Percent phosphorus across treatment combinations (A0 = No aphid, A1 = with aphid, N0 = low nutrient, N1 = medium nutrient, N2 = high nutrient) (**A**) and water hyacinth leaves (**B**). Means sharing the same letter are not significantly different from each other at the 5% level, Tukey's studentized range test (HSD)

biomass per tank was greater in tanks without water hyacinth weevils and had a higher nutrient concentration. It is because the leaf and root numbers are positively associated with the level of nutrients (Xie et al. 2004; Li et al. 2015). Comparatively, water nutrient status was far more important than herbivory on the water hyacinth growth parameters, according to Coetzee and Hill (2012).

Percent nitrogen and phosphorus of water hyacinth leaves

The results of this study showed that the mean percent of nitrogen and phosphorus of the water hyacinth leaves had differences across treatments. Congruently, Bownes et al. (2013) reported that water hyacinth nitrogen and phosphorous were positively correlated with the nutrient concentration in which the water hyacinth was grown. According to Coetzee et al. (2007), water hyacinth was more sensitive to nutrient concentration level than the herbivores. Whatsoever, the herbivore feeding resulted in the reduction of the plant nutrient (Moran 2004; Sun et al. 2009; Dray et al. 2012). In this study, nitrogen and phosphorus of water hyacinth showed increasing trend from basal to apical leaf. In line with this, Chau et al. (2005) reported the nitrogen contents of leaves were consistently higher in the apical and middle layers than in the basal stratum. The variations in nitrogen and phosphorous concentrations suggested to be as a result of herbivore feeding and nutrient levels that were available to the water hyacinth.

Aphis gossypii population dynamics

In this study result, more aphids were recorded on apical leaves of water hyacinth that received high and medium nutrient levels. Likewise, Chau et al. (2005) and Araújo et al. (2019) reported that the basal leaf stratum was less preferred by *A. gossypii*. The aggregation of aphids on the apical leaves of the water hyacinth that received high nutrient levels was more than two-fold to the mean aphids found on the basal leaves of the water hyacinth that received lower nutrient levels. However, more mean aphid population per three leaves (greater than three-fold) recorded as nitrogen doses increased on cotton (*Gossypium hirsutum* L.) (Anusha et al. 2017). The current study result was much lower than 490 *A. gossypii* per leaf of a cotton plant reported by Parajulee et al. (1997). This difference could be due to variations of the host plant and agro-ecological conditions. It is because, aphids' capacity to proliferate is greatly influenced by the host plant, the origin and adaptation of the aphid population, and climate (Xia et al. 1999; Hu et al. 2017; Sharma et al. 2017; Chamuene et al. 2018; Nagrare et al. 2021).

Conclusion

A suitable biological control candidate complies with feeding and host specificity, population increase, and potentially damage to a host plant. *A. gossypii* is not host-specific, and its feeding on water hyacinth supports its polyphagous nature. *A. gossypii* showed a synergetic effect with nutrients on water hyacinth growth parameters. The results also indicated that the mean *A. gossypii* population density was enhanced when it fed on well fertilized water hyacinth plants. Generally, *A. gossypii* came up with a challenge and an opportunity. The *A. gossypii* feeding-associated indirect damage to the water hyacinth needs to be considered. Besides, the aphid damage to the economically important crops where the water hyacinth serves as a reservoir needs further investigation.

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Author contributions
Tatek Kassu and Emana Getu conceived and designed the research. Tatek Kassu and Emana Getu collected data and analyzed. Emana Getu and Tatek Kassu identified specimen. Tatek Kassu wrote draft manuscript. Tatek Kassu, Emana Getu and Diriba Muleta reviewed and edited the manuscript. The publishable version of the manuscript has been read and approved by all authors.

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Availability of data and materials
Data and material can be made accessible from the corresponding author when requested.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that there is no conflict of interest with the contents of this article.

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