

SPRINGTAIL (COLLEMBOLA) ABUNDANCE IN *Trichoderma*-ENHANCED AND CONVENTIONAL CABBAGE (*Brassica oleracea* L.) PLOTS IN SARIAYA, QUEZON, PHILIPPINES¹

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ABSTRACT

The effect of *Trichoderma*-based biofertilizer applied to cabbage farms on the abundance of collembolans in cabbage farms was assessed, this being the first study conducted on this subject. Emphasis was given on collembolans mainly because they include fungivores and share the same ecological requirements with *Trichoderma*. Farmer's field experiments were conducted in Barangays Mamala 1 (Site 1) and Sampaloc 1 (Site 2) in Sariaya, Quezon to determine possible differences in abundance between *Trichoderma*-enhanced and conventional cabbage plots. Soil samples were collected at 20, 40 and 60 days after planting (DAP) from both sites and run through Berlese-Tullgren funnel to extract arthropods. Four collembolan species were identified, namely: *Isotomurus parabalteatus* Gapud, *Willowsia* sp., *Seira* sp. and *Xenylla* sp. Results showed that for both sites, the total abundance of collembolans was higher in *Trichoderma*-treated (Site 1: n=1341, Site 2: n=311) than in conventional plots (Site 1: n=399, Site 2: n=76). However, results varied between sampling periods depending on the prevailing physical conditions, thus showing no significant difference for collembolans. Therefore, *Trichoderma* may enhance the population of collembolans given optimal conditions but beneficial effects in maintaining such populations may be diminished under suboptimal conditions.

Key words: biofertilizer, cabbage, Collembola, springtails, *Trichoderma*

INTRODUCTION

In the last decade, the development of biofertilizers has invited many studies to totally find alternatives to synthetic fertilizers and pesticides. Among the many locally available biofertilizers, *Trichoderma*-based fertilizers or soil enhancers possess unique features that are environmentally sound and economically sustainable (Cuevas, 2010; Cuevas et al., 2011). *Trichoderma* species are ubiquitous fungi and are among the most common saprophytic organisms in the soil. Being mycoparasites, *Trichoderma* spp. grow toward the hyphae of other pathogenic fungi, coil about them in a lectin-mediated reaction and degrade the cell walls of the target fungi by a combination of lytic enzymes. Studies showed that *Trichoderma* can aid in the absorption of essential nutrients such as nitrogen, phosphorus, calcium, copper, molybdenum, magnesium, zinc, and iron, and very importantly, become a source of metabolic water. It has been shown to have the ability to solubilize manganese. Aside from being a biofertilizer, *Trichoderma* inoculant is also used as a biological control agent against some soil-borne pathogens. Crop yields are increased by growth stimulation and by protection as the vigorous growth of plants is accompanied by improved resistance to fungal diseases (Cuevas et al., 2001; Cuevas, 2005 & 2010).

Cabbage (*Brassica oleracea* L.) is one of the commonly used crops in studying the efficiency of *Trichoderma* biofertilizer. Aside from being in demand in the market, another reason for this may be its susceptibility to fungal pathogens and insect herbivores, such that benefits other than those connected to plant nutrient metabolism may also be assessed. Cabbage plants are fed upon by herbivorous insects throughout their life cycle. In fact, about 15 insect species are known to feed on them but only nine are destructive (Medina, 1979). Often, these destructive insect pests are controlled by their respective natural enemies. However, the natural enemies are present only when the conditions are suitable. As a result, farmers who want to cope with the high demand for this quality crop rely on wide array of chemical pesticide sprays to control insect pest populations. Chemical control, however, eliminates not only the destructive organisms but also the natural enemies. Increasing dependence on the use of pesticides caused high concerns about the possible risks to human health and the environment (Medina, 1979; Robles, 1999). Therefore, an alternative to synthetic pesticides is needed in order to maintain the population of these non-target organisms below economically damaging levels while assuring profit for farmers.

As in most crops and other agricultural technologies, studies of biofertilizers, insects and other arthropods, etc. have been conducted mainly using conventional experimental designs. Designs like RCBD and others with proper replications and other requisites give the investigator control over assignment of treatments and schedule of field activities. Nonetheless, while experiments conducted in farmer's fields have intrinsic limitations, they provide insights into realities on the part of farmer-cooperators who personify potential users of agrotechnologies and of miscellaneous on-site situations. Conducting experiments in farmer's fields constitutes a first-stage of dialogue between farmers and scientists, and if successful, such dialogue "can lead to more

productive, stable, equitable, and sustainable agricultural systems” (Bellon, 2001). Further, previously for conventional fertilizers, “simple fertilizer trials on farmers’ fields proved to be a quick and direct means of developing fertilizer recommendations which are valid and economically profitable under existing farm conditions” and facilitated “the immediate use of fertilizer and increased yields without necessitating large changes in farm practices” (FAO, 1970).

This study, being also a part of a larger collaboration with farmer-cooperators was, therefore, performed in farmers’ cabbage fields. Prior to this work, the performance of the *Trichoderma*-inoculant has been tested on cabbage’s final yield, aboveground arthropod profile, and occurrence of diseases (e.g., Zarate et al., 2015). However, studies about soil arthropods and/or non-target organisms like collembolans need to be conducted as these organisms in the hypogean community are often left unnoticed (Gapud, 1968).

Collembola or springtails are found in great numbers in every soil layer making them a key group in soil arthropod communities (Marx et al., 2012). They generally rank next to mites (Acari) in terms of abundance and, hence, possibly play important roles in the soil arthropod community of cabbage farms. Several studies have been conducted (Sabado et al., 2006 & 2009; Caasi-Lit et al., 2011; Vacarizas, 2012) regarding pests attacking cabbage but only few concentrated on soil arthropods. Considering that this crop requires adequate soil moisture, the cabbage crop provides a suitable environment for a lot of organisms in the soil. This paper aims to differentiate the hypogean arthropod community, specifically the collembolans, in *Trichoderma*-treated and conventional cabbage plots and determine the possible effects of *Trichoderma* biofertilizer on collembolan abundance.

MATERIALS AND METHODS

Experimental / sampling sites

Two sites were selected for two seasons of cabbage planting. The first and second sites are located at Barangays Mamala I (13°56'N, 121°30'E) and Sampaloc 1 (13°58'N, 121°31'E), both in Sariaya, Quezon Province, respectively. The characteristics of the sites are summarized in Table 1.

The first experimental site (Site 1) is an upland cabbage farm (altitude: 1010 m) and was divided into two different treatments. The farm has a total land area of 0.25 ha with 59 plots in which 32 plots (96 plants per plot) were used for *Trichoderma*-enhanced farming and 27 plots (74 plants per plot) were used for conventional farming. Banana plants are planted between the two treatments and served as buffer. Each treatment was divided into three parts that served as experimental replicates.

Table 1. Topography and other geophysical data of the two experimental sites in Sariaya, Quezon Province, Philippines.

Parameter	Site 1	Site 2
Location	Brgy. Mamala 1	Brgy. Sampaloc 1
Coordinates	13°56'N, 121°30'E	13°58'N, 121°31'E
Altitude	1,010 m	120 m
Total land area	0.25 ha	0.17 ha

The second experimental site (Site 2) is a plane cabbage farm (altitude: 120 m) relatively smaller than the Site 1 with a total of 32 rows in which 17 rows (90 plants per row) were used for *Trichoderma*-based farming and 15 rows (92 plants per row) were used for conventional farming. Corn was planted between the treatments to serve as buffer. Each treatment was also divided into three parts to serve as experimental replicates.

Physical Conditions of Experimental Sites

Since the experimental sites are located at different elevations in Mt. Banahaw, and Sariaya does not have a weather station, the prevailing weather conditions as observed by the researcher and companions as well as local residents were used to account for some pertinent results. Table 2 shows the prevailing physical conditions per sampling period for the two sites.

For already a very long time, farmers normally plant cabbage at higher elevation during the summer season. They have observed that rains are normal occurrences at this elevation (~1000 m asl) and more frequent than in the lower elevations. During the initial period of sampling at 20 days after planting (DAP) in Site 1, irregular but recurring rains prevailed, making the trail going to the experimental site very slippery. At 40 DAP, only light rains were experienced in the site contrary to what the farmers were expecting. The rains were not sufficient to wet the topsoil. A high population of the cabbage-head caterpillar, *Crocidolomia pavonana* (Fabricius), was observed before the 60 DAP prompting the farmers to harvest the crop in order to prevent further losses brought about by infestation.

Site 2 was located in the lowland where they regularly plant during the rainy season. However, rains were so heavy up to 40 DAP that even led to slight flooding of the experimental site at 20 DAP. Nevertheless, the crops still survived and the conditions became optimum at 60 DAP.

Table 2. Prevailing weather conditions and other relevant observations in the two experimental sites at every sampling period.

Sampling period	Site 1	Site 2
20 DAP*	Intermittent rains Soil is moist	Frequent heavy rains Site is slightly flooded
40 DAP	Light rains Soil is almost dry No sample collection conducted	Frequent heavy rains Moderate rains
60 DAP	Infestation of <i>Crocidolomia pavonana</i>	

*days after planting

Treatment and experimental design

The study involved two different treatments, namely: *Trichoderma*-treated/enhanced and synthetic pesticides-treated (conventional). The *Trichoderma*-treated plots involved the use of Biospark® contents mixed with chicken manure and then added to the soil between rows before cabbage planting. The

Trichoderma Microbial Inoculant, commercially produced by BIOSPARK Corp., consisted of two strains of *Trichoderma ghanense* Doi and one strain of UV-irradiated *T. harzianum* Rifai mixed in equal proportions. Conventional farming uses 20 ml Malathion mixed with 7.5 liters of water sprayed directly on plants every other week. Randomized complete block design was used to divide both treatments. Each treatment was composed of three replicates.

Brassica oleracea, *capitata* group var. 'Lucky Ball' was used in this study. All the recommended cultural management practices in cabbage production were followed except that no insecticide was applied to the *Trichoderma*-treated plots.

Sampling and processing of specimens

Soil samples were collected to determine soil collembolan composition and diversity. Three soil samples of approximately two liters per replicate were collected in each treatment and then placed in Berlese-Tullgren funnels for one week extraction time. The organisms extracted were viewed under a dissecting microscope to sort out the collembolans from the others.

Portion of the extracted collembolans were mounted on glass slides with modified Hoyer's fluid as mounting medium prior to identification. These were identified up to species level under a compound microscope, using dichotomous keys and illustrations provided by Gapud (1968, 1969 & 1971) and Zhao (1998). Initially, counts per collembolan species were made from ~1500 slide-mounted specimens. This facilitated the examination of morphological characteristics to gain familiarity with each species. Subsequent counts were made from unmounted specimens using a dissecting microscope (10X).

All processed specimens are deposited in the Entomology Section of the UPLB Museum of Natural History.

Data analysis

One-Way Repeated Measures ANOVA was used to measure equality of means. The measurement of the dependent variable (insect parameter) was repeated since all members of random sample were measured under a number of different conditions. Differences between treatments were measured statistically using the F value.

Biological indices were also computed for each treatment (*Trichoderma* and Conventional), and for different varying number of days after planting (DAP). These indices included: Diversity following Shannon Index: $H' = -\sum [(n_i/N) \ln (n_i/N)]$ where; n_i is the proportion of individuals found in the i th species and \ln is the natural logarithm; Pielou's Evenness Index (e) using Shannon's Diversity Index computed as: $e = H'/\log S$ where; S = total number of species; Species dominance using Simpson's Dominance Index formula: $c = \sum [n_i (n_i - 1) / N(N - 2)]$ where; n_i is the number of individuals in the i th species and N is the total number of individuals.

Diversity Permutation tests were performed to test significant differences in the computed biological indices (Shannon, Pielou's Evenness, and Simpson's Dominance indices). Permutation test entail computation of the aforementioned indices for any two samples (e.g., collembolan taxa and abundance in

Trichoderma vs. Conventional in Site 1), and then comparing the diversities using random permutations computed for 9999 iterations.

All test statistics (One-Way Repeated Measures ANOVA and Diversity Permutation test) were appraised at 5% level of significance.

RESULTS AND DISCUSSION

Collembola or springtails can be found in every soil layer in great numbers making them one of the key groups of detritivores in the soil arthropod community (Marx et al., 2012). Four species representing three families of Collembola were identified (Table 3, Figure 1).

The total collembolans collected in each treatment were compared to determine the effects of the two treatments. Due to the difference in altitude and other prevailing conditions during the sampling, we treated the sampling sites separately.

Figure 2 shows that collembolans in the first site were higher by 428% (1341 individuals) in *Trichoderma*-treated plots relative to those in the conventional treatment (399 individuals). The results from the second site also showed a 525% higher numbers of collembolans in *Trichoderma*-treated plots (311 individuals) as compared to the conventional (76 individuals). The fewer collembolans in the conventional treatment may be due to the slight toxicity (according to EPA classification) of the pesticide Malathion used in treatment (Newhart, 2006). Malathion has a half-life of 3-7 days in soil depending on soil pH but the continuous application may have affected the number of the collembolans (Endlweber et al., 2005). In contrast, there was no toxic chemical added to the soil in the *Trichoderma*-treated plots that could adversely affect the collembolans. The higher population observed may also be accounted for by the general food preference of this insect order. The Collembola are not only great contributors to the decomposition process but also to fungal activity. Collembolans can feed on saprophytic and mycorrhizal fungi but with higher preference to the latter. This feeding behavior of the collembolans was found to stimulate fungal growth. Hence, it can be assumed that Collembola and fungi may have positive interactions.

Table 3. Collembolan families and genera/species observed in Site 1 (high elevation, dry season) and Site 2 (low elevation, wet season) of *Trichoderma*-treated and conventional cabbage farms in Sariaya, Quezon.

Family	Species
Entomobryidae	<i>Willowsia</i> sp. <i>Seira</i> sp.
Hypogastruridae	<i>Xenylla</i> sp.
Isotomidae	<i>Isotomurus parabalteatus</i> Gapud

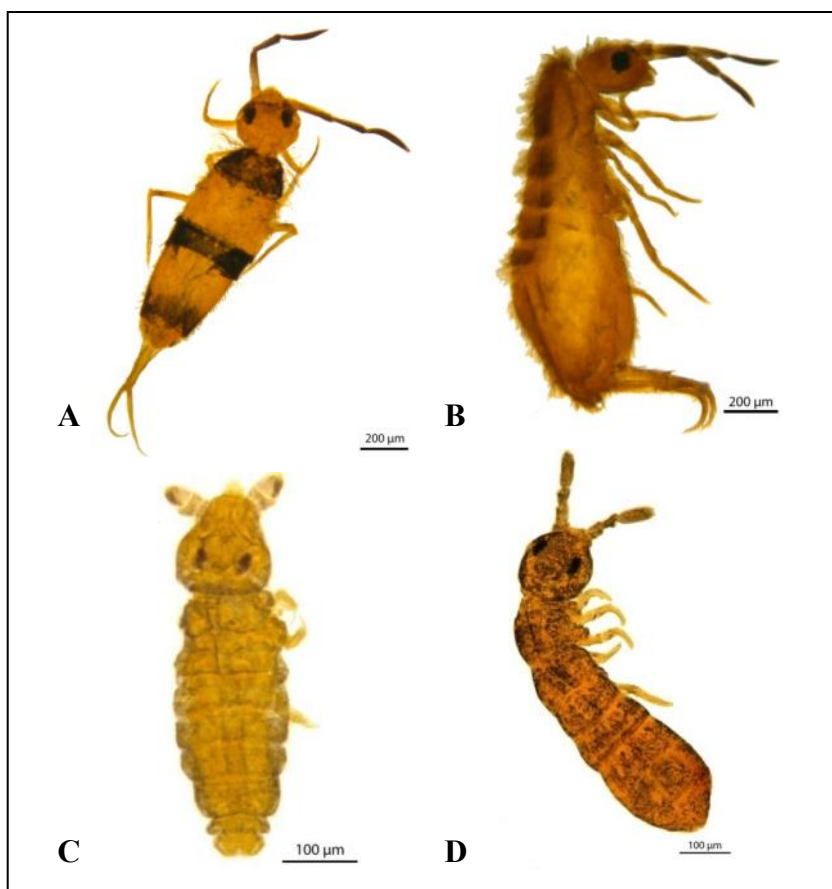


Figure 1. Collembolans observed in the cabbage agro-ecosystem **a.** *Willowsia* sp., **b.** *Seira* sp., **c.** *Xenylla* sp., **d.** *Isotomurus parabalteatus* Gapud.

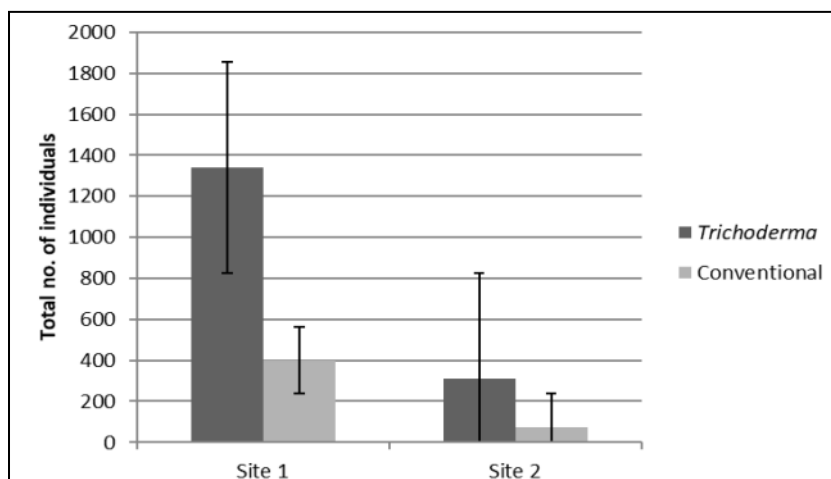


Figure 2. Total number of collembolans collected from *Trichoderma*-treated and conventional cabbage farms in Site 1 (high elevation, dry season) and Site 2 (low elevation, wet season) of the study.

Collembola in Different Physical Conditions

Figure 3 shows the abundance of collembolans at 20, 40 and 60 DAP. For both sites, the total number of individual collembolans was consistently higher in *Trichoderma*-treated plots than in the conventional plots. Between sampling periods, collembolans were more abundant at 20 DAP than at 40 DAP in Site 1. They were probably favored by the varying amounts of rainfall from 20 to 40 DAP. Being ubiquitous in nature, these insects have developed different adaptations to changing environmental conditions. Moisture/water availability influences the abundance of collembolans like most arthropods (Holmstrup, 2002). Collembolan metabolism largely depends on water. The course of evolution has led them to develop adaptations in both drought and flooding conditions. However, Vannier (1970, as cited by Gregory & Duvali 1974) reported that their adaptations to drought tolerance are more pronounced and developed since moisture will always be available in the soil. The high number of collembolans collected at 20 DAP in Site 1 may have reflected the favorable conditions of the site when there were intermittent rains, making the soil moist that generally represents their preferred habitat. However, as described in Table 2, light rains later prevailed in the experimental site making the soil relatively dry. Collembolans still managed to survive which may suggest some drought adaptations among them (Holmstrup, 2002). However, the populations still declined from the level at 20 DAP due to prolonged drought conditions that may have caused physiological malfunctions and stress to the collembolans (Marx et al., 2012). Being consistent with the decrease in total number of arthropods at 40 DAP in Site 1 (Figure 2), the plant production of secondary metabolites as a response to *Crociodolomia* infestation may also account for the similar trend observed in Collembola (Ahuja et al., 2010; Das & Joy, 2009).

The total number of individual collembolans observed in Site 2 per sampling was also consistently higher in *Trichoderma*-treated plots than in the conventional. However, the populations at 20 and 40 DAP were much lower than at 60 DAP. Looking at the physical conditions at the time of collection, 20 and 40 DAP samples were characterized by excessive moisture brought about by heavy

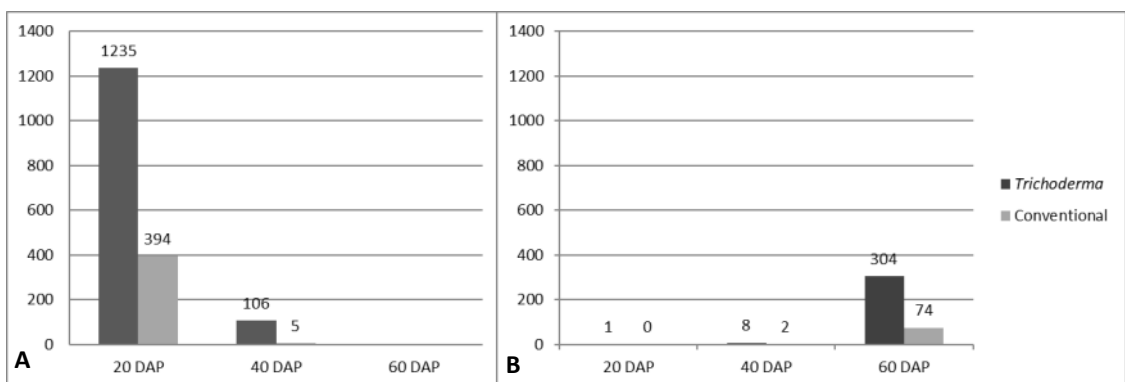


Figure 3. Comparison of the number of collembolans collected in 20 DAP and 40 DAP of (A) Site 1 (high elevation, dry season) and (B) Site 2 (low elevation, wet season) of the *Trichoderma*-treated and conventional cabbage plots.

rains that led to slight flooding of the experimental site at 20 DAP. Having developed adaptations to drought, researchers have also noted some adaptations of collembolans to flooded conditions. Among many others, these include morphological adaptations such as special surface cuticular structures, physiological adaptations such as metabolic shifting under anoxic conditions, and behavioral changes such as migration (Marx et al., 2012). However, the cited adaptations may have not been reflected by the populations of collembolans at 20 and 40 DAP in Site 1 because collembolans were almost absent. One reason that can account for this is the cropping season that spanned from June to August 2011, a period considered to be within the wet season. This also means that the field has undergone prolonged drought in the previous dry season and subsequent rehydration brought upon by the start of the wet season. A study conducted by Waagner et al. (2011) showed that such shift in water availability can have detrimental effects on insect cells. This is because rapid water diffusion can cause cells to swell and be disrupted that can eventually lead to cell death. However, the results at 60 DAP suggest that the collembolan population has been recovering due to moderate rains during this period.

Based on the trends observed in this part of the study, it seems that during adverse conditions brought about by environmental factors, the beneficial effects of *Trichoderma* biofertilizer in maintaining populations of soil arthropods is diminished. Hence, the survival of soil arthropods will depend only on their evolutionary adaptations.

Comparing the relative abundance of the four collembolan species collected, Figure 4 shows that *Isotomurus parabalteatus* Gapud (family Isotomidae) is the most represented while *Willowsia* sp. (Family Entomobryidae) is the least. The high relative abundance of *I. parabalteatus* may be attributed to the means of reproduction of most species under this family which is by parthenogenesis or development of egg cells without fertilization (Marx et al., 2009). With their ability to reproduce asexually, they are expected to reproduce and even recover faster. Aside from their mode of reproduction, they are also surface-dwelling or epigeic which means that they are more likely to be collected

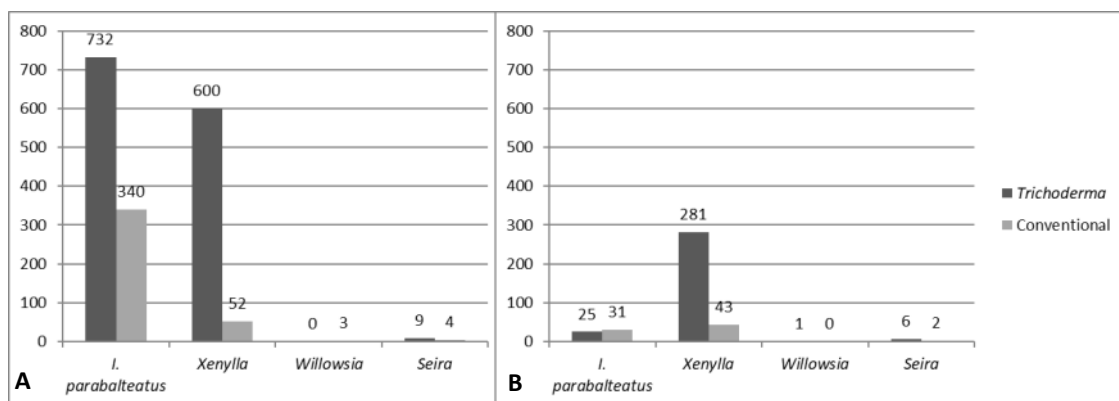


Figure 4. Relative abundance of five collembolan species represented in *Trichoderma*-treated and conventional cabbage farms in (A) Site 1 (high elevation, dry season) and (B) Site 2 (low elevation, wet season) in Sariaya, Quezon.

through the soil sampling method used. However, no literature on the ecology of this species has been published. *Xenylla* sp. is also abundant, probably because it is also surface-dwelling. *Xenylla* is considered to be one of the most widespread and largest genera of Hypogastruridae (Wu & Yin, 2007). In the second site, *I. parabalteatus* is slightly higher in the conventional treatment (31 individuals) than in the *Trichoderma*-treatment (25 individuals). This was possibly due to the flood and excessive water brought about by heavy rains that could have temporarily disturbed soil features and caused interplot migration or movement of the species. The two other species, *Willowsia* sp. and *Seira* sp., represented only a small fraction of the collembolan population in both the first and second sites. This may imply that the conditions prevailing at the time of sampling in both sites may not be optimal to enhance their populations or the collection of samples employed may not be appropriate for their specific distribution in the soil. However, no supporting studies or literature was found to support this claim as there have been no studies conducted regarding these species.

Table 4 shows that the means of the *Trichoderma*-treated plots were consistently higher than those of the conventional. However, results of the One-Way Repeated Measures ANOVA showed no significant difference between sampling periods in both *Trichoderma*-treated plots (F ratio value: 1.8186, $\rho = 0.2144$, significance level $\rho < 0.05$) and conventional plots (F ratio value: 1.1118, $\rho = 0.3225$, significance level $\rho < 0.05$) in Site 1.

In contrast with Site 2, significant difference was observed in the conventional plots (F ratio value: 7.5284, $\rho = 0.005$, significance level $\rho < 0.05$). No significance was also computed for the *Trichoderma*-treated (F ratio value: 1.9472, $\rho = 0.175$, significance level $\rho < 0.05$) plots in Site 2. This highlighted the possibly more adverse effect of excessive water (than drought) for both the *Trichoderma* and springtails. Another reason is the flooding caused by heavy rains wherein pesticide residues may have been more mobile, thereby affecting both treatments in the study.

On the other hand, the computed Shannon diversity indices (per sampling period) in Table 5 did not show any pattern which can be explained by the differences in the relative abundance of the species collected.

At 20 DAP of Site 1, the *Trichoderma*-treated plots had higher diversity index compared to the conventional plots. This was before the drought occurred at 40 DAP causing lower diversity index for *Trichoderma*-treated plots.

Table 4. Differences of the means of collembolans in the two treatments using Repeated Measures ANOVA.

Sampling Period	Site 1 (High elevation)		Site 2 (Low elevation)	
	<i>Trichoderma</i>	Conventional	<i>Trichoderma</i>	Conventional
20 DAP	137.2222	11.7778	0.1111	0
40 DAP	11.7778	0.5556	0.8889	0.2222
60 DAP	*	*	33.5556	8.2222
Treatment Means	74.5	6.167	11.519	2.815

*Note: No sample collection conducted due to *Crocidolomia pavonana* infestation

Table 5. Comparison of Shannon diversity indices of collembolans in *Trichoderma*-treated and conventional cabbage farms in Site 1 (high elevation, dry season) and Site 2 (low elevation, wet season) in Sariaya, Quezon.

Sampling Period	Site 1 (High elevation)		Site 2 (Low elevation)	
	<i>Trichoderma</i>	Conventional	<i>Trichoderma</i>	Conventional
20 DAP	0.6788	0.4248	0	-
40 DAP	0.5942	0.673	0.5623	0
60 DAP	*	*	0.3074	0.6799

Note: * No collection was conducted due to *Crocidolomia pavonana* infestation

- No collembolan species was collected

0 Only one species was collected

At 20 DAP of Site 2, only one species (*Xenylla*) was collected in *Trichoderma*-treated plots while no collembolans were collected in the conventional plots. At 40 DAP, only one species (*Seira*) was again collected in the conventional plots, implying that the arthropods might have been stressed from the flooding then experienced in the Site.

Combining the collections across sampling periods in Site 1 (Table 6), *Trichoderma*-treated plots had higher Shannon diversity index and evenness (lower dominance) than the conventional plots. These results were found to be significant using the permutation test which somehow affirms the ability of both *Trichoderma* and collembolans to survive drought conditions experienced in Site 1. A common Collembolan adaptation is vertical migration since it is likely that water becomes more available with increasing soil depth. Some collembolan species can also reduce evaporation through immobility. Other adaptations include thickening of epicuticular wax layer, drought resistant eggs, behavioral changes and many others (Holmstrup, 2002).

Table 6 also shows the Shannon diversity indices for both the *Trichoderma*-treated and conventional plots in Site 2. In contrast with the results from Site 1, Shannon diversity index and evenness were higher in conventional plots than in *Trichoderma*-treated plots. Since lower diversity index is related to high dominance and low evenness, the presence of *Xenylla* in high numbers (relative to the other three species recorded) in *Trichoderma*-treated plots would have accounted for the low index recorded for *Trichoderma*-treated plots. Compared with the conventional plots, the three collembolan species recorded are relatively more even. In addition, the sudden excessive water experienced in Site 2 might have had negative effects on both the springtails and *Trichoderma*. The water

Table 6. Summary of the results of Permutation Test on diversity indices of collembolans in *Trichoderma*-enhanced and conventional cabbage farms, Sariaya, Quezon, Philippines.

Indices	Site 1			Site 2		
	<i>Trichoderma</i>	Conventional	Perm p(eq)	<i>Trichoderma</i>	Conventional	Perm p(eq)
Taxa S	3	4	0.4845	4	3	0.9652
Individuals	1341	399	0	311	76	0
Dominance	0.4982	0.7433	0.0001*	0.8116	0.4872	0.0001*
Shannon H	0.7239	0.4848	0.0001*	0.3947	0.7837	0.0004*
Evenness	0.6875	0.406	0.0149*	0.371	0.7299	0.0472*

*significant difference

condition in the soil greatly influences the activity of most *Trichoderma* species (Kredics et al., 2003) and collembolans (Holmstrup, 2002). This condition would have also interfered with the performance of the said biofertilizer.

CONCLUSION

This study is the first report regarding the reverse effects of *Trichoderma* spp. on collembolans, which are possibly related due to their shared sensitivity to water stress. The main objective of this study was to compare collembolan abundance in *Trichoderma*-treated and conventional cabbage plots in two experimental sites in Sariaya, Quezon. Collembolan diversity was determined by soil sample collection and Berlese-Tullgren funnel extraction. Soil sample collections were done at 20, 40 and 60 DAP.

I. parabalteatus was the most represented among collembolans probably due to their parthenogenic mode of reproduction. Results show that collembolans were generally higher in *Trichoderma*-treated plots under optimal conditions but not in suboptimal or adverse conditions as statistical analysis showed no significant differences between two treatments.

Trichoderma probably enhanced collembolan diversity that can make the cabbage agro-ecosystem more resilient to changes in the environment. However, the effects of *Trichoderma* treatment varied with time and condition during sampling. Therefore, *Trichoderma* may enhance populations of collembolans given optimal conditions, but the beneficial effects in maintaining these populations are diminished under suboptimal conditions.

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