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Intraguild predation in three generalist predatory mites of the family Phytoseiidae (Acari: Phytoseiidae)

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Abstract

Background: The predatory mites, *Neoseiulus californicus* (McGregor), *N. barkeri* (Hughes), and *Amblyseius swirskii* Athias-Henriot, are important predators attacking many insect and mite pests. They can coexist in the same habitat and engage in intraguild predation (IGP).

Main body: IGP was assessed among the exotic one *N. californicus* and the native species *N. barkeri* and *A. swirskii* as Intraguild predator (IG-predator)/intraguild prey (IG-prey) in either absence or presence of extra-guild prey *Tetranychus urticae* Koch (EG-prey). In the laboratory, the physiological parameters, longevity, fecundity, and predation rate of these predatory mites' females, fed on EG-prey, were evaluated, where phytoseiid larvae are considered as (IG-prey) or combined IG-prey with EG-prey. All predatory species consumed larval stages of each other's, but in case of *N. californicus*, females failed to sustain oviposition on *N. barkeri* larvae. Also, it was noticed that *N. californicus* females killed 3 times more *A. swirskii* larvae than *N. barkeri* larvae, whereas *A. swirskii* consumed more *N. californicus* than *N. barkeri* larvae, respectively. *Neoseiulus californicus* lived longer on *T. urticae* and *A. swirskii* larvae than on *N. barkeri*, while the latter survived longer on *T. urticae* only than on the other prey or with combinations with *T. urticae*. *Amblyseius swirskii* lived shorter when fed exclusively on *T. urticae* or IG-prey than on EG-prey combined with IG-prey. In choice experiments, *N. californicus* showed a higher preference to consume more *T. urticae* than any of phytoseiid larvae. The comparison between *T. urticae* and IG-prey diets definite the higher influence of *T. urticae* on the fecundity in *N. californicus* and *N. barkeri* than on IG-prey, whereas in *A. swirskii* fecundity was as equal on *T. urticae* as on IG-prey *N. californicus* larvae.

Conclusion: *A. swirskii* seemed to be the strongest IG-predator.

Keywords: Phytoseiid mites, *Tetranychus urticae*, Intraguild prey, Choice test

Background

Neoseiulus barkeri (Hughes), *Amblyseius swirskii* Athias-Henriot, and *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) are efficient control agents of the mite pest *Tetranychus urticae* (Koch) (Tetranychidae). *Neoseiulus barkeri* is considered as a generalist predatory mite (type III subtype e) which can feed on *Frankliniella occidentalis* (Pergande) (Ramakers and Van Lieburg 1982), *Thrips tabaci* Lind. (Bonde 1989), spider mites (Momen and El-

Borolossy 1999), stored product mites (Huang et al. 2013), and pollen grains (Addison et al. 2000). *Amblyseius swirskii* (type III subtype b) feeds usually on whitefly as well as spider, tarsonomid, and eriophyid mites, also thrips and pollen grains (Messelink et al. 2006; Momen 2009; Riahi et al. 2017), whereas *N. californicus* (the selective predator of tetranychid mites, type II) feeds on various species of the family Tetranychidae (McMurtry et al. 2013).

Maleknia et al. (2016) stated that in both greenhouse and outdoor conditions, *T. urticae* is an important pest of cucumber and it is necessary to be controlled by

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predatory mites of the family Phytoseiidae. Intraguild predation (IGP) can occur when two or more predatory species sharing the same habitat and one species-being the intraguild predator (IG-predator) and the others-intraguild preys (IG-prey) and competing for the same prey (extra-guild prey (EG-prey) (Janssen et al. 2006; Momen and Abdel-Khalek 2009b). Some phytoseiid mites can kill and consume phytoseiid competitors when their natural or favorable mite/insect preys density is low (Ahmad et al. 2015). Discrimination between conspecific (the same predatory species) and heterospecific (another predatory species) individuals as (IG-prey) was known in some generalist phytoseiid mites (Schausberger 1999). Generalist phytoseiid mites (type III) preferred to predate on heterospecific to conspecific, although *T. urticae* was not reduced (Schausberger 1999). Ahmad et al. (2015) indicated that predation on heterospecific immature stage is the main aspect in IGP. In previous investigations, some traits of IGP in immatures and females predatory phytoseiid mites were investigated (Momen and Abdel-Khalek 2009a, b; Momen 2010; Ahmad et al. 2015). *Amblyseius swirskii* had higher predation rates on heterospecific prey *Typhlodromus athiasae* Porth and Swirski and *Eusieus scutalis* (Athias-Henriot) than on conspecific prey and all females failed to predate on eggs and protonymphs of its own (Momen and Abdel-Khalek 2009b). Also, *A. swirskii* was able to consume all stages (eggs, larvae, protonymphs, deutonymphs) of *N. barkeri* and *P. persimilis* Athias-Henriot (Maleknia et al. 2016). *Neoseiulus barkeri* females consumed more larvae and protonymphs of *Typhlodromus negevi* Swirski and Amitai than its own (Momen 2010) and also attacked similar amounts of *A. swirskii* as *P. persimilis* (Maleknia et al. 2016). *Neoseiulus californicus*, *Typhlodromus montdorensis* (Schicha), and *T. pyri* (Scheuten) can feed on larval stages of each other and sustain oviposition (Hatherly et al. 2005). Both *N. californicus* and *A. swirskii* could serve as IG-predators and could develop on their IG-prey (Guo et al. 2016). Some factors may affect the strength of IGP and outcome of biological control and this primary is dependent on the predator species and ranges from harmful to harmless IG predators (Walzer and Schausberger 2013). These factors included predator aggressiveness, activity, and habitat characteristics (Walzer et al. 2004).

Because there was no previous study exists on IGP among *N. barkeri*, *N. californicus*, and *A. swirskii* in the absence or presence of *T. urticae*, the aim of the present study was to determine the interactions among the generalist predators in absence and presence of the EG-prey *T. urticae*. As well, the effect of different IG-prey in ovipositional period, longevity, predation rate, and fecundity of predatory mite females as IG-predators was investigated. Also, comparison of all the above

parameters for IG-predators fed IG-prey with those obtained on mixed (IG-prey) with (EG-prey) *T. urticae* was done.

Materials and methods

Mite rearing

Initial culture of the two-spotted spider mite, *T. urticae*, was obtained from bean plants (*Phaseolus vulgaris* L.) grown in the field, at Giza Governorate, Egypt. It was maintained under the laboratory conditions of 25 ± 1 °C, 60 ± 5 % RH, and 16:8 h (L:D) photoperiod on acalypha plant *Acalypha wilkesiana* (Eupharbiaceae) as a wild plant in plastic trays. Fresh plants infested with *T. urticae* were placed in the trays weekly.

Neoseiulus barkeri and *A. swirskii* were obtained from cucumber plants (*Cucumis sativus* L.), grown in Fayoum Governorate, while *N. californicus* was collected from pepper in Giza Province. In the laboratory, they were reared on whole acalypha leaves that densely infested with *T. urticae* in a growth chamber at 28 ± 2 °C, 75 ± 5 % RH, 16:8 h (L:D). New infested bean plants leaves were added to each predatory culture and the old ones were removed from each colony daily. The leaves were placed on water-saturated cotton pads in Petri dishes.

Leaf disks

Leaf disks, cut from leaflets collected from the middle part of acalypha plant, were placed in Petri dishes (6 cm in diameter). Each plate was considered a replicate. The leaf disks (with 3.5 cm of diameter each) were placed on a water-saturated cotton pad in the Petri dishes in order to keep the leaves fresh. Water-saturated, absorbent cotton strip, (1 cm wide), placed around the edge of the leaf disk, covered by a water-saturated cotton strip to prevent mites from escaping.

Newly emerged of each species and one male were transferred onto rearing leaf disk with excess of food and left to mate. The male was removed, and the female transferred to fresh leaf disk and left 24 h without food to guarantee that all females had been starved for an equal period of time. Each experiment consisted of 24 mated females on individual disks supplied with a specific prey species.

Intraguild predation test

In the experiments, predatory mites' females were considered as (IG-predator), while larvae of heterospecifics species were considered as IG-prey (Montserrat et al. 2012).

The first set of experiments was female's predatory mite provided with only larval stages of its phytoseiid prey. Larval stage was selected because it is easy to handle and could be quickly selected once they had hatched. Larva was also a preferred stage for *N. barkeri*, *A.*

swirskii, and *N. californicus* (Momen 2010). As a control, females of each predatory species were fed solely on *T. urticae* larvae.

Choice test

The second set of experiments was the choice test, which provided female mites of each predatory species with (50% of *T. urticae* larvae and 50% of phytoseiid larva) as a food source.

Every 24 h, the ovipositional period, ovipositional rate, the number of each food source consumed (determined by larval corpses), and female survival, was recorded. All excess food and corpses larvae on each disk were removed at each observation period and replaced with an identical amount of food as previously supplied. Dead and eaten larvae were removed from arenas and replaced daily. The shriveled corpses of the dead larvae were taken as evidence of predation. Observations were made daily and predatory females were checked until their death. In the preference test (*T. urticae* and phytoseiid larvae), the number of *T. urticae* eaten compared with the number of phytoseiid larval prey consumed was determined.

Statistical analysis

One-way analysis of variance (ANOVA) (SPSS computer program) was conducted to evaluate the mean pre-oviposition and oviposition periods, longevity, mean total and daily number of eggs laid per female, mean total, and daily number of prey (IG-prey/EG-prey) consumed per female for each predator species kept on each of its prey sources.

Before the analyses, data were checked for normality. Data were fitted with the assumption of normality, not transformed, and means were compared by Tukey's HSD ($P = 0.05$ level).

Results and discussion

Performance of *Neoseiulus californicus* (IG-predator) on *Neoseiulus barkeri*/*Amblyseius swirskii* (IG-prey) and *Tetranychus urticae* (EG-prey)

Neoseiulus californicus lived significantly longer when fed solely on *T. urticae* and *A. swirskii* than when fed on *A. barkeri* or on a mixed diet of *T. urticae* and phytoseiid prey ($F_{6,161} = 85.70$, $P = 0.0001$). The mean ovipositional period of *N. californicus* females fed on combined diets (10 *T. urticae* + 10 *N. barkeri*) performed shorter than those fed only on *A. swirskii* or *T. urticae* combined with other IG-prey. When *N. californicus* fed solely on *N. barkeri* larvae, females failed to sustain oviposition, while on *T. urticae* gave a higher fecundity rate than on *A. swirskii* or on a mixture of *T. urticae* and any other phytoseiid larvae ($F_{6,161} = 3364$, $P = 0.000$) (Table 1).

Prey type or number influenced the number of prey consumed by *N. californicus*. When *N. californicus* fed solely on EG-prey/IG-prey/combined prey, a significant difference was observed in its predation rate ($F_{6,161} = 4009.60$, 3017.76 , $P = 0.000$). *Neoseiulus californicus* fed *N. barkeri*/*A. swirskii* larvae, its predation rate was significantly higher on the latter species (Table 1). *Neoseiulus californicus* consumed more *T. urticae* in total than those fed a mixed diet. It consumed significantly similar amount of IG-prey *N. barkeri*/*A. swirskii*, when combined with *T. urticae* (case of 20 *T. urticae* + 20 IG-prey). It was also noticed that providing of *T. urticae* significantly decreased the predation rate of IG-prey (Table 1). *Neoseiulus californicus* consumed up to 3.68, 4.13, and 2.93, 3.67 *T. urticae* for every 1 *N. barkeri* and *A. swirskii* when fed on both prey sources. According to Lucas (2005), IGP can be unidirectional/bidirectional (mutual), the latter case when 2/3 predator species prey on each other and each predator is also prey and vice versa. The present study proved that predation rates of the 3 tested predator species were bidirectional in absence or presence of *T. urticae* as EG-prey. Previous research has demonstrated that *N. barkeri*, *N. californicus*, and *A. swirskii* can serve as either prey or predators in intraguild predatory interactions among biological control agents (Maleknia et al. 2016; Haghani et al. 2019).

Females of *N. californicus* consumed IG-prey of *N. barkeri* and *A. swirskii* in non-choice experiments. Female's predator ate nearly 3 times more *A. swirskii* than *N. barkeri*. When *T. urticae* was combined, females of *N. californicus* fed on both *T. urticae* and both IG-prey with higher preference to *T. urticae* than phytoseiid larvae suggesting that the two-spotted spider mite is its preferred food. Resemble results were reported by Hatherly et al. (2005) who stated that when *N. californicus* offered a mixed diet of (phytoseiid larvae and *T. urticae*), it showed a marked preference for *T. urticae*. When *N. californicus* females were offered *T. urticae* combined with IG-prey, the IGP rate declined although the fecundity increased, except when fed on *A. swirskii*. This result is similar to those obtained by Meszaros et al. (2007) with *Typhlodromus exhilarates* Ragusa and *T. phialatus* Athias-Henriot and in general trends reported for the family Phytoseiidae (Schausberger 2003). The difference in IGP by *N. californicus* on *A. swirskii* and *N. barkerii* suggested that *N. barkerii* was unfavorable IG-prey to be fed and reproduce by *N. californicus* and could explain that both predators have differences in distribution in their habitat where *N. californicus* is more dominant on plants and always associated with tetranychid mites that producing heavy webbing; while *N. barkeri* living in soil/litter habitat while *A. swirskii* living on glabrous leaves (McMurtry et al. 2013). Moreover, *N. californicus* failed to sustain egg production when it was

Table 1 Mean (\pm SE) pre-oviposition, oviposition periods and longevity, mean number (\pm SE) of total and daily eggs laid per female, total and daily number (\pm SE) of prey consumed per female for *Neoseiulus californicus* fed solely on *Tetranychus urticae* (T.u.) or larval *Neoseiulus barkeri* (N.b.), *Amblyseius swirskii* (A.S.) or on a combination of *T. urticae* and larval phytoseiid

| Prey and number | Periods | | | Eggs laid per females | | Consumption rates | | | | Ratio of T. u: predator larvae consumed |
|-------------------|-----------------------|------------------------|------------------------|-----------------------|----------------------|------------------------|------------------------|-----------------------|----------------------|---|
| | Pre-oviposition | Oviposition | Longevity | Total eggs | Daily eggs | Total consumption | | Daily consumption | | |
| | | | | | | T.u. | Phytoseiid larvae | T.u. | Phytoseiid larvae | |
| 20 T.u. | 1.58 \pm 0.10 b | 26.17 \pm 0.17 a | 30.25 \pm 0.23 a | 37.50 \pm 0.23 a | 1.44 \pm 0.02 a | 444.5 \pm 4.20 a | | 14.69 \pm 0.05 a | | |
| 20 N.b. | 0.00 \pm 0.00 c | 0.00 \pm 0.00 e | 23.50 \pm 0.25 e | 0.00 \pm 0.00 f | 0.00 \pm 0.00 e | | 124.83 \pm 1.59 b | | 5.31 \pm 0.02 b | |
| 20 A.s. | 2.00 \pm 0.00 a | 25.00 \pm 0.15 bc | 29.58 \pm 0.20 ab | 19.75 \pm 0.19 e | 0.79 \pm 0.01 d | | 363.92 \pm 2.04 a | | 12.30 \pm .02 a | |
| 10 T.u. + 10 N.b. | 1.67 \pm 0.10 ab | 23.42 \pm 0.22 d | 27.58 \pm 0.28 d | 19.50 \pm 0.25 e | 0.83 \pm 0.01 d | 194.5 \pm 1.03 e | 53.25 \pm 0.88 e | 7.07 \pm 0.08 d | 1.93 \pm 0.03 e | 3.68:1 |
| 10 T.u. + 10 A.s. | 1.58 \pm 0.10 b | 24.25 \pm 0.19 c | 28.25 \pm 0.23 cd | 24.00 \pm 0.17 d | 0.99 \pm 0.01 c | 231.92 \pm 1.11 d | 79.25 \pm 0.68 d | 8.22 \pm 0.70 c | 2.81 \pm 0.01 d | 2.93:1 |
| 20 T.u. + 20 N.b. | 1.75 \pm 0.09 ab | 25.58 \pm 0.25 ab | 29.17 \pm 0.25 bc | 27.58 \pm 0.20 b | 1.08 \pm 0.01 b | 424.33 \pm 2.86 b | 103.08 \pm 1.32 c | 14.57 \pm 0.15 a | 3.53 \pm 0.02 c | 4.13:1 |
| 20 T.u. + 20 A.s. | 1.75 \pm 0.09 ab | 25.33 \pm 0.25 b | 28.67 \pm 0.25 bc | 26.67 \pm 0.23 c | 1.06 \pm 0.02 b | 379.58 \pm 5.81 c | 107.67 \pm 4.67 c | 13.23 \pm 0.14 b | 3.75 \pm 0.15 c | 3.67:1 |
| F | 65.95 | 2463.95 | 85.70 | 3364.53 | 1548.31 | 4009.60 | 3017.31 | 5255.02 | 4384.79 | 853.77 |
| P | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Where applicable, the ratio of *T. urticae* to larval phytoseiids consumed by adult females is given. Values in each column followed by the same letter are not significantly different ($P > 0.05$) when *Neoseiulus californicus* fed on 20 *T. urticae*/phytoseiid larvae are compared to their other four prey combinations

fed IG-prey *N. barkeri*. On the contrary, Farazmand et al. (2015) indicated that *N. californicus* was able to sustain oviposition on IG prey. When the population of *T. urticae* is low and that could happen at the beginning and end of the cropping season, *N. californicus* may be able to feed and reproduce on IG-prey *A. swirskii* to maintain its population for a short time and certainly not on IG-prey *N. barkeri* since predation on that diet for survival only and not to producing offspring.

Performance of *Neoseiulus barkeri* (IG-predator) on *Neoseiulus californicus*/*Amblyseius swirskii* (IG-prey) and *Tetranychus urticae* (EG-prey)

The mean ovipositional period of *N. barkeri* females fed *A. swirskii* larvae was significantly longer than those fed *N. californicus* ($F_{6,161} = 320.47$, $P = 0.000$). *Neoseiulus barkeri* survived significantly longer period when fed exclusively on *T. urticae* than when fed only on *N. californicus*/*A. swirskii* larvae/a mixed diet of *T. urticae* with phytoseiid larvae ($F_{6,161} = 226.45$, $P = 0.000$) (Table 2).

When *N. barkeri* was fed solely on *N. californicus*/*A. swirskii* larvae, females laid statistically similar total eggs production, while on *T. urticae* solely showed a higher fecundity than on both IG-prey or on a mixture of *T. urticae* and phytoseiid larvae ($F_{6,161} = 1529.19$, $P = 0.000$) (Table 2).

When *N. barkeri* fed solely on EG-prey/IG-prey/combined prey, a significant difference was observed in its

predation rate ($F_{6,161} = 7782.66$, 1512.10 , $P = 0.000$). *Neoseiulus barkeri* consumed more in total and daily number of *T. urticae* than those fed on a mixed diet (Table 2). The mean total number of *A. swirskii* larvae eaten by *N. barkeri* was statistically higher than that of *N. californicus*. Providing of *T. urticae* significantly decreased the predation of IG-prey (Table 2). *Neoseiulus barkeri* consumed up to 1.85 and 1.48 *T. urticae* for every 1 *A. swirskii* while that ratio was 0.96 and 0.90 *T. urticae* for every 1 *N. californicus* when fed on both prey sources (Table 2).

Females of *N. barkeri* fed daily on similar amount of both IG-prey *A. swirskii* and *N. californicus*. When *T. urticae* was combined with IG-prey, females of *N. barkeri* fed on both prey with preference to *T. urticae* than IG-prey *A. swirskii* also to IG-prey *N. californicus* than *T. urticae*. IG-prey might comprise a less nutritive food for the IG-predator, especially in its oviposition period (Walzer and Schausberger 1999). Also, the daily number of IG-prey consumed by *N. barkeri* was lower (nearly half) than that of prey offered, suggesting that IG-predator response was affected by food quality (Ahmad et al. 2015). The total egg production of *N. barkeri* on both IG-prey was similar and relatively higher than those fed IG-prey combined with EG-prey. Walzer and Schausberger (1999), Hatherly et al. (2005), Momen and Abdel-Khalek (2009b), and Farazmand et al. (2015) indicated that predatory phytoseiids receive more nutritional

Table 2 Mean (\pm SE) pre-oviposition, oviposition periods and longevity, mean number (\pm SE) of total and daily eggs laid per female, total and daily number (\pm SE) of prey consumed per female for *Neoseiulus barkeri* fed solely on *Tetranychus urticae* (T.u.) or larval *Neoseiulus californicus* (N.c.), *Amblyseius swirskii* (A.S.) or on a combination of *T. urticae*, and larval phytoseiid

| Prey and number | Periods | | | Eggs laid per female | | Consumption rates | | | | Ratio of T. u.: predator larvae consumed |
|-------------------|-----------------------|-----------------------|------------------------|------------------------|-----------------------|------------------------|------------------------|-----------------------|----------------------|--|
| | Pre-oviposition | Oviposition | Longevity | Total eggs | Daily eggs | Total consumption | | Daily consumption | | |
| | | | | | | T.u. | Phytoseiid larvae | T.u. | Phytoseiid larvae | |
| 20 T.u. | 1.50 \pm 0.10 b | 26.50 \pm 0.23 a | 30.50 \pm 0.28 a | 36.00 \pm 0.28 a | 1.36 \pm 0.01 a | 478.33 \pm 3.65 a | | 15.69 \pm 0.04 a | | |
| 20 N.c. | 1.67 \pm 0.10 ab | 18.50 \pm 0.23 c | 22.42 \pm 0.29 c | 16.00 \pm 0.19 bc | 0.87 \pm 0.01 c | | 214.67 \pm 4.18 b | | 9.77 \pm 0.05 a | |
| 20 A.s. | 1.50 \pm 0.10 b | 21.75 \pm 0.19 b | 25.58 \pm 0.22 b | 16.75 \pm 0.21 b | 0.77 \pm 0.01 d | | 248.58 \pm 2.20 a | | 9.72 \pm 0.03 a | |
| 10 T.u. + 10 N.c. | 1.58 \pm 0.10 b | 16.25 \pm 0.19 e | 19.67 \pm 0.25 e | 10.75 \pm 0.19 e | 0.66 \pm 0.02 e | 97.31 \pm 0.77 e | 101.58 \pm 1.06 e | 4.96 \pm 0.05 e | 5.18 \pm 0.08 d | 0.96:1 |
| 10 T.u. + 10 A.s. | 2.00 \pm 0.00 a | 15.92 \pm 0.18 e | 20.17 \pm 0.22 e | 10.67 \pm 0.25 e | 0.67 \pm 0.02 e | 113.71 \pm 1.37 d | 61.50 \pm 0.96 f | 5.65 \pm 0.07 d | 3.05 \pm 0.02 e | 1.85:1 |
| 20 T.u. + 20 N.c. | 1.75 \pm 0.09 ab | 16.42 \pm 0.23 e | 20.50 \pm 0.26 de | 15.00 \pm 0.17 d | 0.92 \pm 0.01 b | 169.08 \pm 2.47 c | 188.42 \pm 2.70 c | 8.25 \pm 0.07 c | 9.19 \pm 0.03 b | 0.90:1 |
| 20 T.u. + 20 A.s. | 1.58 \pm 0.10 b | 17.33 \pm 0.25 d | 21.50 \pm 0.29 cd | 15.58 \pm 0.23 cd | 0.90 \pm 0.01 bc | 234.52 \pm 1.66 b | 159.08 \pm 2.21 d | 10.94 \pm 0.11 b | 7.40 \pm 0.02 c | 1.48:1 |
| F | 3.59 | 320.47 | 226.45 | 1529.19 | 525.34 | 7782.66 | 1512.10 | 9108.09 | 8081.34 | 3999.77 |
| P | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Where applicable, the ratio of *T. urticae* to larval phytoseiids consumed by adult females is given. Values in each column followed by the same letter are not significantly different ($P > 0.05$) when *Neoseiulus barkeri* fed on 20 *T. urticae*/phytoseiid larvae are compared to their other four prey combinations

benefits from phytoseiid larvae in the absence of their main prey (EG-prey). Prey conversion rate was low for *N. barkeri* considering *N. californicus* as IG-prey to *A. swirskii*. According to Ahmad et al. (2015), that parameter could be a sign of the ability for population persistence when prey is moving back.

Performance of *Amblyseius swirskii* (IG-predator) on *Neoseiulus californicus*/*N. barkeri* (IG-prey) and *Tetranychus urticae* (EG-prey)

Amblyseius swirskii females survived significantly longer time when fed on a mixed diet of *T. urticae* with *N. barkeri*/*N. californicus* (10 T.u. + 10 *N. barkeri*, 10 T.u. + 10 *N. californicus*, 20 T. u + 20 *N. californicus*), than those fed solely on IG-prey/EG-prey/(20 T. u + 20 *N. barkeri*) ($F_{6,161} = 18.03$, $P = 0.0001$). Females of *A. swirskii* fed solely on *T. urticae*/*N. californicus* gave a higher fecundity and daily number of eggs than on *N. barkeri*/on a mixture of *T. urticae* and phytoseiid larvae ($F_{6,161} = 570.77$, 452.90, $P = 0.0001$) (Table 3).

When *A. swirskii* fed solely on *T. urticae*/combined prey, a significant difference was observed in its predation rate ($F_{6,161} = 3799.15$, $P = 0.000$). When *A. swirskii* fed solely on IG-prey, the total and daily rate of predation were significantly higher on *N. californicus* (Table 3). *Amblyseius swirskii* consumed more *T. urticae* in total than those fed on a mixed diet. Providing of *T. urticae* significantly decreased the

predation of IG-prey (Table 3). *Amblyseius swirskii* consumed significantly a higher number of IG-prey *N. barkeri*/*N. californicus* than when mixed with *T. urticae* (case of 20 *T. urticae* + 20 IG-prey) than in (case of 10 *T. urticae* + 10 IG-prey). *Amblyseius swirskii* consumed up to 1.62, 1.79, and 1.41, 1.73 *T. urticae* for every 1 *N. barkeri* and *N. californicus* when fed on both prey sources.

Interesting results presently in the fecundity of *A. swirskii* fed exclusively IG-prey *N. californicus* was similar to those fed EG-prey *T. urticae*. IG-prey might be an equally good or better food source than the EG-prey (thrips) for both *A. swirskii* and *N. cucumeris* (Oudemans) (Buitenhuis et al. 2010). In their studies, Guo et al. (2016) indicated that IG-prey *A. orientalis* (Ehara) appeared to be better food source for the development of *A. swirskii* than EG-prey *Bemisia tabaci* Gennadius. They added that *A. swirskii* appears to be a less suitable prey for *A. orientalis*. In the contrary, Polis et al. (1989) demonstrated that the quality of IG-prey is often lower than the quality of EG-prey. Momen and El-Borolossy (2010) showed that *A. swirskii* was able to feed and develop on both IG-prey *C. negevi* and *Phytoseius finitimus* Ribaga, whereas the latter species failed to develop on other both IG-prey. Research has been done by Pratt et al. (2002) and also Xu and Enkegard (2010) indicated that some factors are responsible for the preference of predatory mites, such as plant architecture, prey stage

Table 3 Mean (\pm SE) pre-oviposition, oviposition periods and longevity, mean number (\pm SE) of total and daily eggs laid per female, total and daily number (\pm SE) of prey consumed per female for *Amblyseius swirskii* fed solely on *Tetranychus urticae* (T.u.) or larval *Neoseiulus barkeri* (N.b.), *Neoseiulus californicus* (N.c.), or on a combination of *T. urticae* and larval phytoseiid

| Prey and number | Periods | | | Eggs laid per female | | Consumption rates | | | | Ratio of T. u.: predator larvae consumed |
|-------------------|----------------------|------------------------|------------------------|-----------------------|----------------------|------------------------|-------------------------|-----------------------|-----------------------|--|
| | Pre-oviposition | Oviposition | Longevity | Total eggs | Daily eggs | Total consumption | | Daily consumption | | |
| | | | | | | T.u. | Phytoseiid larvae | T.u. | Phytoseiid larvae | |
| 20 T.u. | 1.58 \pm 0.10 a | 24.33 \pm 0.16 de | 28.25 \pm 0.19 cd | 26.42 \pm 0.20 a | 1.09 \pm 0.01 a | 394.67 \pm 3.63 a | | 13.98 \pm 0.13 a | | |
| 20 N.b. | 1.67 \pm 0.10 a | 24.58 \pm 0.22 cd | 28.58 \pm 0.25 cd | 24.42 \pm 0.16 b | 1.00 \pm 0.01 b | | 300.83 \pm 2.65 b | | 10.53 \pm 0.02 b | |
| 20 N.c. | 1.75 \pm 0.09 a | 23.83 \pm 0.17 e | 28.00 \pm 0.19 d | 25.67 \pm 0.23 a | 1.08 \pm 0.01 a | | 403.33 \pm 10.43 a | | 14.39 \pm 0.34 a | |
| 10 T.u. + 10 N.b. | 1.67 \pm 0.10 a | 26.17 \pm 0.14 a | 30.08 \pm 0.16 a | 15.83 \pm 0.17 d | 0.61 \pm 0.01 d | 184.02 \pm 2.08 d | 113.58 \pm 0.93 e | 6.13 \pm 0.09 e | 3.78 \pm 0.02 e | 1.62:1 |
| 10 T.u. + 10 N.c. | 1.58 \pm 0.10 a | 26.25 \pm 0.15 a | 30.25 \pm 0.23 a | 14.58 \pm 0.23 e | 0.56 \pm 0.01 e | 197.73 \pm 2.45 c | 114.54 \pm 1.15 e | 6.54 \pm 0.09 d | 3.79 \pm 0.02 e | 1.73:1 |
| 20 T.u. + 20 N.b. | 1.67 \pm 0.10 a | 25.17 \pm 0.17 bc | 29.08 \pm 0.16 bc | 18.58 \pm 0.23 c | 0.74 \pm 0.01 c | 355.69 \pm 3.47 b | 199.00 \pm 1.76 d | 12.23 \pm 0.09 b | 6.84 \pm 0.03 d | 1.79:1 |
| 20 T.u. + 20 N.c. | 1.58 \pm 0.10 a | 25.83 \pm 0.17 ab | 29.75 \pm 0.28 ab | 18.92 \pm 0.18 c | 0.73 \pm 0.01 c | 353.31 \pm 3.9 b | 250.92 \pm 2.19 c | 11.88 \pm 0.05 c | 8.44 \pm 0.03 c | 1.41:1 |
| F | 0.40 | 32.09 | 18.03 | 570.77 | 452.90 | 3799.15 | 1009.22 | 5297.62 | 1332.71 | 3379.11 |
| P | 0.876 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Where applicable, the ratio of *T. urticae* to larval phytoseiids consumed by adult females is given. Values in each column followed by the same letter are not significantly different ($P > 0.05$) when *Amblyseius swirskii* fed on 20 *T. urticae*/phytoseiid larvae are compared to their other four prey combinations

preference, and interaction between the pest and the predator.

Conclusion

Base on this study, *A. swirskii* seems to be a stronger IG predator than both other species because it consumed more larvae of *N. barkeri* and *N. californicus* and also, laid more eggs on both IG prey. According to this study, *A. swirskii*, *N. barkeri*, and *N. californicus* are IG predators on each other even when *T. urticae* is present. The results of this study showed that IGP among these 3 phytoseiids is not unidirectional. Potential IG-interaction among these predatory mites may strongly influence the predator efficiency in *T. urticae* control. Information about the strength and direction of IGP among these predators can be helpful for choosing the best strategy of multiple releases to improve the control of *T. urticae*.

Abbreviations

IGP: Intraguild predation; IG-predator: Intraguild predator; IG-prey: Intraguild prey; EG-prey: Extra-guild prey

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Authors' contributions

FM designed and wrote the manuscript. AA performed the experiment and analyzed the data. All authors read and approved the final manuscript.

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All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. This article does not contain any studies with human participants or vertebrates performed by any of the authors.

Consent for publication

Not applicable.

Competing interests

This study was performed in absence of any competing interests.

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