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The Development, Predation, and Reproduction of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) from Hatay Fed *Tetranychus cinnabarinus* Boisduval (Acari: Tetranychidae) Larvae and Protonymphs at Different Temperatures

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Abstract: Developmental time, predation, and reproduction of *Phytoseiulus persimilis* Athias-Henriot from Hatay on a diet of *Tetranychus cinnabarinus* Boisduval larvae and protonymphs at temperatures of 20, 25, and 30 °C (75% ± 10% RH and a 14:10-h L:D (light:dark) cycle) were studied. *P. persimilis* females feeding on *T. cinnabarinus* larvae completed development in 8.12, 5.79, and 3.88 days at 20, 25, and 30 °C, respectively, during which time the females consumed on average 16.10, 16.09, and 17.18 *T. cinnabarinus* larvae, respectively. Alternatively, *P. persimilis* females completed development at the same 3 temperatures in 8.16, 5.73, and 4.27 days, respectively, on a diet of *T. cinnabarinus* protonymphs, and during development the females consumed 12.84, 9.69, and 12.21 *T. cinnabarinus* protonymphs, respectively. Mean daily consumption of adult *P. persimilis* females was 11.85, 20.64, and 15.41, while *P. persimilis* males consumed 2.41, 2.60, and 3.25 *T. cinnabarinus* larvae at 20, 25, and 30 °C, respectively. Females laid on average 1.85, 3.42, and 2.30 eggs per female per day, respectively, at the above-mentioned temperatures. Higher temperatures shortened the development time of *P. persimilis*, but the amount of food consumed was mainly influenced by diet type.

Key Words: *Phytoseiulus persimilis*, *Tetranychus cinnabarinus*, development, temperature, food consumption

Avcı Akar *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae)'in Hatay Populasyonunun Farklı Sıcaklıklarda *Tetranychus cinnabarinus* Boisduval (Acari: Tetranychidae) Larva ve Protonimfleri Üzerinde Gelişme, Beslenme ve Üremesi

Özet: Avcı akar *Phytoseiulus persimilis* Athias-Henriot'in Hatay populasyonunun 20, 25 ve 30 °C sıcaklıklarda ayrı ayrı (% 75 ± 10 nem ve A:K = 14:10 saat (aydınlık:karanlık)) *Tetranychus cinnabarinus* Boisduval larva ve protonimfleri üzerinde gelişme süresi, besin tüketimi ve üremesi çalışılmıştır. *P. persimilis* dişileri *T. cinnabarinus* larva tüketimlerine bağlı olarak gelişme sürelerini sırası ile 8,12, 5,79 ve 3,88 günde tamamlamışlardır. Gelişme süresince dişi bireyler 20, 25 ve 30 °C sıcaklıklarda 16,10, 16,09 ve 17,18 adet *T. cinnabarinus* larvası tüketmişlerdir. Yukarıda bildirilen sıcaklıklarda, *P. persimilis* dişilerine *T. cinnabarinus* protonimfleri besin olarak verildiğinde dişi bireylerin gelişme süreleri 8,16, 5,73 ve 4,27 gün olarak bulunmuştur. Gelişme süresince dişi bireyler 12,84, 9,69 ve 12,21 adet *T. cinnabarinus* protonimfi tüketmişlerdir. *P. persimilis* ergin dişi ve erkekleri ise 20, 25, 30 °C sıcaklıklarda 11,85, 20,64, 15,41 ve 2,41, 2,60 ve 3,25 adet *T. cinnabarinus* larvası tüketirken bir dişi birey günlük ortalama 1,85, 3,42 ve 2,30 adet yumurta bırakmıştır. Artan ortam sıcaklığı *P. persimilis* dişi bireylerinin gelişme sürelerini kısaltmış fakat besin tüketimi daha çok besin tipinden etkilenmiştir.

Anahtar Sözcükler: *Phytoseiulus persimilis*, *Tetranychus cinnabarinus*, gelişme, sıcaklık, besin tüketimi

Introduction

Phytoseiulus persimilis Athias-Henriot was first described by Athias-Henriot in 1954 (Athias-Henriot, 1957). This species is one of the most important predators of the *Tetranychus* mites *Tetranychus cinnabarinus* Boisduval and *T. urticae* Koch. Nowadays, *P. persimilis* is used as a biological control agent for tetranychids worldwide, especially in protected crops (Zhang and Sanderson, 1995; McMurtry and Croft, 1997; Zhang, 2003).

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In Turkey, indigenous populations of *P. persimilis* were first found in Kaledran (Antalya) on *Malva neglecta* Wallr. in association with *T. cinnabarinus*. In the surveys that followed *P. persimilis* was also discovered in Alanya (Antalya) on *T. cinnabarinus*-infested *Solanum melongena* L. in 1989 (Şekeroğlu and Kazak, 1993). The third naturally occurring population of *P. persimilis* was found in Samandağ (Hatay), which was first detected in 1991 on *S. melongena* (Kazak, 2001). In contrast to Kaledran and Alanya, *P. persimilis* has a very wide distribution with well-established colonies on both natural and agricultural plants in Samandağ.

Kazak (2006) reported that the females of *P. persimilis* from Hatay completed development in 19.4, 8.3, 5.3, and 4.0 days at 15, 20, 25, and 30 °C when only *T. cinnabarinus* eggs were offered to predators. During development, females consumed on average 13.9, 15.6, 14.8, and 16.7 eggs, respectively. The comparative biology of the Kaledran and Hatay populations of *P. persimilis* was also studied in the laboratory (Kazak and Şekeroğlu, 1992). Mean *T. cinnabarinus* egg, protonymph, and deutonymph consumption of immature *P. persimilis* females from Hatay and Kaledran were similar; however, numerical response, intrinsic rate of increase (r_m), and generation time of the Kaledran population were lower than those of the predator's Hohenheim population (Kazak and Şekeroğlu, 1990; Zaman et al., 1990).

Although the biology of *P. persimilis* was studied intensively by numerous authors under controlled conditions, most of the research was conducted using mixed stages of the spider mite or only with eggs being provided as food to the predator. A few studies have been carried out to examine the effects of immature prey stage on the biology of *P. persimilis* in the laboratory. Takafuji and Chant (1976) reported that protonymph, deutonymph, and adult females of *P. persimilis* consumed 5.6, 6.8, and 17.6 *T. pacificus* McGregor protonymphs per day, respectively, at 25 °C and 75%-90% RH. When larvae, proto-, and deutonymphs of *T. cinnabarinus* were given together as food to *P. persimilis*, Kılınçer et al. (1996) found that a mean of 1.5, 3.88, and 4.64 of the immature stages were preyed on by the predator's larval, protonymph, and deutonymph stages, respectively. Pruszynski (1976) demonstrated that consumption of *T. urticae* deutonymphs by *P. persimilis* females increased as the relative humidity decreased and temperature increased; however, a search of the literature showed that there is limited information on the development and predation of immature stages of the predator, particularly when larvae and protonymphs of the prey were provided separately as food to *P. persimilis*.

With the exception of larvae, all immature stage and adult *P. persimilis* feed exclusively on tetranychid mite eggs, immatures, and adults (Laing, 1968; Ashihara et al., 1978; Chittenden and Saito, 2001); however, *P. persimilis* demonstrated a significant preference for eggs (Takafuji and Chant, 1976; Blackwood et al., 2001). Spider mite colonies most often include multiple life stages, including mobile immatures such as larvae and protonymphs. When the preferred life stage of spider mites become scarce, predators either have to disperse or feed on those life stages less preferred; therefore, understanding the nutritive value and consumption of the less-preferred life stages becomes important for the continuity of predator populations, especially specialized predators like *P. persimilis*.

The present study examined the development and predation of the immature stages of a specialized predatory mite from Hatay, Turkey, *P. persimilis*, which were fed *T. cinnabarinus* larvae and protonymphs at different temperatures. We also studied predation by adult female and male *P. persimilis* on a diet of *T. cinnabarinus* larvae, as well as female oviposition at 25 °C.

Materials and Methods

Mite Rearing

A laboratory colony of *P. persimilis* was started in the Çukurova University Plant Protection Department from adults collected from *T. cinnabarinus*-infested bean plants in Samandağ-Hatay, Turkey. The predator colony was reared continuously on potted bean plants (*Phaseolus vulgaris* L. var. Barbunia) infested with *T. cinnabarinus* in a temperature-controlled rearing room.

Developmental and Predation Performance of *Phytoseiulus persimilis* Immatures

We monitored the development and predation performance of female *P. persimilis* immatures on a diet of *T. cinnabarinus* larvae or protonymphs under laboratory conditions at 20, 25, and 30 °C, 75 ± 10% RH, and a L:D (light:dark) period of 14:10 h.

Development and predation by the predator was evaluated in a 5 × 3.5 × 0.6-cm Plexiglas cell in which a 2-cm diameter hole was drilled. To obtain an experimental arena, a 5 × 4-cm moist filter paper was placed on a 5 × 3.5 × 0.2-cm Plexiglas plate to prevent desiccation of the leaf, which was later placed on a plate abaxial side up. After this procedure, the above mentioned 5 × 3.5 × 0.6-cm Plexiglas cell was assembled on a bean leaf, and 2 edges of the cell were pressed together with clips. One mated *P. persimilis* was transferred to each cell in order to obtain eggs. Each cell on a Plexiglas plate was surrounded by tangle-foot (The Tangle Foot Co. Grand Rapids, MI, USA) as a preventative barrier. Afterwards, Plexiglas cells were placed in a moist tray, which was placed in a temperature-controlled growth-chamber. The Plexiglas cells in the growth chamber were checked after 8 h. Once 1 egg was established on each cell, female mites were removed. The *P. persimilis* eggs (F_1) on each cell were observed twice a day (0800 and 2000 hours), from egg through adult stages. When an egg reached the larval stages it was transferred to another Plexiglas cell containing either 20 newly hatched *T. cinnabarinus* larvae or 20 protonymphs; therefore, experiments were conducted in 2 phases, with the first started by providing 20 newly hatched *T. cinnabarinus* larvae as prey for *P. persimilis* and the second started by providing 20 *T. cinnabarinus* protonymphs for the predator. In both cases, daily observations were made at 12-h intervals to follow the development of the immature stages. Additionally, the number of *T. cinnabarinus* larvae and protonymphs consumed by *P. persimilis* immatures were counted under a binocular microscope at the end of the each 12-h period. Food was replenished at the end of the same period as well.

Larval Predation and Oviposition of *Phytoseiulus persimilis* Adults

Consumption of larvae by newly mated *P. persimilis* adult females and males was studied at 3 constant temperatures. Larval consumption by *P. persimilis* adults was evaluated according to the following method: 1. Thirty-five *T. cinnabarinus* larvae were provided daily as prey for predator males and females; 2. At the end of each 24-h period the numbers of *T. cinnabarinus* larvae consumed and eggs laid by mated *P. persimilis* adults were recorded; 3. The experiments were continued for 5 days and the same individuals were followed; 4. The above experiments were conducted with at least 10 replications and with new individuals taken from the predator colony.

Statistical Analyses

Data on development time and prey consumption were analyzed by two-way ANOVA, including the effects of diet (or prey type) and temperature, and the interaction between temperature and diet. This was followed by Tukey's HSD test (temperature) and t-test (diets) analysis when there was a significant main effect or interaction difference ($P = 0.05$). Data on fecundity and prey consumption of *P. persimilis* adults (female and male) were analyzed separately by one-way ANOVA, followed by Tukey's HSD test at $P = 0.05$. All analyses were performed using SPSS v.10.01 for Windows (SPSS, Chicago, IL, USA).

Results

Two-way ANOVA indicated differences between immatures and total developmental time at different temperatures (protonymphs: $F = 66.89$, $df = 2$, $P < 0.001$; deutonymphs: $F = 62.25$, $df = 2$, $P < 0.001$; total: $F = 336.64$, $df = 2$, $P < 0.001$); however, no significant effect of diet or interaction between temperature and diet was found ($P > 0.05$)

The duration of all immature stages of females decreased as temperature increased, and was statistically different when *P. persimilis* fed on *T. cinnabarinus* larvae. The effect of temperature on the immature developmental time of the predator was more evident at 30 °C. The average time required to develop from egg to adult for *P. persimilis* females on a diet of *T. cinnabarinus* larvae at 20 °C was almost double that which was required at 30 °C, and almost 2 days longer than at 25 °C. The effect of temperature on the immature developmental time of *P. persimilis* was similar to larval diet when the predatory mite fed on *T. cinnabarinus* protonymphs. With the exception of the larval stage, the duration of all female immature stages significantly decreased as temperature increased. Similar to larval diet, the shortest mean total developmental time for *P. persimilis* was at 30 °C, followed by 25 and 20 °C (Table 1).

Two-way ANOVA revealed a significant effect of diet ($F = 6.13$, $df = 1$, $P = 0.016$) and temperature ($F = 4.56$, $df = 2$, $P = 0.014$), but no interaction effect (P >

Table 1. Duration (in days) of various stages of *P. persimilis* (Hatay population) feeding on *T. cinnabarinus* larvae and protonymphs at different temperatures (°C) (mean ± SEM)*.

	Diets	Temperature			F ratio
		20	25	30	
n^z	larvae	10	11	11	df 29
	protonymph	15	16	14	df 42
Egg	larvae	3.16 ± 0.12 ^{a}	1.96 ± 0.10 ^{b}	1.50 ± 0.12 ^{c}	59.28 P < 0.001
	protonymph	3.27 ± 0.06 ^{a}	2.10 ± 0.06 ^{b}	1.60 ± 0.07 ^{c}	194.27 P < 0.001
Larvae	larvae	1.20 ± 0.08 ^{a}	1.10 ± 0.06 ^{ab}	0.90 ± 0.09 ^{b}	3.62 P = 0.037
	protonymph	1.13 ± 0.04	1.00 ± 0.02	0.95 ± 0.08	ns P > 0.05
Protonymph	larvae	1.78 ± 0.13 ^{a}	1.19 ± 0.10 ^{b}	0.72 ± 0.09 ^{c}	31.99 P < 0.001
	protonymph	1.83 ± 0.08 ^{a}	1.32 ± 0.10 ^{b}	0.85 ± 0.02 ^{c}	41.20 P < 0.001
Deutonymph	larvae	1.98 ± 0.18 ^{a}	1.54 ± 0.14 ^{a}	0.76 ± 0.07 ^{b}	20.62 P < 0.001
	protonymph	1.93 ± 0.08 ^{a}	1.31 ± 0.09 ^{b}	0.87 ± 0.03 ^{c}	52.45 P < 0.001
Total development time	larvae	8.12 ± 0.25 ^{a}	5.79 ± 0.24 ^{b}	3.88 ± 0.16 ^{c}	91.40 P < 0.001
	protonymph	8.16 ± 0.09 ^{a}	5.73 ± 0.10 ^{b}	4.27 ± 0.10 ^{c}	374.36 P < 0.001

^{z}Number of replicates.
*Within rows, mean followed by the same lower case letter do not differ significantly (P > 0.05, Tukey's HSD test).
ns: not significant.

0.05) on food consumption by *P. persimilis* protonymphs. In contrast to protonymphs, there was a significant diet × temperature interaction for deutonymphs (F = 3.79, df = 2, P = 0.027). Additionally, an effect of diet (F = 47.66, df = 1, P < 0.001) on food consumption by deutonymphs was observed. Only mean total food consumption of immatures was significantly affected by diet (F = 51.84, df = 1, P < 0.001).

P. persimilis immatures consumed a significantly higher mean number of *T. cinnabarinus* larvae when compared to protonymph consumption at each stage and temperature (t-test, P < 0.05); however, there was no significant difference between mean *P. persimilis* larval and protonymph consumption of protonymphs at 20 and 25 °C (t-test, P > 0.05) (Table 2).

The increase in the consumption rate of *P. persimilis* was not significantly different between temperatures, with the exception of a significant difference in the protonymph rate of consumption of larvae at 25 and 30 °C (Table 2).

During the experiment daily average consumption by *P. persimilis* females was 11.85, 20.64, and 15.41, while *P. persimilis* males consumed 2.41, 2.60, and 3.25 *T. cinnabarinus* larvae at 20, 25, and 30 °C, respectively. Females laid on average 1.85, 3.42, and 2.30 eggs per female per day at the above-mentioned temperatures, respectively (Table 3).

Discussion

P. persimilis larvae advanced to the next developmental stage without feeding on *T. cinnabarinus* larvae or protonymphs. Similar results were reported by Laing (1968), Ashihara et al. (1978), and Chittenden and Saito (2001) when *T. cinnabarinus* eggs or *T. urticae* immature stages were provided as food for *P. persimilis*. Zhang and Croft (1994) reviewed larval feeding patterns and proposed 3 types of larvae within the Phytoseiidae family: non-feeding, facultative-feeding, and obligatory-feeding larvae. They suggested that the mouthparts of non-feeding larvae may be nonfunctional (Chittenden and Saito, 2001); therefore, our results are in agreement with their findings.

The overall, immature, and total development period of *P. persimilis* decreased as temperature increased,

Table 2. Number of *T. cinnabarinus* larvae and protonymphs consumed by *P. persimilis* (Hatay population) immatures at different temperatures (°C) (mean ± SEM).*

	Diets	Temperature			F ratio
		20	25	30	
n^z	larvae	10	11	11	df 29
	protonymph	15	16	14	df 42
Larvae	larvae	-	-	-	-
	protonymph	-	-	-	-
Protonymph	larvae	7.10 ± 0.85 ^{ab}	5.64 ± 0.51 ^{b}	8.09 ± 0.49 $^{a\ y}$	4.03 P = 0.028
	protonymph	6.13 ± 0.61	4.75 ± 0.55	6.00 ± 0.75	ns P > 0.05
Deutonymph	larvae	9.00 ± 0.92 ^{y}	10.45 ± 0.65 ^{y}	9.09 ± 0.71 ^{y}	ns P > 0.05
	protonymph	6.71 ± 0.52	4.94 ± 0.46	6.21 ± 0.60	ns P > 0.05
Total prey consumption	larvae	16.10 ± 1.07 ^{y}	16.09 ± 0.98 ^{y}	17.18 ± 0.89 ^{y}	ns P > 0.05
	protonymph	12.84 ± 0.64	9.69 ± 0.47	12.21 ± 1.10	ns P > 0.05

^{z}Number of replicates.
*Within rows, mean followed by the same lower case letter do not differ significantly (P > 0.05, Tukey's HSD test).
ns: not significant.
^{y}Within columns, for both diets, means differ significantly (t test; P < 0.05).

Table 3. Daily consumption of *T. cinnabarinus* larvae by adult females and males, and fecundity of *P. persimilis* (Hatay population) at different temperatures (°C) (mean ± SEM).*

Stages	Temperature			F ratio df = 35
	20	25	30	
	(n^z = 14)**	(n = 14)	(n = 10)	
Female	11.85 ± 0.71 ^{b}	20.64 ± 1.82 ^{a}	15.40 ± 1.79 ^{ab}	9.67 P < 0.001
Fecundity	1.85 ± 0.20 ^{b}	3.42 ± 0.17 ^{a}	2.30 ± 0.36 ^{b}	12.58 P < 0.001
Male	2.41 ± 0.55 ^{a}	2.60 ± 0.33 ^{a}	3.25 ± 0.42 ^{a}	ns P > 0.05

^{z}Number of replicates. *Means in rows followed by the same letter are not significantly different (P > 0.05, Tukey's HSD test).
**Replications were followed for 5 days.
ns: not significant.

regardless of the diet used in the experiment. Bravenboer and Dosse (1962) reported that total development times of *P. riegeli* (= *persimilis* Athias-Henriot) females feeding on *T. cinnabarinus* mixed stages were 17.2, 4.6, and 3.8 days at 15, 25, and 30 °C, respectively. Development time of this species was also studied by Sabelis (1981) at 15, 20, and 30 °C, and mean developmental times of *P. persimilis* females fed *T. urticae* mixed stages were 19.6, 7.2, and 3.9 days, respectively. Kazak (2006) reported that total development times of *P. persimilis* females from Hatay on a diet of *T. cinnabarinus* eggs at 20, 25, and 30 °C were 8.3, 5.3, and 4.0 days, respectively. When those results were compared to data from the present study, the results were in general agreement with those obtained by Kazak (2006) on a diet of *T. cinnabarinus* eggs; however, the findings reported by Bravenboer and Dosse (1962), and Sabelis (1981) with regard to development time of *P. persimilis* were relatively shorter than the *P. persimilis* from Hatay at 20 and 25 °C. This might have been due to 2 reasons: first, there might have been an increased effect of the mixed prey species, which decreased the development time of *P. persimilis*; second, differences in the biological characteristics of the predator population (Hassan, 1982; Kazak and Şekeroğlu, 1990; Goodwin and Wellham, 1992).

In general, food consumption by immatures was not significantly affected by increasing temperature during the protonymph or deutonymph stages, regardless of the diet used in the experiment. Çölkesen (1995) found that the effect of temperature was minimal on predation of *T. cinnabarinus* eggs, larvae, and males by *A. longispinosus* Evans immatures and adults at 25 and 30 °C. Similarly, Kazak (2006) reported that the effect of temperature on *P. persimilis* immatures food consumption was not significant on a diet of *T. cinnabarinus* eggs at 15, 20, 25, and 30 °C. From this it could be concluded that *P. persimilis* immatures consume specific amounts of prey to complete development, which is generally independent of increasing temperature; however, the differences in the consumption rates of *P. persimilis* protonymphs on larvae between 25 and 30 °C might be due to increasing temperature since temperature caused a significant effect on preying. In addition to temperature, several other factors, such as humidity, lighting, and type of experimental arena, may also affect a predator's feeding (Fernando and Hassel, 1980).

P. persimilis immatures consumed a significantly higher mean number of *T. cinnabarinus* larvae when compared to protonymphs. Fernando and Hassel (1980) showed that the highest number of prey consumed by *P. persimilis* decreased from egg to deutonymph. Additionally, *P. persimilis* proto- and deutonymphs are relatively larger than prey larvae. This could also enable the predator to consume higher numbers of smaller prey.

Takafuji and Chant (1976) stated that protonymph, deutonymph, and adult *P. persimilis* females consumed 5.6, 6.8, and 17.6 *T. pacificus* McGregor protonymphs per day, respectively, at 25 °C and 75%-90% RH. When larvae, proto-, and deutonymphs of *T. cinnabarinus* were given together as food to *P. persimilis*, Kılınçer et al. (1996) found that a mean of 3.88 and 4.64 immature stages preyed upon by the predator's protonymph and deutonymph stages, respectively, at 23 ± 2 °C. Pruszynski (1976) demonstrated that consumption of *T. urticae* deutonymphs by *P. persimilis* females increased as the relative humidity decreased and temperature increased. With the exception of *T. pacificus* consumption by adult *P. persimilis*, these results were relatively similar to the above-documented data on this subject. The differences between results may be attributable to the different prey species used in the experiments. Additionally, in contrast to Pruszynski (1976), we found the effect of increasing temperature on the consumption of a predator to be minimal. Differences in results between the studies may be due to the experimental conditions of relative humidity.

It has been stated that eggs and larvae of *T. urticae* provide similar nutritional benefits to predators (Ohnesorge, 1981; Sabelis, 1985; Blackwood et al., 2001). When mixed stages of *T. cinnabarinus* were provided to predatory mites at 24 °C, daily mean number of eggs laid was 4.6 (Ashihara et al., 1978). Kazak (2006) reported that *P. persimilis* from Hatay laid on average 2.4, 3.2, and 3.5 eggs per female per day when they fed on *T. cinnabarinus* eggs at 20, 25, and 30 °C, respectively. In the present study, however, the fecundity of *P. persimilis* was lower than the above-reported fecundities, with the exception of Kazak (2006), at 25 °C. It could therefore be concluded that the nutritional benefits of *T. cinnabarinus* larvae and protonymphs were not as great as prey eggs or mixed stages, in terms of *P. persimilis* reproduction.

In conclusion, this study advanced our understanding of the detailed biology of the most important predator of the tetranychid mites by investigating the effect of temperature on their development time and immature prey consumption. Increases in temperature decreased the development time of *P. persimilis*; however, mean food consumption was influenced mainly by the type of diet. In general, development and immature stage consumption by *P. persimilis* from Hatay showed similarities to other populations; however, before reaching a final conclusion, additional experiments involving different prey ratios (egg:active stages) and humidities, while monitoring the development and food consumption of *P. persimilis*, should be performed to obtain optimized results.

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