Prospects for usage of predatory mite *Neoseiulus californicus* (MCGREGOR, 1954) (order Mesostigmata: subfamily, Amblyseiinae, family Phytoseiidae)

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Abstract. The predatory mite *Neoseiulus californicus* (MCGREGOR, 1954) is used as a specialized acariphage on vegetable, flower and berry crops. In protected ground, *N. californicus* is one of the effective carnivores of spider mites (Tetranychidae), the intensity of attacks depends on the temperature. The predator prefers to consume immature individuals of *T. uirticae*, often ignoring adult female mites. Simultaneously, predaceous organism does not express preferences between eggs and *T. urticae* nymphs. However, as the density of the spider mite population increases, the predatory mite shifts its diet from the eggs of the victim to larvae and nymphs. Adult females *N. californicus* exhibit a type 2 functional response to both eggs and *T. urticae* nymphs. Pyrethroid and avermectin drugs are highly toxic to predator populations. At the same time, there is low acute toxicity to many insecticides (Actara, Envidor, etc.) is exibited.

1 Overview of current systematic characteristics of the species

The genus *Neoseiulus Hughes*, 1948 [1] is included in the family of phytoseiid mites (Phytoseiidae) subfamily Amblyseiinae of the order Mesostigmata of the superorder Parasitiform mites (Parasitiformes) of the Arachnid class.

The genus *Neoseiulus* is characterized by a dorsal shield chete consisting of 17 pairs of short setae almost uniform in length. The anterolateral setae of the 4th pair (A4, or s4) and the postmedial 2nd pair (PM2, or Z4) differ little from the rest of the lateral setae. Only the postmedial setae of the 3rd pair (PM3, or Z5) are slightly longer than all the setae.

The species of predatory mite *Neoseiulus californicus* (MCGREGOR, 1954) (formerly *Typhlodromus californicus* McGregor, 1954 [2], *Typhlodromus chilenensis* Dosse, 1958 [3], *Typhlodromus mungeri* McGregor, 1954 [2]) is naturally distributed in the Pacific

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coasts of America and Asia, as well as in some European countries of the Mediterranean region.

2 Diagnostic signs

The differences in the sizes of the lateral and dorsal setae are small, i.e. the setae L1-L4 (=j3-z2-z4-s4) are approximately equal to the setae D2 (=j4) and D3 (=j5) or not much longer than the latter. The dorsal setae L5 (=Z1) are shorter than the distance between the tips of the setae L5-L6 (=Z1-S2). Movable finger chelicer D_m with 3 additional teeth. On the ventroanal shield, all 3 pairs of preanal setae are located at different levels, in transverse rows significantly removed from each other. The preanal pores are large, crescent-shaped, and strongly converged. The funnel of the sperm is short, its length is approximately equal to or not much (no more than 1.5 times) exceeds the largest width. The shape of the funnel of the spermatheca is cup-shaped (= bell-shaped) with a rounded top and almost parallel walls. The atrium is small, adjacent to the top of the funnel.

Neoseiulus californicus is morphologically similar to the *phytoseiid* mite *Neoseiulus cucumeris* (Oudemans, 1930). It is distinguished by slightly longer setae on the dorsal shield (Fig. 1), the presence of 3 teeth on the movable finger of the chelicerae, large converging pores on the ventrial shield, a bell-shaped funnel of the spermateca with an atrium on the short neck (Fig. 2).

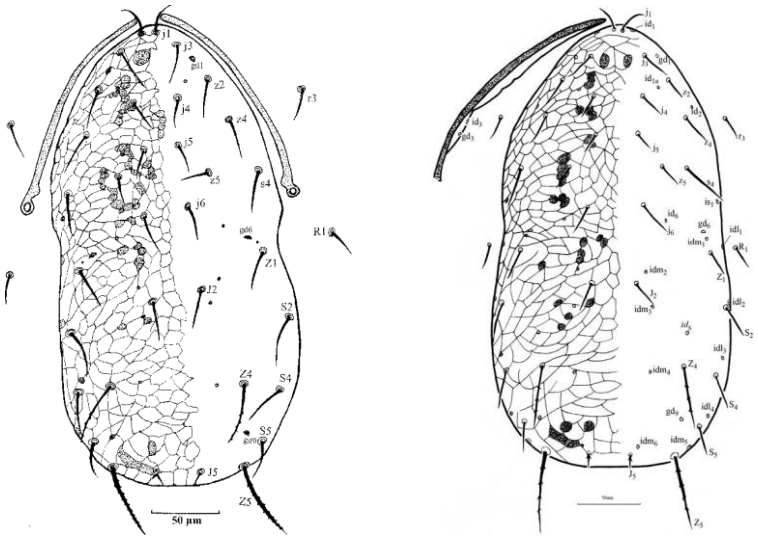

Fig. 1. Dorsal idiosome (shield and peritremes are shown) of *Neoseiulus californicus* [4, 5].

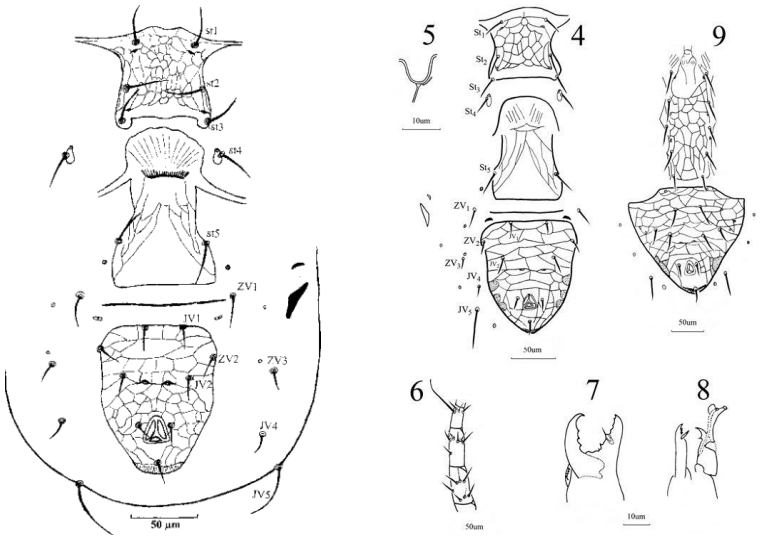

Fig. 2. Some details of the structure of *Neoseiulus californicus* [4, 5]: 4) ventral side of the female's body, 5) spermatheca, 6) macrochete on the 4th pair of legs, 7) female chelicerae, 8) male chelicerae, 9) ventral side of the male's body.

The predatory mite *Neoseiulus californicus* was first discovered in January 1953 in California on lemon fruits, where it fed on the red citrus mite *Panonychus citri* [2]. Later, it was repeatedly found in California on garden strawberries, in the Mediterranean region on garden strawberries, in vineyards, citrus and fruit crops, in Japan on pears and weeds. Natural populations from South America are also known under the name *Neoseiulus chilensis* [3].

By type of diet, it refers to predators that prefer to hunt spider mites and are able to survive on alternative food [6]. The range of its victims includes various species of herbivorous mites: from *Tetranychidae* (Spider mites) family – *Tetranychus urticae*, T. *cinnabarinus, T. atlanticus, T. turkestani, Oligonychus pratensis*, *O. perseae*, *O. ilicis*, *Panonychus citri, P. ulmi*; 1) from *Eriophyidae* (Four-legged mites) family – *Aculus schlechtendali*; 2) from Tarsonemidae (Variegated mites) family – *Phytonemus pallidus*, *Ph. pallidus, Polyphagotarsonemus latus*. The predator also attacks the larvae of thrips – *Thrips tabaci, Frankliniella occidentalis* [7, 8].

Neoseiulus californicus can be fed with *Ricinus communis*. Biological parameters of predatory mite are identical when feeding on a spider mite [9]. For some time, the predator can feed on the pollen of corn *Zea mays* [10]. These data can be used, for example, in the development of a method of mass breeding in the laboratory. The predatory mite *N. californicus* is used all over the world in open and protected ground [for example: 11, 12]. To combat spider mites in greenhouses, acariphage has been introduced to France, Belgium, the Netherlands, Germany, Italy, Great Britain, Ireland, Denmark, Norway, Finland, Austria, Poland.

In some areas of England in 2000s, it was discovered in fruit orchards, where it entered independently from greenhouses. To the Soviet Union this organism entered by accident in 1969, on grape leaves together with the predatory mite *Metaseiulus occidentalis*, introduced from USA on the initiative of G.A. Beglyarov. Currently, this mite is imported into the Russian Federation by various foreign companies, manufacturers of entomophages, and is recommended for use at protected and open ground on a variety of crops.

The development cycle consists of 4 stages – egg (ovum), larva, nymph (proto- and deuto-), imago (female or male). The female prefers to lay eggs in colonies of spider mites.

Individual preimaginal development also ends here: from 6-legged larvae, turning into 8-legged protonymphs and further into deutonymphs, subsequently reaching the adult stage.

The adult female is broadly oval in shape, with 4 pairs of legs, about 0.5 mm long. The body is usually pale yellowish in color, but varies from orange to reddish in color if it feeds on spider mites. The legs are relatively long, especially the front pair. There are 17 pairs of setae on the dorsal shield, of which the posterior pair is slightly longer and they are serrated. A spermateca with a bell-shaped funnel. There are 3 teeth on the movable finger of the chelicerae, 4 distal and 2 basal teeth on the stationary one. Males are somewhat smaller than females, their chelicerae bear a specific form of spermatodacty.

Pale eggs whitish in color have the elongated-oval shape, almost the same width along the egg. The surface of the egg is smooth and shiny. The length is about 0.16 mm. Females lay eggs on the leaf underside, often along the veins and on the threads of web.

The larvae are pale from white to translucent in color. There are a pair of long setae on the opisthosome. There are only three pairs of legs. Without nutrition, they molt into protonymph. The second and third stages of preimaginal development (proto- and deuto-nymphs) have four pairs of legs. They are somewhat milky in color. The body length is 0.2–0.4 mm.

Neoseiulus californicus It is capable of developing and reproducing in the temperature range from 13 to 33 °C. As the temperature increases, the time of individual predator development decreases (Table. 1), but the rate of its development is always almost 2 times higher than that of the spider mite.

The fertility of the predator is relatively low (Table 2). The sex ratio in the offspring (female–male) 2 to 1. Therefore, the population growth in *Neoseiulus californicus* is slower than, for example, in the population of phytoseiulus.

Table 1. The effect of temperature on the duration of development of *Neoseiulus californicus* when feeding on the spider mite *Tetranychus urticae* [13].

Age of predaceous organism	**Preimaginal development span (days) at fixed temperature, °C**				
	15	20	25	30	35
Egg (ovum)	6.07	2.24	1.61	1.23	1.14
Larva	2.71	0.97	0.78	0.53	0.5
Protonymph	5.68	1.71	1.44	1.1	1.11
Deutonymph	7.25	1.81	1.24	1.03	1.03
Overall	21.71	6.73	5.07	3.89	3.78

Adult predators of *Neoseiulus californicus* attack all stages of the spider mite, but the larvae feed mainly on eggs, while the nymphs of the acariphage eat eggs, larvae and nymphs of the victim [13–16]. The intensity of feeding depends on the density of the victim's population, as well as on the temperature and humidity of the surrounding air.

The predatory activity of *N. californicus* when feeding on spider mite eggs reaches approximately 15–20 pieces per day [17]. *Californicus* is adapted to inhabit many crops. Of the predatory mites used in European greenhouses on ornamental crops, including roses, one of the most important is *N. californicus* [18]. High fertility and low mortality were noted on strawberry orchards. The predator is more mobile on pepper and tomato, but less active on eggplant [19]. At the beginning of colonization, the biotic potential on tomatoes

decreases (r_m = 0.118), but after several generations this demographic indicator increases to 0.256 [20].

N. californicus is considered the most resistant species of predatory mites to some widely used insecticides. For example, a population with 24–fold resistance to deltamethrin was found in commercial orchards in Brazil [21]. After the application of pesticides, this predator quickly restores its population on the protected crop.

Table 2. Population characteristics of *Neoseiulus californicus* depending on temperature [13]

Parameters	Temperature, °C		
	20	25	30
Egg laying period	16.7	17.9	11.7
Average daily fecundity	1.5	1.9	2.3
Total fecundity	25.8	34.7	27.9
Generation span	20.6	17.8	16.8
Biotic potential	0.162	0.209	0.285

The insecticide spiromesiphene is highly toxic to the common spider mite, but harmless to the predatory mite *N. californicus*. In this regard, for integrated management of the number of spider mites, the use of spiromesiphene in combination with predatory mites is recognized as promising, abandoning the use in this case of highly toxic drugs based on chlorphenapir, abamectin, milbemectin and diaphentiuron [22]. Many modern acaricides do not show direct toxicity to predatory mites. Thus, after treatment with bifenazate, all development stages survived, the females maintained normal level of fertility. In addition, predators survived by feeding them with processed spider mite eggs [23]. At evaluation of acaricides effect (cyenpirofen, spirodiclofen, spiromesiphene, flufonoxurone and cyflomethophene) on *Neoseiulus californicus*, their low toxicity to predaceous organism females and nymphs is demonstrated, but a slight reduction in reproductive function occured.

When evaluating the action of acaricides The predatory mite *Neoseiulus californicus* is found to have low toxicity to predator females and nymphs, but they slightly reduced reproductive function. These drugs did not affect the fertility of females fed on spider mites treated with acaricides. On the other hand, the integrated protection system cannot use pesticides based on ethaxosol, which significantly reduce the fertility of predatory mites, and pyraclophos, which causes 100% mortality in females [22]. The pesticides Pride (phenazachine) and Envidor (spirodiclofen) increase the duration of the predatory mite's preimaginal development, as well as shorten the reproductive period of *N. californicus* females by 1.6 times and reduce their fertility by almost 3 times [23].

3 Laboratory population

Predatory mite *Neoseiulus californicus* It has been repeatedly introduced and continues to be imported by foreign companies (for example, Syngenta Bioline) into the territory of the Russian Federation for commercial use in protected soil.

Currently, this species is contained in the State Collections of some scientific institutions (for example, the FSBSI VNIIF, Russia, Bolshye Vyazemy, Moscow region).

To ensure efficiency of the counter-sanctions, it is necessary to start production on the territory of the Russian Federation. The mite population is successfully cultivated in laboratory conditions, where it is currently bred over the method using spider mites (family Tetranychidae) or barn mites (family Tyroglyphidae). The purified uterine culture of the predatory mite *Neoseiulus californicus* is provided to industrial biological laboratories to establish foundation of scaled reproduction.

Consideration of medical and environmental safety issues arising during breeding and use of acariphage shows that predatory mite *Neoseiulus californicus* is safe for humans and warm-blooded animals. Allergic reactions in the maintenance personnel during its dilution and application are not recorded. The predaceous mite is safe for beneficial insect pollinators and biological control agents against harmful arthropods.

4 Application characteristics

Neoseiulus californicus it is a specialized oligophagus. The predator feeds on various species of spider mites (at all development stages), as well as some species of mites from other families. It can be used on vegetable and ornamental crops of protected ground, as well as on crops in the open ground.

The best plants for predator colonization are cucumber, pepper, rose, strawberry and gerbera. To a lesser extent, a tomato is an acceptable host plant. It is advisable to use *Californicus* as a preventive control of the spider mite when the pest population is insignificant. The usual rate of use for each colonization is 4 females per 1 m^2. Up to 5–10 females per leaf are released into the primary colonies of the spider mite. The optimal ratio of predator and prey is 1 to 3 or 1 to 5. It should be emphasized that the predator does not instantly control outbreaks of spider mite populations, except for use at very high release rates. Optimal hygrothermal conditions for a predator are the average daily temperature in the range of 26–32 ° C, relative humidity in the range of 70–80%.

Short-term storage of the accumulated population (imago and nymphs of predatory mite) can be stored in the refrigerator for 5–7 days before releases, at a temperature of 8–10 °C. Long-term storage of the predatory mite population requires maintenance in the refrigerator at 15–17 ° C for up to 2–3 months with mandatory feeding of mites every fortnight with forage mites from the Tyroglyphidae family.

5 Test results

Some drugs approved for use in the protected soil of Russia against the predatory mite *Neoseiulus californicus* have been tested in laboratory conditions [23]. The death of phytoseids is assessed 24 hours after treatment with organophosphorus insecticides, 72 hours later – avermectins and neonicotinoids, 5 days later – bitoxibacillin [Glinushkin, Yakovleva, Meshkov 2019]. Table 3 presents data on the assessment of the lethal effect of insecticides on N.salifornicus in concentrations permitted for practical use ("State Catalog of Pesticides and Agrochemicals, approved for use on the territory of the Russian Federation for 2023").

Table 3. Toxicity of insecticides to females *Neoseiulus californicus*.

Commercial name	Preparative form	Active substance	Pesticide concentration, %	Female mortality, %
Vertimek	CE	abamectin, 8 g/l	0.05 *	100
Phytoverm	CE	aversectin C, 2 g/l	0.2 *	100

Clipper	CE	bifentrine, 100 g/l	0.08 *	100
Novaktion	WE	malathion, 440 g/l	0.15 *	16.8
BTB	P	BA-1500 CFU/mg *B. thuringiensis*	1.0 *	11.4
Actara	WDG	thiamethoxam, 250 g/kg	0.08 *	10.7

* *concentrations of substances approved in Russia*

Avermectin preparations and pyrethroid Clipper showed acute toxicity. Thus, the release of predatory mites against the background of the use of avermectins and bifentrin is impossible. Neonicotinoids Actara, recommended for control of greenhouse whitefly, as well as the insecticides Bitoxibacillin and Novaction had a lesser effect on *N. californicus*.

6 Discussion

The *N. californicus* mite is an effective predator of spider mites on floral, ornamental, berry, vegetable, green, medicinal crops. However, each crop, depending on the agrobiological characteristics, has its own requirements for the cost-effective use of predator. It is also important to know the characteristics of varieties that are not resistant to damage by harmful mites. *Neoseiulus californicus* often has advantage due to low humidity, required for replication and for maintaining its development. Populations of *Neoseiulus californicus* (McGregor, 1954) with unique adaptive characteristics are often found in greenhouses. Perhaps the occurrence in greenhouses is associated with the small size of *Neoseiulus californicus* (McGregor, 1954) and, consequently, less nutrition for the population [23 – 27].

There are practices of using pesticides when the mobile stages were reduced in the spider mite population. The violation of the age structure did not have a protective effect. In our opinion, expert consultations could make it possible to adjust the time frame and quantitative norms of the predator in the protection of culture.

There are difficulties in chemical, breeding, and monitoring control of spider mites (Tetranychidae) on plants. We have also established the risks of using pesticides in the fight against spider mites, pests of food, decorative, and flower crops [30, 31]. The limitations of the "Catalog of Pesticides and Agrochemicals ... for 2023" and the global range of acaricides, both in active substances, formulations, and developed systems for their routine use, create difficulties for plant protection. The formation of resistant populations of harmful mites is noted in some foreign countries.

In the Russian Federation, the multiplicity and consumption rate of pesticides are legally regulated, which is justified, using the example of Flumite (the drug did not go to large-scale trials).

In the open ground, with tunnel, trellis cultivation, *N. californicus* can be used in systemic use with other predatory mites. For example, flower plants in distillation require more drought-resistant acariphages. Systematic professional protection of plants by predatory mites reduces pesticide loads on agrocenoses [28 – 33].

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