

# Life tables of *Neoseiulus cucumeris* exclusively fed with seven different pollens

Nar B. Ranabhat · Irina Goleva ·  
Claus P. W. Zebitz

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**Abstract** The juvenile development and survival, and demographic parameters of the predatory mite *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae) fed on pollen of castor bean, tulip, apple, Christmas cactus, horse-chestnut, maize, and birch were assessed under laboratory conditions. Deprivation of food and pollen of castor bean plants resulted in 100 % juvenile mite mortality. Feeding mites with tulip and horse-chestnut pollen resulted in the shortest development and the highest total fecundity. Adult mites fed on birch, tulip, maize, and apple pollen lived significantly longer compared with those fed on pollen of horse-chestnut and Christmas cactus. The intrinsic rate of natural increase ranged between 0.1013 ♀♀/♀/day for maize and 0.1806 ♀♀/♀/day for horse-chestnut

pollen as food. Net reproductive rate was the lowest when fed with maize pollen and highest when fed with horse-chestnut pollen. Population doubling time was highest on maize pollen and shortest on horse-chestnut pollen. Our study revealed that birch, tulip, horse-chestnut, apple, and maize pollen can be used by *N. cucumeris* from early spring to late summer as a suitable alternative food in periods when prey in the field are scarce or absent.

**Keywords** *Neoseiulus cucumeris* · Acari · Phytoseiidae · Development · Demographic parameters · Alternative food

## Introduction

Phytoseiid predatory mite species (Acari: Phytoseiidae) have been categorized according to both their life-style and their diet breadth into four types: specialists (type I, II), and generalists (type III, IV) (McMurtry and Croft 1997; Croft et al. 2004). Concerning diet breadth, specialists are oligophagous predators of tetranychid mites (Gerson et al. 2003; de Moraes et al. 2004). In addition to arthropod prey of different families, generalists may also feed on plant-derived food and even on artificial diets, at times resulting in higher reproduction rates when fed on pollen than preying on arthropod prey (Abdallah et al. 2001; Gerson and Weintraub 2012; Nguyen et al. 2013). However, generalist species differ in their prey

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N. B. Ranabhat · I. Goleva · C. P. W. Zebitz (✉)  
Institute of Phytomedicine, University of Hohenheim,  
70599 Stuttgart, Germany  
e-mail: Claus.Zebitz@uni-hohenheim.de

N. B. Ranabhat  
e-mail: nar.ranabhat@msu.montana.edu

I. Goleva  
e-mail: irgoleva@uni-hohenheim.de

## Present Address:

N. B. Ranabhat  
Department of Land Resources and Environmental  
Science, Montana State University, Bozeman,  
MT 59717-3120, USA

preferences and their abilities to utilize prey, resulting in different efficacies to control particular target pests (Schausberger and Walzer 2001).

To warrant long-term control of greenhouse pests, beneficial arthropods are often provided with alternative food, either alternative prey or host species, or plant resources in open-rearing systems on “banker-plants” to conserve the biocontrol agents when the target pest species is scarce (Ramakers and Voet 1996; van Rijn and Tanigoshi 1999b; Coll and Guershon 2002). Pollen offered as alternative or supplementary food source to type III and IV phytoseiid mites used in greenhouse production of vegetables and ornamentals may provide important nutrients. As a consequence, the predator population may persist during shortage of their primary food and a stable population is established impeding pest resurgence. The abundant predator population may also attack pests at an early stage of immigration into the greenhouses from adjacent vegetation and prevent the pests from establishing rather than controlling their population peak in high value crops such as ornamentals (Wardlow 1990; van Rijn et al. 2002).

Only few studies (Ramakers 1990; van Rijn and van Houten 1991; van Rijn and Tanigoshi 1999a) evaluated the suitability of pollen as the exclusive food source for juveniles and adults of *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae). The objectives of the present study were to assess the suitability of seven different pollen species as alternative foods by performing a full life table study under laboratory conditions, thus extending the knowledge of the food spectrum of this economically important predatory mite.

## Materials and methods

### Rearing of *Neoseiulus cucumeris*

The stock population of *N. cucumeris* (obtained from Sautter and Stepper, Biologischer Pflanzenschutz, Ammerbuch, Germany) was kept in the laboratory at 25 °C (65–70 % RH) in stackable plastic boxes (20 × 13 × 5 cm) with mould mites (*Tyrophagus* sp.) (Acari: Acaridae) as food. For rearing the mites on a smaller scale to obtain the later experimental population or synchronized eggs, adults were transferred from the stock population to rearing plates (Goleva and Zebitz 2013).

To avoid cannibalism by deutonymphs and adults on larvae and protonymphs, eggs were collected every second day and transferred to new rearing units, to obtain rearing populations of the same age class and to avoid overcrowding. These rearing trays were kept in an incubator at  $25 \pm 1$  °C and  $75 \pm 5$  % RH with a 16:8 h, L:D regimen.

### Pollen selection

Seven different pollen species were tested, which either had not been tested before on *N. cucumeris*, or for which only incomplete life tables had been produced. Castor bean (*Ricinus communis* L.) (Euphorbiaceae), tulip (*Tulipa* sp.) (Liliaceae), apple (*Malus domestica* Borkh.) (Rosaceae), Christmas cactus (*Schlumbergera* sp.) (Cactaceae), horse-chestnut (*Aesculus hippocastaneum* L.) (Sapindaceae), maize (*Zea mays* L.) (Poaceae), and birch (*Betula pendula* Roth) (Betulaceae) were selected for the experiments. Except apple pollen (provided by H. Schneller, LTZ, Dept. of Plant Health and Product Quality, Germany), which was ca. seven - years old and had always been kept in a freezer at −20 °C, the pollen used were not older than one year, collected from pesticide-free plants in sunny, dry weather using a fine dry brush for tulip, Christmas cactus and horse-chestnut, or by shedding the flowers for castor bean, maize, and birch. All pollen was stored in a freezer at −20 °C (Pernal and Currie 2000).

### Experimental design and procedure

All experiments were conducted in an experimental arena following Overmeer (1985) with slight modifications according to Goleva and Zebitz (2013). The sponges used by Overmeer as spacers were replaced by Petri dishes placed between the plastic dish bottom and a black PVC plate (10 × 15 × 0.5 cm). The PVC plate was divided into six sub-arenas of 2 × 3.5 cm separated by moistened filter paper to supply the mites with water (Munktel and Filtrak, No. 3, Bärenstein, Germany) and a strip of insect glue (Heller Raupenleim–Brutonia, Schacht GmbH and CoKG, Germany) mixed with citronella and castor oil, serving as repellent and thus considerably reducing loss of mites without exerting negative side-effects to the mites (Al-Shammery 2011). These experimental units were kept in a separate incubator at the same regimen as given for the stock rearing.

Newly laid eggs ( $\leq 12$  h) were collected from the rearing plates and five eggs were transferred onto each small observation arena on the experimental plate, with 25–30 replicates (five eggs per replicate) for each pollen type, and 20 replicates for the control without any food except water. Each test set was examined twice daily, once in the morning and once in the late afternoon, and developmental stages and numbers were recorded. Exuviae of the moulted stages were removed at each observation time. Although the larvae develop to protonymphs without feeding, powdered pollen was offered ad libitum at larval hatch (Schausberger and Croft 2000) and replaced every second or third day removing the old pollen by a fine brush. Freshly moulted adults obtained from the experiments for assessment of development and juvenile mortality were transferred as pairs of males and females to new plates with a larger surface area ( $15 \times 10$  cm) to assess adult survival and number of eggs deposited in daily intervals.

### Statistical analysis

All data obtained were subjected to statistical analysis using JMP 7.0.2 software (SAS Institute Inc., Cary, NC, USA). One-way analysis of variance (ANOVA) was conducted to evaluate the effects of diet on the duration of the immature stages, total mortality, preoviposition and reproductive period, total fecundity, adult longevity and life table parameters of *N. cucumeris*. When a Shapiro–Wilk test indicated normal distribution, the parameter was analyzed using an one-way analysis of variance (ANOVA) otherwise a non-parametric Kruskal–Wallis ANOVA was used and means were separated using a Mann–Whitney  $U$  test. Sex ratios were tested for differences against a 1:1 ratio using a  $\chi^2$  test. Values of life table parameters net reproductive rate ( $R_0$ ), generation time (GT), intrinsic rate of natural increase ( $r_m$ ), population doubling time (DT), and finite rate of increase ( $\lambda$ ) were estimated using the Jackknife technique (Maia et al. 2000). The respective statistical procedures and data are provided in the legends of the figures and tables.

### Results

All pollen used was accepted as food by juvenile and adult mites and no repellent effect of the pollen, as

shown by escape rates, could be found. Food deprivation resulted in 5 % larval and 95 % protonymphal mortality (Table 1). Development and mortality rates of immature stages of *N. cucumeris* varied as a function of pollen species. Total immature mortality of *N. cucumeris* ranged from 4.7 to 94.0 %, for horse-chestnut and castor bean, respectively. Low juvenile mortality rates occurred when feeding on apple, tulip, Christmas cactus, and birch pollen. Only maize pollen resulted in a higher mortality rate. Mortality at individual development stages showed that the protonymph was the most vulnerable stage, suffering the highest mortality irrespective of the pollen fed. Only when feeding on castor bean pollen, an almost similar mortality rate to protonymphs was found in deutonymphs. The sex ratio of the survivors was not affected by the pollen fed (Table 1).

Mean developmental time of females was significantly longer than that of males, except when the mites were offered horse-chestnut or tulip pollen. On all diets, development to adults did not exceed eight days on average. The fastest development was achieved on tulip or horse-chestnut pollen, whereas offering maize pollen resulted in the longest developmental period (Table 1).

The preoviposition, reproductive, and post-reproductive period of females, and longevity of females and males of *N. cucumeris* varied significantly when fed with different pollen (Table 2). Mean reproductive period of females was superior on maize pollen, followed by females given apple and birch pollen, and was the shortest when fed with horse-chestnut, Christmas cactus and tulip pollen. In contrast with the reproductive period, the post-reproductive period of females fed with tulip pollen was significantly longer compared with other pollen tested, whereas it was the shortest when the females were fed with Christmas cactus pollen. Adult longevity did not differ between sex, except when supplied with Christmas cactus or horse-chestnut pollen. Adults fed with birch, tulip, maize and apple pollen lived significantly longer than when fed with horse-chestnut and Christmas cactus pollen. Within these two groups, longevity did not differ significantly.

Feeding on tulip and horse-chestnut pollen resulted in the highest total number of eggs per female and oviposition rate, whereas mites fed with maize or birch pollen had the lowest mean total number of eggs produced (Table 2).

**Table 1** Total immature mortality, percent contribution of the larval, protonymphal (PN), and deutonymphal (DN) mortality to total mortality, duration of immature development, and sex ratio (percent females) (mean  $\pm$  SE) of *N. cucumeris* when starved or fed with pollen from seven plant species

Pollen species	N	Total mortality (%)	% Contribution of stage mortality to total mortality			Duration of development (h)		t, P, df	(%) Females	$\chi^2$ , P
			Larvae	PN	DN	Females	Males			
Apple	25	11.0 $\pm$ 2.47 cd	8.33 $\pm$ 8.33	79.17 $\pm$ 11.45	12.50 $\pm$ 8.97	172.1 $\pm$ 2.8 c <i>n</i> = 56	159.5 $\pm$ 2.9 b <i>n</i> = 44	3.0814 0.0027 df = 98	56.67 $\pm$ 6.04 a	1.4400 0.2301
Birch	24	24.23 $\pm$ 5.19 c	31.25 $\pm$ 11.06	18.75 $\pm$ 8.98	37.50 $\pm$ 12.50	184.8 $\pm$ 2.5 b <i>n</i> = 41	171.1 $\pm$ 2.5 a <i>n</i> = 36	3.8332 0.0003 df = 75	51.88 $\pm$ 6.30 a	0.1200 0.7290
Castor bean	30	100 a	7.78 $\pm$ 2.40	42.28 $\pm$ 4.41	49.11 $\pm$ 5.54	–	–	–	–	–
Christmas cactus	25	20.0 $\pm$ 3.95 c	20.83 $\pm$ 10.03	64.58 $\pm$ 11.06	14.58 $\pm$ 7.28	169.5 $\pm$ 2.7 c <i>n</i> = 41	154.3 $\pm$ 2.5 bc <i>n</i> = 47	4.1197 < 0.0001 df = 86	44.38 $\pm$ 6.02 a	0.9529 0.3290
Horse chestnut	25	4.73 $\pm$ 1.99 d	20.00 $\pm$ 20.00	60.00 $\pm$ 24.49	20.00 $\pm$ 20.00	151.2 $\pm$ 1.8 d <i>n</i> = 60	147.3 $\pm$ 1.8 cd <i>n</i> = 43	1.5147 0.1330 df = 101	58.13 $\pm$ 3.37 a	2.8085 0.0939
Maize	24	43.68 $\pm$ 5.37 b	24.64 $\pm$ 7.47	58.69 $\pm$ 8.17	16.67 $\pm$ 5.93	197.1 $\pm$ 4.9 a <i>n</i> = 32	172.6 $\pm$ 3.7 a <i>n</i> = 27	3.8705 0.0003 df = 57	51.89 $\pm$ 6.37 a	0.1579 0.6911
Tulip	25	12.60 $\pm$ 2.96 cd	0.00 $\pm$ 0.00	91.67 $\pm$ 8.33	8.33 $\pm$ 8.33	142.5 $\pm$ 1.9 d <i>n</i> = 45	141.2 $\pm$ 2.4 d <i>n</i> = 45	0.4054 0.6862 df = 88	48.93 $\pm$ 3.17 a	0.0112 0.9156
No food (hunger)	20	100 a	5.00 $\pm$ 5.00	95.00 $\pm$ 5.00	0.00 $\pm$ 0.00	–	–	–	–	–

One-way ANOVA; for total mortality:  $\chi^2 = 134.9139$ ,  $P < 0.0001$ , df = 7, followed by Mann–Whitney *U* test; for preimaginal development of females:  $F = 52.00$ ,  $P < 0.0001$ , df = 5, 269; for preimaginal development of males:  $F = 21.3584$ ,  $P < 0.0001$ , df = 5, 236; followed by Tukey–Kramer HSD test at  $P \leq 0.05$  level; for % females:  $\chi^2 = 5.1965$ ,  $P < 0.3924$ , df = 5; means in a column followed by the same letter are not significantly different

Number of repeats as groups of five individuals

t, *P* and df values of the bilateral *t* test for immature development of females versus males

$\chi^2$  and *P* values of Pearson  $\chi^2$  test for difference of overall sex ratio found from 1:1 sex ratio, df = 1

**Table 2** Average preoviposition, reproduction, and post-reproduction period, fecundity, and longevity (mean  $\pm$  SE) of *N. cucumeris* fed with different pollen

Pollen	Pre-oviposition period (days)	Reproductive period (days)	Post-reproductive period (days)	Oviposition rate (egg/♀/day)	Total fecundity (eggs/♀)	Longevity females (days)	Longevity males (days)	<i>P</i>
Apple	2.6 $\pm$ 0.1 ab <i>n</i> = 37	49.9 $\pm$ 1.7 b <i>n</i> = 18	41.5 $\pm$ 2.1 b <i>n</i> = 18	1.53 $\pm$ 0.08 c	76.72 $\pm$ 4.37 bc	93.9 $\pm$ 2.1 a <i>n</i> = 18	89.4 $\pm$ 2.5 a <i>n</i> = 23	0.1829 df = 39
Birch	3.0 $\pm$ 0.1 a <i>n</i> = 33	52.2 $\pm$ 1.8 b <i>n</i> = 21	43.6 $\pm$ 2.0 b <i>n</i> = 21	1.31 $\pm$ 0.04 d	67.33 $\pm$ 2.09 c	98.9 $\pm$ 2.6 a <i>n</i> = 21	95.6 $\pm$ 2.5 a <i>n</i> = 20	0.3822 df = 39
Christmas cactus	2.6 $\pm$ 0.1 ab <i>n</i> = 28	42.1 $\pm$ 1.2 c <i>n</i> = 20	28.7 $\pm$ 0.9 c <i>n</i> = 20	1.92 $\pm$ 0.06 b	80.15 $\pm$ 2.89 ab	73.3 $\pm$ 1.2 b <i>n</i> = 20	65.6 $\pm$ 2.1 b <i>n</i> = 19	0.0022 df <sub>corr.</sub> = 29
Horse-chestnut	2.5 $\pm$ 0.1 b <i>n</i> = 43	41.6 $\pm$ 1.1 c <i>n</i> = 22	37.0 $\pm$ 0.9 b <i>n</i> = 22	2.15 $\pm$ 0.04 a	89.23 $\pm$ 2.56 a	81.1 $\pm$ 1.1 b <i>n</i> = 22	73.9 $\pm$ 1.5 b <i>n</i> = 18	0.0003 df = 38
Maize	2.7 $\pm$ 0.1 ab <i>n</i> = 22	58.7 $\pm$ 1.3 a <i>n</i> = 17	36.5 $\pm$ 2.7 b <i>n</i> = 17	1.19 $\pm$ 0.05 d	69.59 $\pm$ 2.58 bc	97.8 $\pm$ 2.6 a <i>n</i> = 17	94.5 $\pm$ 2.5 a <i>n</i> = 17	0.3579 df = 32
Tulip	2.1 $\pm$ 0.1 c <i>n</i> = 35	43.7 $\pm$ 1.4 c <i>n</i> = 23	52.8 $\pm$ 1.9 a <i>n</i> = 23	2.06 $\pm$ 0.04 ab	89.48 $\pm$ 2.69 a	98.4 $\pm$ 2.7 a <i>n</i> = 23	94.4 $\pm$ 2.9 a <i>n</i> = 21	0.3205 df = 42
F	8.008	21.117	21.739	61.2746	11.054	25.517	26.776	
df	5, 192	5, 115	5, 115	5, 115	5, 115	5, 115	5, 112	
<i>P</i>	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	

One-way ANOVA; respective F, df, and *P*-values are given in the columns; each ANOVA was followed by Tukey–Kramer HSD test at  $P \leq 0.05$  level; means in a column followed by the same letter are not significantly different

Longevity of females versus males (*t* test); a correction of df was made if inequality of variances was found (Bartlett's test)

**Table 3** Mean ( $\pm$ SE) cohort intrinsic rate of natural increase ( $r_m$ ), finite rate of increase ( $\lambda$ ), net reproductive rate ( $R_0$ ), generation time (GT), and population doubling time (DT) of *N. cucumeris* fed with different pollen

Pollen	N	n	$r_m$ (day <sup>-1</sup> )	$\lambda$	$R_0$	GT (days)	DT (days)
Apple	18	5	0.1486 $\pm$ 0.0046 c	1.1603 $\pm$ 0.0053 c	38.7920 $\pm$ 2.8680 b	24.64 $\pm$ 0.90 bc	4.68 $\pm$ 0.15 c
Birch	21	5	0.1269 $\pm$ 0.0054 d	1.1354 $\pm$ 0.0061 d	26.8807 $\pm$ 0.9918 c	26.09 $\pm$ 1.10 ab	5.50 $\pm$ 0.24 b
Christmas cactus	20	5	0.1555 $\pm$ 0.0018 bc	1.1683 $\pm$ 0.0046 bc	28.8734 $\pm$ 0.9271 bc	21.63 $\pm$ 0.42 c	4.46 $\pm$ 0.05 cd
Horse-chestnut	22	5	0.1806 $\pm$ 0.0048 a	1.1980 $\pm$ 0.0057 a	49.8330 $\pm$ 3.2068 a	21.69 $\pm$ 0.91 c	3.85 $\pm$ 1.00 d
Maize	17	4	0.1013 $\pm$ 0.0048 e	1.1067 $\pm$ 0.0053 e	20.9604 $\pm$ 3.2617 c	29.57 $\pm$ 0.64 a	6.89 $\pm$ 0.34 a
Tulip	23	5	0.1672 $\pm$ 0.0036 ab	1.1820 $\pm$ 0.0043 ab	38.9958 $\pm$ 2.3684 b	21.92 $\pm$ 0.69 c	4.15 $\pm$ 0.09 cd
F			41.2906	40.8973	18.1364	13.806	37.3447
df			5, 23	5, 23	5, 23	5, 23	5, 23
P			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

One-way ANOVA; respective F, df, and *P* values are given in the columns; each ANOVA was followed by Tukey–Kramer HSD-test at *P*  $\leq$  0.05 level; means in a column followed by the same letter are not significantly different

N denotes total number of females assessed

*n* denotes number of female groups considered for calculation

According to all cohort life table parameters of *N. cucumeris*, feeding on pollen of horse-chestnut, tulip and apple resulted in the best performance while feeding on pollen of birch, Christmas cactus and maize resulted in a poor performance (Table 3).

## Discussion

Juvenile stages and, in part, adults could feed on any pollen offered in our experiments. Thus, possible repellent odours in the pollenkitt, evolved as a defence against pollen-feeding animals (Dobson and Bergström 2000), were either absent or had no repellent effect on *N. cucumeris*. However, development and juvenile survival varied considerably depending upon food consumed. In the control set deprived of food, larvae of *N. cucumeris* were not able to develop beyond the protonymphal stage as reported also for other phytoseiid species (van Rijn and Tanigoshi 1999a; Schausberger and Croft 1999; Chittenden and Saito 2001). Although larvae may facultatively feed or starve (Schausberger and Croft 1999), mortality during the larval stage at a higher percentage than found under deprivation of food should be due to feeding on the particular pollen. Besides larval mortality, pollen-induced mortality should also be more pronounced in the protonymphs or later developmental stages, when the mites have to feed upon the pollen to continue development. Larval mortality proved food uptake by larvae and also toxic effects

of pollen. In later developmental stages, onset of mortality was mostly found in the protonymphal stage, except when feeding on castor bean pollen, where mortality in the deutonymphal stage was the highest. This may be due to toxic compounds produced as a chemical defence against herbivores or plant pathogens in whole plants which may also be selectively secreted into their pollen (Detzel and Wink 1993). These allelochemicals, such as alkaloids, terpenes, or phenolics have been reported to cause mortality when consumed by honey bees (Stanley and Linskens 1974; Reinhard et al. 2009; Junior et al. 2011). The present study shows that feeding on pollen of different plants can cause mortality between 4.7 and 100 %. Particularly in regard to castor bean pollen, we assume the total juvenile mortality to be caused by toxins, since similar effects on honey bees have been reported by Junior et al. (2011). To test the detrimental effect of castor bean pollen on *N. cucumeris*, a check with freshly moulted adults, initially fed with tulip pollen, was conducted. Switching to pollen of castor bean as adult food resulted in a decreased mean longevity of 8.7 days and no oviposition, confirming the negative effects on immature stages. However, these results are absolutely inconsistent with results reported by van Rijn and Tanigoshi (1999a), who found castor bean pollen a fairly suitable pollen diet for *N. cucumeris*.

The suitability of castor bean pollen as a food source differs with phytoseiid species. A poor food quality of castor bean pollen was reported for Brazilian and African populations of *Neoseiulus baraki*

Athias-Henriot (Acari: Phytoseiidae), resulting in the longest development compared with maize pollen or mites as food (Negloh et al. 2008). *Amblyseius lindquisti* Schuster (Acari: Phytoseiidae) also failed to oviposit when fed with pollen of *R. communis* or *Helianthus annuus* L. (Compositae), whereas castor bean pollen was favourable for *Amblyseius zaheri* Yousef and El-Borolossy and *Euseius yousefi* Zaher and El-Borolossy (Acari: Phytoseiidae) (Momen 2004). On the other hand, *Typhlodromus balanites* El-Badry, *T. sennarensis* El-Badry, *Amblyseius cabonus* (Schicha), and *Neoseiulus idaeus* Denmark and Muma (Acari: Phytoseiidae) failed to reach the adult stage when feeding on pollen of *R. communis* (Momen 2004; Gnanvossou et al. 2005). Varying concentrations of toxic compounds or nutrients in castor bean plants due to varietal differences, native habitat, or climate may result in differences in mite performance.

Maize, tulip, and horse-chestnut are all known to produce alkaloids or saponins (Roth et al. 2008). Thus, the differences in juvenile mortality of *N. cucumeris* when fed with pollen of these plants are difficult to explain without knowing the respective chemistry. Possibly, the secondary compounds in pollen were present only in concentrations too low to be harmful (da Silva et al. 2010) or they were detoxified after uptake. Alternatively, the differential performance of the mites may be related to differences in nutrient composition of the pollen.

Not considering mortality of juveniles, males developed slightly faster than females fed with the same pollen, except when supplied with pollen of horse-chestnut and tulip. Feeding on these two pollens resulted in the fastest development, perhaps, equalizing the speed of development between sexes. Goleva and Zebitz (2013) also report a faster development of *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) males when fed with various pollens. Considering developmental time of *N. cucumeris*, pollen seems to be a better or equivalent food source compared with acarid, tetranychid, or thrips prey species (Castagnoli and Simoni 1990; Zhang et al. 2000; Sarwar et al. 2009).

In the resulting adults, we found no statistically significant differences to a 1:1 sex ratio. This controverts a reported female-biased sex ratio after feeding juvenile stages of *Typhlodromus athenas* Swirski and Ragusa (Acari: Phytoseiidae) or *E. scutalis* with apple or castor bean pollen (Momen and Abdel-Khalek 2008; Kolokytha et al. 2011).

Mean total longevity of males and females of *N. cucumeris* did not significantly differ except when offered pollen of horse-chestnut and Christmas cactus. Although these two pollens proved to be a high quality food source during juvenile development, the poor longevity of resulting adults is difficult to explain. It seems highly speculative to postulate differing nutritional demands between immature stages and adults in this mite species when there is no information on similar phenomena in other phytoseiid species available. However, differences in adult longevity have been reported for *N. cucumeris* fed with *T. urticae*, *T. putrescentiae* and *F. occidentalis* (Sarwar et al. 2009), or supplied with different pollen (Matsuo et al. 2003). Since feeding on these three prey species resulted in an obvious shorter adult life-span compared to our results when pollen were offered, these prey species seem to be of poor nutritional quality.

The durations of the reproductive period, oviposition rate, total fecundity, and demographic parameters are illustrative and reliable parameters to describe food quality of pollen. Significant differences in these parameters have been attributed to food quality for various phytoseiid species. Females fed with tulip, horse-chestnut and Christmas cactus pollen had a short reproductive period but obviously compensated this handicap by a higher peak ovipositional rate, resulting in the shortest doubling times (DT) compared to the other pollen tested. A similar observation has been made for *N. cucumeris* and *Iphiseius degenerans* (Berlese) (Acari: Phytoseiidae) supplied with pollen of bean, rosaceous species and cattail (van Rijn and Tanigoshi 1999a).

van Rijn and Tanigoshi (1999a) reported that *N. cucumeris* produces virtually no eggs with pollen from sunflower, willow, and species of the family Betulaceae. As in our study pollen of birch (Betulaceae) was accepted as food by adults and also allowed the females to reproduce, we assume a high variability in food quality of pollen not only among species of a plant family or genus but also within a species. Possibly this variability depends on the prevailing environmental conditions under which the pollen-delivering plant was grown (Bogdanov 2006).

Pollen from different plant species differ in their nutritional values due to a differing composition of potential nutrients or deleterious substances (Baker and Baker 1979). The accessibility of nutritional compounds from pollen, or a low efficiency of food



conversion into mite body mass, energy reserves like lipids, or into eggs may be further reasons for varying life-table and demographic parameters of a phytoseiid mite species fed with pollen (van Rijn and Tanigoshi 1999a).

Suitability of pollen as a food source for phytoseiids depends on mite species and pollen species. Successful pollen-feeding depends on matching mouthpart morphology with pollen morphology, and digestive metabolism in the mites, which requires further investigation. In the present study, *N. cucumeris* was able to survive and reproduce when reared on all pollen tested except on castor bean pollen. Birch, tulip, horse-chestnut, apple, and maize pollen may be used as a suitable alternative food in periods when prey in the field are scarce or absent. Castor beans, often used as banker plants, but according to our study producing unsuitable pollen for *N. cucumeris*, can be substituted by flowering maize plants in the greenhouse.

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## Author Biographies

**Nar B. Ranabhat** This research was part of the MSc project of Nar B. Ranabhat devoted to the analysis of the nutritional value of different food sources for *Neoseiulus cucumeris*. Ranabhat's particular interest is the analysis of intra- and inter-specific variation in predator and parasitoid nutrition.

**Irina Goleva** is a PhD student studying nutritional ecology of predacious mites. Goleva's particular interest is the analysis of intra- and inter-specific variation in predator and parasitoid nutrition.

**Claus P. W. Zebitz** is involved in control of insect pests with emphasis on biological control of greenhouse and fruit pests. Our particular interest is the analysis of intra- and inter-specific variation in predator and parasitoid nutrition.