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Comparative suitability of different nutrients for feeding the predaceous mite, *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae), in the laboratory

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Abstract

Background: The attractiveness, the stickiness and the edibility span of 29 nutrients were assessed to reveal the comparative suitability of each nutrient for feeding the predaceous mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae).

Results: Baker's yeast generally was the most attractive-food source. The mixture of skim milk, honey, yolk, baker's yeast and amino acid solution 10% at a volume ratio of 100:1:1:20:1, respectively, was the most attractive mixture. No mite individual fed on honey, the three nutrients containing amino acid solution at high concentrations, chicken blood, smashed cow liver, living drosophila stages, or cotton pollen. Over two minutes, no mite individual stuck to honey, baker's yeast, the three nutrients containing amino acid solution at high concentrations, chicken blood, smashed cow liver, or drosophila types. On the contrary, all the mite individuals exposed to cotton pollen stuck to it on touching. Grape juice was the most adhesive of the rest of the nutrients. The mixture of skim milk, honey, yolk, baker's yeast, and amino acid solution 10% at the volume ratio of 100: 20: 1: 1: 1, respectively, was the most adhesive mixture. The mixture containing the same components at a volume ratio of 100: 1: 20: 1: 1, respectively, was the least adhesive mixture. By examining each of the 19 edible nutrients individually, water was found to be edible until evaporation. Amongst the rest of the edible nutrients, maize pollen had the longest edibility span; it continued valid for feeding for about four days. On the contrary, the yolk continued to be edible for just seven minutes. As regards the edible mixtures, the mixture containing skim milk, honey, yolk, baker's yeast and amino acid solution 10% at a volume ratio of 100:20:1:1:1, respectively, had the longest edibility span. On the contrary, the mixture containing the same components at a volume ratio of 100:1:20:1:1, respectively, had the shortest edibility span. As regards the components of the edible mixtures, honey percentage showed a negative correlation with the number of the attracted mites, whereas it showed positive correlations with each of the number of the stuck mites and edibility span. Compared with honey, yolk and baker's yeast showed opposite trends.

Conclusions: Each of the examined edibles had its good points as a food for *A. swirskii*.

Keywords: *Amblyseius swirskii*, Nutrients, Evaluation, Attractiveness, Stickiness, Edibility

Background

Many predatory mite species feed on diverse types of diets, making them excellent candidates for conservation biological control programs (Carrillo et al. 2015).

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The phytoseiid mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) originated from the Mediterranean area and is considered type III generalist predatory mite, where it can feed on different insect and mite preys, pollen and plant exudates (McMurtry and Croft 1997). It is the primary agent used in the biological control of whiteflies and thrips. It attacks thrips larvae as well as whitefly eggs and crawlers (Tellez et al. 2017). It also feeds on spider mites and various other types of small insects (Buitenhuis et al. 2010). Mass rearing techniques of *A. swirskii* are mainly based on the use of stored product mites as a dietary food source (Fidgett et al. 2010).

A. swirskii can develop and reproduce on a variety of food sources like pollen (Nguyen et al. 2013). Park et al. (2011) found that the diet of cattail (*Typha latifolia* L.) pollen at 25 ± 0.5 °C and $70 \pm 10\%$ RH was a favorable diet for development, oviposition, and survival of *A. swirskii*.

It is possible to feed different predaceous mites on artificial diets (Ogawa and Osakabe 2008). Food supplements, consisting of alternative or artificial foods, can increase the abundance and impact of arthropod natural enemies in crops, where target prey or plant foods, like pollen and nectar, are absent or only present at low densities (Wade et al. 2008). The addition of alternative food to better suppress a pest species through apparent competition has been used in biological control, often with the desired results (Liu et al. 2006). However, the alternative food often consists of non-prey, such as pollen (van Rijn et al. 2002), or the alternative prey is not a pest, but serves primarily as an alternative food to build up the predator populations (Liu et al. 2006). Nguyen et al. (2015) studied the life table parameters of phytoseiid mites when presented with a liquid artificial diet (consisting of honey, sucrose, tryptone, yeast extract and egg yolk) enriched with extract of dry de-capsulated cysts of the brine shrimp, as compared with pollen. Their findings indicated the potential of this artificial diet for use as a supplemental food source to maintain populations in the crop after release or for use in mass production. Kennett and Hamai (1980) reared different predacious mites on artificial diets consisting of bee honey, sugar, yeast flakes, yeast hydrolysate, enzymatic casein hydrolysate and fresh egg yolk. Ochieng et al. (1987) also reported that *A. teke* Pritchard and Baker could complete more than 25 generations when reared on a liquid diet composed of bee honey, milk powder, egg yolk and Wesson's salt. Abou-Awad et al. (1992) noted that the predacious mites *A. gossipi* El-Badry and *A. swirskii* developed successfully and reproduced on artificial diets composed of yeast, milk, cysteine, proline, arginine, sucrose, glucose, streptomycin sulfate and sorbic acid.

Accordingly, the purpose of the present study was to determine the attractive, non-adhesive, and long-term nutrients for selecting the most suitable nutrient for each of purposes: mass rearing, collecting the mite individuals for commercial purpose, avoiding cannibalism in the commercial predacious-mite bottles, or recompensing the scarcity of the prey in the field, especially after pesticide applications.

Methods

Source of the mite

Cotton leaves were the source of the mite *A. swirskii*. A thin brush with a little sodden hair was used to transfer the mites gently from the leaves; saturating the brush hair with water makes it easier to attach the mites to the brush hair for successful pickup. Obtained mite individuals were kept without food for 24 h before starting the experiments.

Preparing the food stuffs

In previous studies, the effect of certain nutrients on the life aspects of predatory mites were assessed regardless of the nutrient properties. For example, Etienne et al. (2021) mentioned that food supplementation promotes predatory mites and enhances pest control. However, they didn't estimate the stickiness of almond pollen they used. The commonly manipulated nutrients were considered in the present study. Hereupon, the tested nutrients were evaluated into two main categories:

Single nutrients

Skim milk 0.5% fat, honey, yolk, baker's yeast *Saccharomyces cerevisiae*, amino acid solution 10%, whole milk, albumin, grape juice, sugar cane juice, water, chicken blood, smashed cow liver, living and smashed drosophila eggs, living and smashed drosophila larvae, living and smashed drosophila pupae, cotton pollen, maize pollen.

Drosophila melanogaster was reared in the laboratory on smashed grape in Petri dishes to get its immature stages. The tip of a piece of cloth was dipped in the smashed grape, whereas the other wet tip was kept out of the smashed grape for egg laying. Larvae were obtained from the smashed grape, whereas the pupae were obtained from the surrounding dry area. Obtained drosophila eggs, larvae, and pupae were rinsed with water and dried with paper tissue before being presented to the mites as food. Some individuals of each drosophila stage were smashed severally before presenting to the mites as food.

Mixtures of nutrients

Mixtures of skim milk 0.5% fat, honey, yolk, baker's yeast and amino acid solution 10% at the volume ratios of

(100:1:1:1:1), (100:10:1:1:1), (100:20:1:1:1), (100:1:10:1:1), (100:1:20:1:1), (100:1:1:10:1), (100:1:1:20:1), (100:1:1:1:10), (100:1:1:1:20).

Thereupon, each of the components honey, yolk and baker's yeast was used in the mixtures at the percentages of 0.96, 8.85 and 16.26%. However, the percentage of each component wasn't exaggerated in order not to have a mixture similar to the absolute component, which is examined individually as a single nutrient.

Estimating the parameters of the nutrient suitability

Estimating the attractiveness and the stickiness

Three replicates were established to examine the nutrients. For each replicate, 300 mite individuals were placed in a plastic dish (10 cm in diameter), which had a surrounding groove full of camphor oil to prevent the mites from escaping. A drop of about 0.02 ml. of each liquid nutriment was added in each replicate. As for living and smashed drosophila stages, 5 eggs, 3 larvae and one pupa were used for each replicate. As for pollen, a pile of about 50 individuals of each kind was used in each replicate. The space between each nutriment and the adjacent one was about 0.5 cm. After adding all nutrients, mite groups at the dish edges were aroused with a brush tip to move. All experiments were conducted at a temperature of 30 ± 5 °C, relative humidity of $70 \pm 5\%$ and a 16:8 h. (L: D) photoperiod.

Numbers of the congregating mites, in 2 min, to feed on a nutriment, and numbers of the stuck ones to it, within two minutes, were recorded. The percentage of the mites congregating to feed on a nutriment, in relation to the total feeding mites in the same replicate, was calculated. Moreover, the percentage of the mites stuck to an edible nutriment, in relation to the congregating mites feeding on it was also calculated.

As regards the most attractive mixture, i.e., the mixture of milk, honey, yolk, baker's yeast, amino acid solution 10% at the ratio of 100:1:1:20:1, respectively, it was preserved in the fridge for 1, 2, 3 and 4 days, and presented to the mites to estimate its maximum edibility span after preserving.

Estimating the edibility span

The maximum edibility span of each edible nutriment was estimated. Five starved mites, which were kept for 24 h. without food, were introduced to each edible nutriment at different successive times and replicated 3 times. Nutriment mite-neglecting, for 2 min, was an indicator that the nutriment was no longer edible. Solidification of the surface of some edible liquid nutrients, which makes it too solid to feed on and allows the mites to walk on it without sticking, was another indicator that the liquid nutrient is about to be inedible. As regards maize pollen

and grape juice, edibility checks were done every hour. As regards the rest of the edible nutrients, an edibility checkup was done every minute. The five mites were exchanged with others, which were kept for 24 h. without food, for each checkup.

Statistical analysis

The data were analyzed using ANOVA and the "F" Test, with 3 replicates for each treatment. The least significant differences (L.S.D.) at the $0.05 \leq$ level were determined according to the computer program COSTAT software and Duncan's Multiple Range. A correlation between the percentage of each of honey, yolk and baker's yeast, and each studied property of the edible mixtures was calculated.

Results

Estimating the nutriment attractiveness

It is worth mentioning that while counting the congregating feeding mites for each nutrient, some mites weren't congregating around any of the nutrients. The numbers of feeding mites in the 3 replicates were 183, 162 and 177 individuals. The checkup wasn't adjourned for more than 2 min to avoid the period of transformation of some nutriments to the inedible phase.

As shown in Table 1, Baker's yeast was the most attractive nutriment; the average percentage of the congregating individuals feeding on it in 2 min was 14.65%. The mixture of skim milk, honey, yolk, baker's yeast and amino acid solution 10% at a volume ratio of 100:1:1:20:1, respectively, was the most attractive mixture. The average percentage of the congregating individuals, in 2 min was 10.71%. That mixture continued to be edible for the mites after being kept in a tight container in the fridge up to 3 days. No mite individual fed on honey, the 3 nutrients containing amino acid solution at high concentrations, chicken blood, smashed cow liver, living drosophila stages, or cotton pollen. Drosophila larvae expel the mites on touching them.

Estimating the nutriment stickiness

As shown in Table 1, over 2 min, no mite individual stuck to honey, baker's yeast, the 3 nutrients containing amino acid solution at high concentrations, chicken blood, smashed cow liver, or drosophila types. On the contrary, all mite individuals exposed to cotton pollen stuck to it on touching. Grape juice was the most adhesive of the rest of the nutrients. The average percentage of the mite individuals that stuck to it within 2 min, in relation to the congregating ones to feed on it, was 40.48%.

On the other hand, the mixture of skim milk, honey, yolk, baker's yeast, amino acid solution 10% at the volume ratio of 100:20:1:1:1, respectively, was the most adhesive

Table 1 Records of the of the nutrient-suitability parameters

Nutriments	Percentage of the mites feeding on a nutriment in relation to the total feeding mites in the same replicate		Percentage of mites stuck to an edible nutrient in comparison to the number of mites congregating to feed on it		Edibility span of edibles, in minutes		
	Average	Rank	Average	Rank	Average	Rank	
Skim milk	3.25 ^{gh}	14	11.43 ^{de}	8	49.33 ^{cd}	11	
Honey	0 ^j	20	–	–	–	–	
Yolk	9.92 ^b	3	2.22 ^e	15	7 ^d	19	
Baker's yeast	14.65 ^a	1	0 ^e	16	30 ^{cd}	14	
Amino acid solution 10%	0 ^j	20	–	–	–	–	
Skim milk + Honey + Yolk + Baker's yeast + Amino acids 10%	100:1:1:1:1	3.80 ^{gh}	12	13.10 ^{cd}	7	74.33 ^{cd}	5
	100:10:1:1:1	4.94 ^{efg}	8	34.13 ^{ab}	4	89.00 ^{cd}	4
	100:20:1:1:1	2.89 ^{hi}	17	38.33 ^{ab}	3	120.00 ^c	3
	100:1:10:1:1	3.83 ^{gh}	11	6.67 ^{de}	12	59.67 ^{cd}	9
	100:1:20:1:1	6.31 ^{cde}	6	2.56 ^{de}	14	45.00 ^{cd}	12
	100:1:1:10:1	7.87 ^c	4	9.58 ^{de}	10	70.33 ^{cd}	7
	100:1:1:20:1	10.71 ^b	2	8.91 ^{de}	11	65.33 ^{cd}	8
	100:1:1:1:10	0 ^j	20	–	–	–	–
Whole milk	100:1:1:1:20	0 ^j	20	–	–	–	–
		3.61 ^{gh}	13	14.07 ^{cd}	6	41.67 ^{cd}	13
Albumin	1.18 ^{ij}	18	11.11 ^{de}	9	51.00 ^{cd}	10	
Grape juice	4.22 ^{fgh}	10	40.48 ^a	2	900.00 ^b	2	
Sugar cane juice	0.19 ^j	19	0 ^e	16	8.33 ^d	17	
Water	3.06 ^h	16	25.56 ^{bc}	5	70.67 ^{cd}	6	
Chicken blood	0 ^j	20	–	–	–	–	
Smashed cow lever	0 ^j	20	–	–	–	–	
Drosophila eggs	Living	0 ^j	20	–	–	–	–
	Smashed	5.56 ^{def}	7	0 ^e	16	9.33 ^d	16
Drosophila larvae	Living	0 ^j	20	–	–	–	–
	Smashed	4.23 ^{fgh}	9	0 ^e	16	11.33 ^d	15
Drosophila pupae	Living	0.00 ^j	20	–	–	–	–
	Smashed	6.71 ^{cd}	5	0 ^e	16	8 ^d	18
Cotton pollen	0 ^j	20	S	1	–	–	
Maize pollen	3.09 ^h	15	5.56 ^{de}	13	5580 ^a	1	
L.S.D., 0.05	0.0173		13.2806		93.4317		

Significance for the superscript letters is located in the bottom row of the table

Averages followed by the same letter in the same column are not significantly different at $P < 0.05$ level. Ranks are arranged in descending order

S: Sticking without feeding

mixture. The average percentage of the mite individuals stuck to it was 38.33% (Table 1). On the contrary, the mixture containing the same components at the volume ratio of 100:1:20:1:1, respectively, was the least adhesive mixture. The average percentage of the mite individuals stuck to it was 2.56%.

Estimating the nutriment edibility span

As shown in Table 1, by examining each of the 19 edible nutrients individually, water was edible almost until the entire evaporation. Amongst the rest edible nutrients, maize pollen had the longest edibility span since it continued valid for feeding for an average of about 4 days. On the contrary, the yolk continued to be edible for just 7 min. As regards the edible mixtures, each one became inedible in a particular span of time. The mixture containing skim milk, honey, yolk, baker's yeast and amino acid solution 10% at a volume ratio of 100:20:1:1:1,

Table 2 Correlation coefficient between the component percentages, in the edible mixtures, and the studied property records

Components	Studied properties		
	Attractiveness	Stickiness	Edibility span
Honey	-0.4267	0.9395	0.9755
Yolk	0.8622	-0.9941	-0.9998
Baker's yeast	0.9964	-0.9373	-0.9966

respectively, had the longest edibility span since it was edible for an average of 2 h. Contradictorily, the mixture which contains the same components at a volume ratio of 100:1:20:1:1, respectively, had the shortest edibility span, where it was edible for an average of 45 min.

Correlation studies

As far as the edible mixtures are concerned, since each of the components honey, yolk and baker's yeast was used at the percentages of 0.96, 8.85 and 16.26%, calculations were done to determine the correlation between the percentage of component and the record of each studied property as shown in Table 2.

The honey percentage showed a negative correlation with the number of the attracted mites, whereas it showed a positive correlation with each of the numbers of the stuck mites and edibility span. Compared with honey, yolk and baker's yeast showed opposite trends.

Discussion

The strong attractiveness of baker's yeast could be attributed to the appealing effect of the emitting CO₂. Jerry et al. (2017) found that yeast-produced CO₂ can effectively replace octenol baits in BG traps, and this will significantly reduce costs and allow sustainable mass application of the CO₂ baited traps in large scale surveillance programs. Although the studied mite didn't consume drosophila eggs, Nguyen et al. (2019) confirmed that eggs of the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), can be vulnerable to attack by the phyto-seiid mite *A. swirskii*. Drosophila larvae expel the mite on touching. That matches Messelink et al. (2011) who said that preliminary observations of *A. swirskii* in the presence of larvae of *Aphidoletes aphidimyza* showed that the examined predatory mite only incidentally attacked midge larvae. They seem unable to prey on them because the midge larvae defend themselves with rapid head movements towards the attacking predatory mites. On the contrary, when Arthurs et al. (2009) evaluated *A. swirskii* as a predator of chilli thrips, *Scirtothrips dorsalis*, insect larvae were the most preferable

prey compared with adults in no choice tests. They also found that thrips adults were rarely consumed in subsequent choice tests when larvae were also present. Moreover, when Dođramaci et al. (2011) examined the biological control of chilli thrips, *S. dorsalis*, with the predatory mite *A. swirskii* and the insidious flower bug, *Orius insidiosus* Say, laboratory tests showed that at equivalent rates, *O. insidiosus* was a more effective predator of adult thrips than *A. swirskii*, although the same trend was not observed with thrips larvae. Smashed drosophila stages were found to be an alternative food for *A. swirskii*. That matches Nguyen et al. (2015) who stated that artificial diets enriched with pupal hemolymph of the Chinese oak silkworm (*Antheraea pernyi* (Guérin-Méneville)) supported development and reproduction of the generalist predatory mite *A. swirskii*. Hence, smashed drosophila stages could be used as an alternative food. Likewise, Muñoz-Cárdenas et al. (2017) investigated the effect of supplying plant-inhabiting predatory mites with alternative preys such as astigmatic mites, in the litter on pest control. The predator *A. swirskii* controlled thrips better in the presence of the astigmatic mites than in their absence.

It was also notable that *A. swirskii* sucked water. In a previous experiment, Choh et al. (2014) used wet tissue, which served both as a barrier and as a water source.

The mites didn't feed on cotton pollen although previous studies proved that it is possible to feed different predacious mites on pollen (Warburg et al. 2019). It is obvious that the disability to feed on cotton pollen refers to its strong stickiness, which disturbs the mites.

When a mite sticks to a nutrient, it dies. The present study determined the most adhesive nutrients to avoid or reduce their use when feeding mites.

Variation in stickiness may refer to the physical properties such as the power of surface tension. Little stickiness may refer to surface solidification, which makes the surface difficult to penetrate by the mite. Owing to stickiness, cotton pollen was found to be unsuitable food for that mite although pollen is known to be a good food source for certain predatory mites (Buitenhuis et al. 2010). Likewise, Paspati et al. (2021) found that the trichomes and their secondary metabolites abundant on the stems of tomato plants negatively impacted *A. swirskii* mite dispersal on the plant. Owing to the adhesive property of these kinds of pollen, *A. swirskii* may not be an efficient biocontrol agent on cotton plants in the flowering season.

Surface solidification, which makes the nutrient too solid to feed on, was the reason most of the examined nutrients turned inedible. Thereupon, some liquid nutrients became inedible owing to fast surface

solidification, which refers to the chemical and physical properties.

The mites didn't feed on the absolute honey; that explains why the honey percentage in the edible mixtures showed a negative correlation with the number of the attracted mites. On the other hand, it showed a positive correlation with the number of the stuck mites, which may refer to strong viscosity. Moreover, it showed a positive correlation with edibility span, which may refer to a low evaporation rate.

The absolute yolk was the third most appealing nutrient, which explains why the yolk percentage in the edible mixtures showed a positive correlation with the number of attracted mites. On the other hand, it showed a negative correlation with the number of the stuck mites; that may refer to the quick surface solidification, which forbids the mites from sticking. Absolute yolk had the shortest edibility span; that explains why yolk percentage, in the edible mixtures, showed a negative correlation with edibility span.

The absolute amount of baker's yeast was the most attractive nutriment; that explains why the baker's yeast percentage, in the edible mixtures, showed a positive correlation with the number of the attracted mites. No mite stuck to the absolute baker's yeast; that explains why baker's yeast percentage, in the edible mixtures, showed a negative correlation with the number of the stuck mites. The absolute baker's yeast had a short edibility span, which explains why baker's yeast percentage, in the edible mixtures, showed a negative correlation with the edibility span.

Conclusions

Considering certain properties of some nutrients, baker's yeast was the most suitable for feeding *A. swirskii* mites in the laboratory; it was the most attractive one with a moderate edibility span. Besides, no mite stuck to it. On the contrary, cotton pollen was least suitable; all the mite individuals stuck to it on touching, which is considered to be harmful. No mite individual fed on honey, the 3 nutrients containing amino acid solution at high concentrations, chicken blood, smashed cow liver, living drosophila stages. Amongst the edibles, the yolk had the shortest edibility span although it was the third most appealing nutrient. On the contrary, maize pollen had the longest edibility span, although it was comparatively less attractive. Thereupon, each of the examined edibles had its good points as a food for *A. swirskii* mites.

Abbreviations

A. swirskii: *Amblyseius swirskii*; S: Sticking without feeding.

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Authors' contributions

The author read and approved the final manuscript.

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Availability of data and materials

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Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The author declares that he has no competing interests.

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