Romanian Journal for PlantProtection, Vol. XVI, 2023
ISSN 2248 – 129X; ISSN-L 2248 – 129X

THE CURRENT STATE OF THE ART ON THE DIETS USED FOR REARING OF APHIDOPHAGOUS PREDATORS OF THE COCCINELLIDAE FAMILY- A MINI-REVIEW

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http://www.doi.org/10.54574/RJPP.16.16

Abstract: Biological control of plant pests using natural enemies is nowadays considered a viable alternative method to chemical control. There are numerous naturally occurring bio-control agents that can be selected for rearing and used to control agricultural pests. The study brings up to date the knowledge regarding the species of aphidophagous species in the Coccinellidae family already known as Biological Control Agents reared/commercially available or used in various pest control program worldwide. To achieve a more comprehensive understanding of the benefits and drawbacks of existing rearing methods, we reviewed a variety of research papers and specialized literature that investigated various approaches, including reliance on natural hosts, artificial diets, factitious hosts or combination of them. Also, we pointed out the existing research challenges, and outlines directions for research in Coccinellidae rearing programs.

Key words: *Biological control agents*, *aphidophagous Coccinellidae, predators, mass-rearing, diets*

INTRODUCTION

An important and globally significant component of integrated pest management programs and organic agriculture is the substitution of non-chemical pesticides with alternative methods (Orr, 2009; Baker et al., 2019). One essential tactic in this context is represented by biological control, which uses beneficial organisms to reduce populations of pests and decrease pest damage to agricultural crops. The cornerstone of the complex pest management approach known as biological control is the use of natural enemies, also known as biological control agents (BCAs), to lower pest populations (Baker et al., 2019; Trdan, 2020).

Biological control of pest dated back to 3rd century in China, when the first attempt to use natural enemies for the control of citrus insect pest *Tesseratoma papillosa* (Lepidoptera) using nests of the ant *Oecophylla smaragdina* (http://ucanr.edu/sites/W2185/) was recorded. In 1734, de Reaumur suggested to collect the eggs of an "aphidivorous fly" (that in fact it was a lacewing species) and use them in greenhouses to control aphids. The modern biological control also initiated with the highly successful introduction of the coccinellid beetle, *Rodolia cardinalis* (Mulsant) from Australia to California to control the cottony scale of citrus, *Icerya purchasi* Maskell during 1888 (Van Driesche et al., 2008).

Conventional biological control, augmentative control, and conservation biological control are the three primary categories of biological control. In conventional biological control, one or more natural enemy species from the pest's native range are introduced to combat invasive pest species. In areas where natural enemies are insufficient to control pest populations before they cause economic damages, augmentative control that involves rearing and releasing native biological control agents might be used. In protected spaces like greenhouses and nurseries, this tactic is frequently used. Conservation biological control involves manipulating habitat, plant diversity, and crop monitoring practices to enhance the populations and effectiveness of natural enemies (Stoner, 1998).

There are different kinds of natural enemies that can be reared for biological control, including pathogens, predators, and parasitoids (Baker et al., 2019; Trdan, 2020). This kind of Biological Control Agents (BCAs) can be implemented through augmentative releases, which involve the release of biological control agents in large quantities to quickly suppress the pest population, or inoculative releases, meaning release of biological control agents in small quantities to establish a long-term population (Jeffers & Chong, 2021). Over 30 families of insects are known as predators and among them, the Coccinellidae, Chrysopidae, Syrphidae, Anthocoridae, Staphylinidae, Cecidomyiidae, Reduviidae, Carabidae and Formicidae are important in agri-horticultural ecosystems (Seni and Halder, 2022). Numerous field case studies have described predator–prey interactions involving coccinellids and quantified levels of biological control resulting from predation of aphids by these BCAs (Obrycki et al., 2009). The most promising BCAs are compared and selected for rearing based on efficacy of pest control, potential environmental risks and economy of mass rearing (van Lenteren et al., 2018).

Mass rearing programs typically have their roots in small-scale research projects, that provide a platform for basic research on a particular target, which is typically an agricultural pest species, and its natural enemy, which could be a parasitoid or a predator species. Therefore, it is essential to establish ideal conditions for the growth and development of both the pest and its natural enemy in order to produce effective natural enemies. Large scale releases involve a mass production of natural enemies that is a commercial activity (van Lenteren 2012). The capacity to rear a variety of natural enemies has improved the past decades thanks to developments in insect rearing technologies, which have included the evolution of artificial diets (Hangay et al., 2008).

The aim of the present study was to bring up to date the knowledge regarding the species of BCAs reared/commercially available or used in various pest control program worldwide. A particular focus of our review was then on aphidophagous insect species, and progress made on diet proposed for rearing the predators of the Coccinellidae Family. Our goal in investigating the use of natural hosts, artificial diets, and factitious hosts was to assess and compare the effectiveness and efficiency of each method in improving our knowledge of predator health and performance, as well as pest population control.

MATERIALS AND METHODS

This review of the specialized literature was carried out on relevant bibliography represented by journal articles, research papers, books, other sources available in English or French, published over a period from 1950's onwards. In case of Internet available resources, in order to highlight significant advances and trends in the field of artificial rearing of insects, we used "invertebrate natural enemies", "biological control agents", "augmentative biological control", "aphidophagous Coccinellidae", "Coccinellidae mass rearing", "Coccinellidae diet", "artificial diet", "factitious host" as our search key words.

RESULTS AND DISCUSSIONS

Van Lenteren et al. (2018) provided as supplementary electronic information a detailed list of over 350 commercial availability species of invertebrate natural enemies used worldwide in augmentative biological control and give information about the target species, region of use, the estimated year of first use and market value as per September 2016. In term of species number, the dominant order was Hymenoptera (178) followed by predators from Coleoptera (44), Hemiptera (29), Neuroptera (22) and Diptera (13) (Figure 1). Forty of the forty-four beetles on the list are Coccinelidae, of which 18 species are commercialised for use against aphids.

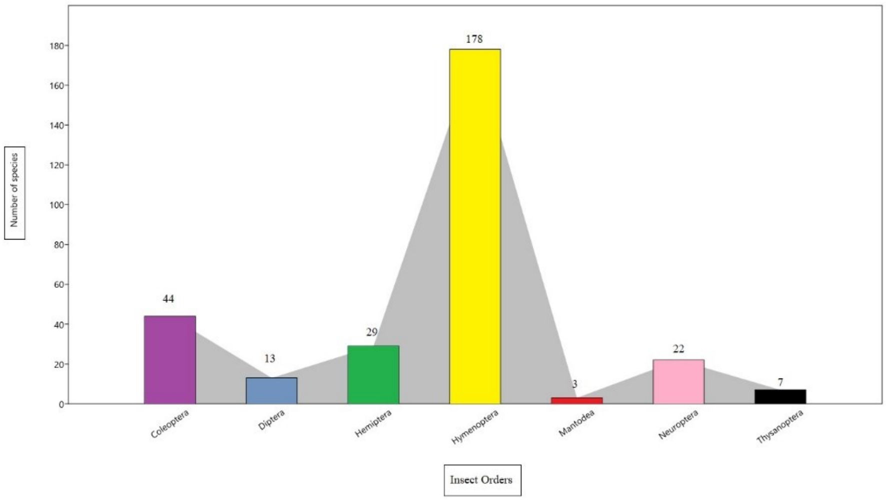

Figure 1. Prevalence of natural enemy's species used worldwide in augmentative biological control (source of data: van Lenteren et al., 2018).

Many Coccinellidae species are potential predator on aphids and found effective for pest management in agriculture crop ecosystem. For augmentative releases, large quantity of high-quality individuals are required to reduce aphid densities. From a practical perspective, the choice of species to use and rear heavily depend on the ease of mass rearing procedure. Choosing the most suitable diet, which should be cheap, permanently available and does not affect the normal development and fitness of the predator is one of the touchstones of insect mass-rearing program. There are the following possibilities: (i) natural hosts represented by aphids, (ii) factitious host (some insect species that are not the preferred host but can be used as a host for the production of predators because they are easier to rear in large numbers than the natural host), (iii) artificial diets/non-prey food and (iv) combinations between. Table 1 summarize the literature dealing with various diets used for rearing 16 aphidophagous Coccinellidae: *Adalia bipunctata, Coccinella septempunctata, C. novemnotata, C. transversalis, C.transversoguttata richardsoni, C.undecimpunctata, Ceratomegilla undecimnotata, Cycloneda sanguinea, Exochomus quadripustulatus, Hippodamia convergens, H. variegata, Harmonia axyridis, H. dimidiata, Propylaea dissecta, Propylea japonica and Propylea quatuordecimpunctata.*

Table 1. Literature studies on various diets used for rearing aphidophagous Coccinellidae

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
Adalia bipunctata	1	*Acyrthosiphon pisum*	-	-	-	Rana et al. 2002
	2	*Aphis fabae*	-	-	-	
Adalia bipunctata	1	-	Irradiated eggs of *Ephestia kuehniella*	-	-	De Clercq et al., 2005

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
	2	-	Frozen *E. kuehniella* eggs	-	-	
	3	*A. pisum*		-	-	
Adalia bipunctata	1	-	Irradiated eggs of *E. kuehniella*	-	-	De Clercq et al., 2005
	2	-	-	-	Irradiated eggs of *E. kuehniella* + Dry pollen	
	3	-	-	-	Irradiated eggs of E. *kuehniella* + Frozen pollen	
Adalia bipunctata	1	-	Frozen *E. kuehniella* eggs	-	-	De Clercq et al., 2005
	2	-	-	-	Frozen *E. kuehniella* eggs + Frozen pollen	
	3	-	-	Frozen pollen	-	
Adalia bipunctata	1	*A. pisum*	-	-	-	Ferrer et. Al., 2008
	2	*Acyrthosiphon craccivora*	-	-	-	
A. bipunctata	1	*Myzus persicae*	-	-	-	Jalali et. al 2009
	2	*A. pisum*	-	-	-	
	3	-	-	-	Mixture of frozen pollen and eggs of *E. kuehniella*	
A. bipunctata	1	*A. pisum*	-	-	-	Bonte et al., 2010
	2	-	-	-	*E. kuehniella* eggs plus pollen	
	3	-	-	-	mixtures of pollen and cysts of *Artemia franciscana*	
	4	-	-	bovine meat and liver		
	5	-	-	-	lyophilized diet, *A. franciscana* cysts and pollen	
A. bipunctata	1	*Dysaphis plantaginea*	-	-	-	He et al.,2019
		M. persicae	-	-	-	
		-	*E. kuehniella* eggs	-	-	
	2	-	-	Flower diets: *Matricaria chamomilla, Daucus carota, Fagopyrum esculentum,Anethum graveolens,* and *Sinapis alba*	-	
	3	-	-	4 pollen diets from 3 plant species: *Typha angustifolia, Malus pumila* (2 varieties) and *A. graveolens*; and 1 M solutions of 3 sugars: glucose, fructose, and sucrose	-	

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
Coccinella septempunctata	1	*Metopolophium dirhodum*	-	-	-	Nielsen et al., 2002
	2	*M. persicae*	-	-	-	
	3	*Aphis sambuci*	-	-	-	
	4	*M. dirhodum* and *M. persicae*	-	-	-	
	5	*M. dirhodum* and *A. sambuci*	-	-	-	
	6	*M. persicae and A. sambuci*	-	-	-	
	7	*M. dirhodum, M. persicae* and *A. sambuci*	-	-	-	
C. septempunctata	1	*M. dirhodum*		-	-	Nielsen et al., 2002
	2	*S. avenae*				
	3	*S. avenae and M. dirhodum*				
C. septempunctata	1	*A. craccivora*	-	-	-	Omkar, 2003
	2	*A. gossypii*	-	-	-	
	3	*Aphis nerii*	-	-	-	
	4	*Lipaphis erysimi*	-	-	-	
	5	*M. persicae*	-	-	-	
	6	*Uroleucon compositae*	-	-	-	
C. septempunctata	1	*Eucalipterus tiliae*	-	-	-	Kalushkov et al.,2004
	2	*Tuberculatus annulatus*	-	-	-	
	3	*Euceraphis betulae*	-	-	-	
	4	*Cavariella konoi*	-	-	-	
	5	*Liosomaphis berberidis*	-	-	-	
	6	*Acyrthosiphon ignotum*	-	-	-	
	7	*Aphis spiraephaga*	-	-	-	
	8	*Aphis fabae*	-	-	-	
	9	*Macrosiphoniella artemisiae*	-	-	-	
	10	*Capitophorus hippophaeus*	-	-	-	
	11	*A. pisum*	-	-	-	
	12	*A. craccivora*	-	-	-	
	13	*S. avenae*	-	-	-	
C. septempunctata	1	*Acyrthosiphon pisum*	-	-	-	Nedved and Salvuci, 2008
	2	*Aphis philadelphi*	-	-	-	
	3	*Aphis sambuci*	-	-	-	
C.septempunctata	1	*Lipaphis erysimi*	-	-	-	Sarwar & Saqib, 2010
	2	-	-	yolk, sucrose, honey, casein, protein hydrolyzate	-	
	3	-	-	Agar, cane sugar, honey and protein hydrolyzate, royal jelly	-	
C.septempunctata	1	*Aphis fabae*	-	-	-	Mahyoub et al.2013
C.septempunctata		-	-	10 different artificial diet in semi-	-	Singh et al., 2014

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
				solid form protinex, home food, nutripet, agar powder, yeast powder honey , vitamin B-complex and vitamin E., Methyl paraben and formaldehyde		
C.septempunctata	1	*Uroleucon compositae*				Bukero et al., 2015
	2		*Sitotroga cerealella*			
	3			egg yolk; casein; agar; sucrose; cholesterol; protein hydrolysate; vitamin-E; yeast; honey and sodium benzoate		
C.septempunctata	1	*Rhopalosiphum padi/ Schizaphis graminum*	-	-	-	Abbas et al., 2019
	2			Protein hydrolyzate, Casein protein, Honey, Dry aphid Water	-	
	3	-	-	Yeast , agar, honey, water	-	
	4	-	-	Protein hydrolyzate, honey, dry aphid, water	-	
	5	-	-	Casein protein, Honey, Dry aphid, water	-	
	6	-	-	Honey +water	-	
C. septempunctata	1	*Aphis craccivora*	-	-	-	Cheng et al., 2023
	2	-	-	milk powder, pork liver, olive oil, sucrose, corn oil, eggs, powdered yeast, casein, cholesterol, protein powder, vitamin E and C, honey, agar, distilled water and juvenile hormone III	-	
C. septempunctata & C. transversalis	1	*L. erysimi,*	-	-	-	Gupta et al., 2006
	2	*M. persicae*	-	-	-	
	3	*Aphis nerii*	-	-	-	
C. transversoguttata richardsoni & C. novemnotata	1	*A. pisum*	-	-	-	Hesler et al., 2012
	2	*R. padi*	-	-	-	
	3	*M. persicae and A. pisum*	-	-		
C.undecimpunctata	1	*L. erysimi*	-	-	-	Bakhtawar et al., 2016
	2	*Phenoccocus solenopsis*	-	-	-	
	3	-	*Sitotroga cerealella*	-	-	
	4	-	-	Honey	-	
C.undecimpunctata	1	A. craccivora	-	-	-	Youssif et al., 2021
	2	-	-	fresh chiken liver, sucrose, yeast extract, egg yolk powder peptone, multivitamins and minerals, casein, chlortetracycline	-	

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
	3	-	-	basic artificial diet plus royal jelly, propolis and pollen grains	-	
C.undecimpunctata	1	*B.brassicae*	-	-	-	Ramzan et al., 2023
	2	*M. persicae*	-	-	-	
Harmonia axyridis	1	*A. pisum*	-	-	-	Specty et al., 2003
	2		*E. kuehniella* eggs	-	-	
H. axyridis	1	-	E. kuehniella eggs	-	-	Sighinolfi et colab. 2008
	2	-	-	pork liver, Isio 4 oil, olive oil, sucrose, glycerin, aqueous amino acid solution, yeast extract, and Vanderzant's vitamin mixture	-	
H. axyridis	1	*Megoura japonica*				Chen et al. , 2020
	2	-	-	Pork liver, pork meat, Eggs (whole eggs),Yeast extract, honey, Vitamin B complex, Vitamin C	-	
Hippodamia convergens	1	*A. fabae*	-	-	-	Hinkelman & Tenhumberg, 2012
	2	*A. pisum*	-	-	-	
	3	*A. fabae+ A.pisum*				
H. convergens	1	*A. gossypii*	-	-	-	Arshad et al., 2020
	2	*L. erysimi*	-	-	-	
H. variegata		*S. avenae*	-	-	-	Moghaddam et al., 2016
Propylaea dissecta & C. transversalis	1	*A. gossypii*	-	-	-	Pervez and Omkar, 2004
	2	*Lagenaria vulgaris*	-	-	-	
Propylea japonica	1	*M. persicae*	-	-	-	Tan et al., 2015
	2		-	Liquid artificial diet with fresh pork liver + pure honey + sucrose + olive oil.	-	
	3		-	Microencapsulated artificial diet(ADM)	-	
	4		-	Ca-ALG calcium alginate, CHI-chitoson	-	
P. japonica and H. axyridis	1	*A. pisum*	-		-	Ali et al., 2017
	2		-	shrimp, beef, beef liver, and egg yolk	-	
Ceratomegilla undecimnotata, H. variegata and C. septempunctata	1	*M. persicae*	-		-	Skouras et al., 2015
Cycloneda sanguinea limbifer	1	*A. gossypii*	-	-	-	Sikber & Copland, 2001
C. sanguinea limbifer	1	*A. fabae*	-	-	-	Růžička, 2003
C. sanguinea limbifer	1	*A. spiraecola*	-	-	-	Hodek et al., 2012
	2	*Toxoptera citricida*	-	-	-	
C. sanguinea limbifer	1	*M. persicae*	-	-	-	Duarte et al., 2017
Exochomus quadripustulatus	1	*A. porni*	-	-	-	Radwan & Lovei, 1983
	2	*A. pisum*	-	-	-	

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
	3	*Dysaphis devecta*	-	-	-	
	4	*Dysaphis plantaginea*	-	-	-	
	5	*Megoura viciae*				
	6	*A. fabae*				
Harmonia dimidiata	1	*Rhopalosiphum padi*	-	-	-	Khan, 2022
H. dimidiata	1	*A. gossypii*	-	-	-	Yu, 2013
H. dimidiata	1	*A. gossypii*	-	-	-	Sharma et al., 2017
H. dimidiata	1	*A. pomi*	-	-	-	Kumari, 2018
H. dimidiata	1	*A. gossypii*	-	-	-	Yu, 2018
	2	-	*Bactrocera dorsalis* eggs	-	-	
Hippodamia convergens	1	-	-	experimental diet containing singularly the liver extract S, L, or 2 (liver-S, L, or 2)	-	Racioppi et al., 1981
	2	-	-	The modified Vanderzant's diet (1969) with or without liver extract S, Vand-S and Vand-0	-	
H. convergens	1	*A. pisum*	-	-	-	Giles et al., 2001
H. convergens	1	-	*E. kuehniella* eggs	-	-	Michaud et al., 2006
H. convergens	1	*A. spiraecola*	-	-	-	Hodek et al.,2012
	2	*T. citricida*	-	-	-	
H. convergens		-	*E. kuehniella* eggs	-	-	Vargas, 2012
H. convergens	1	*Brevicoryne brassicae*	-	-	-	Jessie et al., 2015
	2	*Lipaphis erysimi*	-	-	-	
	3	*Myzus persicae*	-	-	-	
H. convergens	1	-	-	water, sucrose solution (referred to as sugar), honey, bee pollen substitute, protein	-	Mercer et al., 2019
	2	-	frozen *E.kuehniella* eggs	-	-	
	3	*A. pisum*	-	-	-	
H. convergens	1	-	-	sugars, pollen, and seedling wheat leaves	-	Stowe et al., 2021
	2	-	eggs of Ephestia kuehniella	-	-	
	3	*S. graminum*	-	-	-	
H. variegata	1	*A. gossypii*	-	-	-	Wu et al.,2010
H. variegata	1			Chicken liver, Baker's yeast, Sucrose, Agar, Distilled water, Egg yolk, Honey, Olive oil	-	Mirkhalilzadeh et al., 2013
	2			Agar, Distilled water, Sucrose, Honey, Yeast extract, Corn flour, Soy powdered Milk, Gelatin, Ascorbic acid, Powdered milk Tryptophan, Wheat germ oil, Vitamin, Sorbic acid, Egg yolk	-	
H. variegata	1	*A. gossypii*				

Predator species	Tr. no	Food type				References
		Aphid species	Factitious host	Artificial diet/ other non-prey food	Mixed	
	2	*A. craccivora*				Pervez et al., 2020
	3	*B. brassicae*				
H. variegata	1	*L. erysimi*				Pervez et al., 2020
	2	*M. persicae*				
	3	*Uroleucon compositae*				
H. variegata	1	*A. craccivora*	-	-		Ramadan et al., 2022
	2	-	*E. kuehniella* eggs	-	-	
	3	-	-	pollen	-	
	4	-	-	-	*A. craccivora* + *E. kuehniella* eggs	
Propylea quatuordecimpunctata	1	*A. pisum*	-	-	-	Obrycki et al.,1993
P. quatuordecimpunctata	1	*A. pisum*	-	-	-	Kalushkov et al., 2005
	2	*A. craccivora*	-	-	-	
	3	*Eucallipterus tiliae*	-	-	-	
	4	*Euceraphis betulae*	-	-	-	
	5	*Phorodon humuli*	-	-	-	
	6	*M. persicae*	-	-	-	
P. quatuordecimpunctata	1	*Aphis glycines*	-	-	-	Mignault ei al., 2006
P. quatuordecimpunctata	1	A. fabae	-	-	-	Kontodimas et al.,2008
P. quatuordecimpunctata	1	A. fabae	-	-	-	Papanikolaou et al., 2013
P. quatuordecimpunctata	1	A. fabae	-	-	-	Keshavarz et al., 2015
	2	A. gossypii	-	-	-	
P. quatuordecimpunctata	1	M. rosae	-	-	-	Sarmad et al., 2015
P. quatuordecimpunctata	1	A. fabae	-	-	-	Salerno et al.,2022

There are some Coccinellid species that have preference to consume only certain aphid species but the great majority are polyphagous species, a feature that enhance their capacity to survive in nature (Habeck et al., 1990). Numerous studies were therefore conducted to determine the predatory potential of polyphagous Coccinellidae against a large number of aphids species under the laboratory conditions. We found 36 species of aphids offered as natural host for the 16 species of Coccinellidae listed in table 1.

Some dietary preferences was highlighted among Coccinellidae species when feed on aphids, The use of a particular prey or mixture of prey aphid species may affect rearing outcomes and the suitability of different aphid as diets for various coccinellid species. For example, even though diets of mixed aphid species may be more nutritionally diverse, they are not necessarily better for rearing *Coccinella septempunctata* (Nielsen et al., 2002 a and b). Another sensitive aspect is related with prey size, for example the pea aphid is relatively large, consequently first- and second-instar coccinellid larvae have difficulty when eating pea aphids late-instar nymphs or adults. Provision of smaller aphid prey might improve feeding efficiency and success in rearing early instars of Coccinelidae (Hesler et al., 2012; Sloggett, 2008).

The use of factitious hosts are suggested in order to decrease production costs by reducing the amount of space and labor required for mass rearing of live prey, as well as optimizing rearing procedures through mechanization. One of the main difficulties in obtaining an alternative host for a predator is selecting a diet that fully supports the natural enemy's growth and reproduction while having no negative effects on its capacity as a biological control agent (Riddick, 2008). Some factitious food has had a significant impact on meeting the nutritional requirements of predatory beetles, especially lepidopteran species, on top of them we found *E. kuehniella* eggs having higher amino acid and lipid compositions than natural food.

Another lepidoptera used as a factitious diet is *Sitotroga cerealella,* whose eggs were tested to rear *Coccinela undecimpunctata* (Bakhtawar et al., 2016). The authors examined the influence of four diets on the larval development of *C. undecimpunctata*: aphids *Lipaphis erysimi*, second instar larvae of *Phenacoccus solenopsis*, eggs of *S. cerealella*, and honey. The diet based on aphid *Lipaphis erysimi* resulted in the highest survival rate followed by factitious host *S. cerealella* eggs. The diet consisting on mealybug larvae induced the lowest survival rate while larvae fed with honey did not surviving beyond four days.

De Clercq et al. (2005) examined the potential of *Ephestia kuehniella* (Zeller, 1879) eggs as a food source for *Adalia bipunctata* (Linnaeus, 1758), with and without pollen supplementation. The experiments involved the analysis of various diets, including live aphids, frozen/iradiated *E. kuehniella* eggs, and pollen. The results showed that *A. bipunctata* larvae developed and survived better on irradiated *E. kuehniella* eggs than on live aphids. Supplementing the diet with frozen pollen increased reproductive success while supplementing with dry pollen did not yield satisfactory results. The composition and nutritional value of pollen mixtures influenced *A. bipunctata's* performance. The main conclusion of this study was that frozen *E. kuehniella* eggs, when supplemented with moist pollen, open up possibilities for more efficient production methods of *A. bipunctata*.

Jalali et al. (2009) investigated the efficiency of food conversion, consumption indices, and growth rates at various instars of *A. bipunctata* species. This study compared feeding with a mixture of frozen *Ephestia kuehniella* eggs and fresh pollen versus natural prey, *Myzus persicae* and *Acyrthosiphon pisum*. The results showed that larvae fed with *M. persicae* or *E. kuehniella* eggs supplemented with fresh pollen had similar survival rates and body weights, indicating that these two diets are nutritionally equivalent. The two groups did not differ significantly in terms of aphid consumption rates, food conversion indices, or development times, so the study emphasized the practical potential of factitious hosts in BCA mass rearing.

A recent meta-analyses of literature (Lundgren, 2009) demonstrate that non-prey foods are an important component of the diets of most predaceous coccinellids under field conditions, used by them to increase survival when prey is scarce, reduce mortality during diapause, support dispersal, and enhance reproductive capacity. Example of non-prey food are: nectar, honeydew, pollen, fruit, vegetation, and fungus.

Pollen has been used as a diet, a supplemental ingredient for factitious prey or as a component of some artificial diets offered to Coccinellidae. When rearing *A. bipunctata* with *E. kuehniella* eggs and pollen, over 84% of the larvae developed to adults, and females exhibited superior fecundity, which was similar to the fecundity of females fed with pea aphids (Bonte et al., 2010).

Development of artificial diets are the next level to facilitate mass rearing of predatory insect species for biological control purposes. Over the last century, much intensive research has been carried out on recipe optimization, functional supplementary components and rearing substrate material of artificial diets. First artificial diets formulation was developed in the 1950s (Singh, 1997). Smirnoff, (1958) was the first that propose an artificial diet containing as a main ingredient the aphid prey powder, that was successful for rearing some species of Coccinellidae.

Predatory insects diet consisted of carbohydrates, proteins, lipids, sterols, vitamins, inorganic salts, and other nutrients to meet requirements for growth, development, and reproduction. If the content and proportion of these nutrients in the artificial diet are suitable for their metabolic needs, insects grow and develop normally and have high fecundity (Cohen et al., 2015).

Sarwar and Saqib (2010) conducted an experiment to determine how different diet affect the performance and development of the species *Coccinella septempunctata* on mustard aphids *Lipaphis erysimi*, artificial diets and combination of them. It was found that although feeding on aphids proved to be the most efficient for predator growth, supplementing with an artificial diet was beneficial in promoting reproduction, particularly under mass production conditions or during periods of limited natural food availability.

Sighinolfi et al. (2008) conducted an experiment to compare the biological parameters of *H. axyridis* reared on a liver-based diet to those fed *E. kuehniella* eggs. The artificial diet used in the study was a combination of fresh pork liver, Isio 4 oil, olive oil, sugar, glycerin, an aqueous solution of amino acids, yeast extract, and a mixture of Vanderzant vitamins. It was found that artificial diet supported survival and reproduction, and predator full development from larvae to adults. Anyway, the results show that the group fed with *E. kuehniella* eggs performed better biologically than the group fed with the artificial diet.

Overall, we found a great variation in the formulation of artificial diets, from very simple option like animal meat and liver (Bonte et al., 2010) to very complex diet, as for example the one proposed by Cheng and collaborators (2023) whose ingredients are: milk powder; pork liver; olive oil; sucrose; corn oil; eggs; powdered yeast; casein; cholesterol; protein powder; vitamin; vitamin C; honey; agar; distilled water, juvenile hormone III (omitted from larval diets) shrimp, pollen, honey, and lard.

Even their ingredients are relatively simple, ready available, rich in nutrients (as for example pork meat, chicken liver or whole egg) that is practical and economical advantage, some artificial diets are not supporting well the development of predators. For example, *C. septempunctata* larval mortality was 100% after feeding on an artificial diet based on yolk, sucrose, honey, casein and protein (Sarwar & Saqib, 2010). Providing a diet based on pork liver, pork meat, whole eggs, honey, yeast extract, honey, Vitamin B complex and Vitamin C to *H. axyridis* enabled to complete growth and development from larvae to adults but further adversely affected growth and reproduction (Chen et al., 2020).

Not only the components of the artificial diet are important for mass-rearing success. The ability of the reared insect to convert and utilize the components of the diet must be also considered (Cheng et al., 2023). Also, properties and state (liquid or solid) can strongly affect feeding efficiency of mass-reared coccinellid species (Bukero et al., 2015). Most artificial diets have been made in liquid or semi-solid form due to ease of mixture and insect ingestion, but the adhesive nature of the diet increases mortality (Sravanthi, 2018). Formulating an artificial diet that meets nutritional requirements while also stimulating feeding is a challenging task. Another challenge in efficiently packaging food for maintaining the optimal moisture content and creating a barrier against microbial invasion while ensuring the diet's accessibility and stimulatory qualities for the insect (Cohen, 2015). Tan et al. (2015) used an innovative approach to improve the stability and efficiency of liquid artificial diets designed for feeding the species *Propylea japonica*. They introduces a new type of microencapsulated artificial diet for mass rearing of predatory ladybirds, the results showed more suitability of the microencapsulated artificial diet compared to a liquid form of the diet in feeding *P. japonica* development, the reproduction and other biological or physiological performances were similar to fresh aphid prey.

CONCLUSIONS

Overall, the literature shows that coccinellids rearing programs need specific aphid food for maintaining the predators' biological characteristics. Aphids reared on some economically plants still remain the preferred food option in mass rearing of predatory coccinellidae for inundative releases. Recent outcomes suggest that using a factitious host, particularly in the egg instar, with *Ephestia kuehniella* on top of commonly used host in current research, combined with alternative food like polen could be an effective alternative method for rearing programs that reduce reliance on natural prey. The artificial diets are still under development, some advanced studies recommend to be used in case of scarce of aphids host availability. The scientific community has concentrated the effort on improving the artificial diet, especially on aspect related with nutritional and non-nutritional components of the diet, their influence on Coccinellidae physiological activities, maximization of mass-rearing process by providing differentiated diets according to the biological stages of the predators. The use of microencapsulated artificial diet in mass rearing is an innovation that might improve the predators feeding efficiency and ensure stability and quality of artificial diets in practices.

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