Scientific Papers. Series D. Animal Science. Vol. LXVI, No. 2, 2023
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

SILKWORMS PUPAE AS PROTEIN SOURCE FOR PIGS - A REVIEW

Mihaela HĂBEANU, Anca GHEORGHE, Teodor MIHALCEA

Research Station for Sericulture Baneasa, 013685, Bucharest, Romania

Corresponding author email: mihaela.habeanu@scsbaneasa.ro

Abstract

This study aimed to identify whether the silkworm pupae (SWP) added to pigs' diets can be considered a valuable protein-rich alternative source. The silkworm (Bombyx mori L.) and its by-products are highly valuable in terms of nutrition, medicine, and commerce. The SWP is the main by-product of the sericulture, considered a well-balanced source of nutrients in terms of proteins, lipids, minerals, vitamins and various bioactive substances such as fatty acids, peptides, and polyphenols with antioxidant, anticancer, cardiovascular, hepato-protective properties. The mulberry silkworm's potential for use in human food has been previously extensively documented, whereas the preponderance of literature data on SWP used in the livestock industry specific focus on poultry. There is limited pig-related data. In this study, we reviewed the most recently published papers on PubMed, Elsevier, MDPI, and Research Gate, using the keywords "silkworm pupae", "composition", "protein", and "pigs". We did not find any negative consequence on pigs' growth and health parameters in the reviewed published data.

***Key words**: feed, pigs, protein, pupae, silkworms.*

INTRODUCTION

Soybean meal, as the main feed plant protein source used in monogastric animal diets, has a considerable impact on the environment (Wiedemann et al., 2016; DiGiacomo & Leury, 2019). Furthermore, the availability of soybean meal for animal feed may be constrained because it is a component of the human diet and is not a highly productive crop.

According to the statistics (OEC; https://oec.world/), in 2020, Romania became the 32nd largest importer of soybean meal in the world (about $204M). Soybean meal was the 111th most imported product in Romania during the same year.

The protein level of soybean meal range between 40-49%, while lipid content varies between 0.5-3% (Banaszkiewicz, 2011).

Another important protein-rich source is fish meal (54-64% proteins, 8-14% lipids, and omega-3 fatty acids). The protein digestibility is comparable to silkworm pupae (SWP), and young pigs can easily digest it. The fish meal typically has no antinutritional factors. There is an increasing need for new, sustainable sources of protein due to the challenges that occurred when fish and soy meal consumption increased. Insects have been recognized as one of the possible options and a suitable method for developing a circular food system, along with other alternative protein sources (FAO, 2013; Aarts, 2020). In industrialized and developing nations, insects present a great opportunity to combine traditional knowledge and cutting-edge research (Meng et al., 2017).

An important monophagous, lepidopteran insect for the industry is the silkworm (*Bombyx mori*) due to the silk produced and its potential for human and animal food, pharmaceutical usage, biogas from substrates of mulberry silkworm (Zhang et al., 2012; Łochyńska & Frankowski, 2018; Wu et al., 2020; Karnjanapratum et al., 2022).

Furthermore, silkworms gained attention as a model in research, having characteristics such as low cost of reproduction, the large size of offspring, short generation times etc. (Zhang et al., 2012; Meng et al., 2017).

The silkworm (*Bombyx mori* L.) plays an important role in economic development, having a significant quantity of by-products that are highly valuable in terms of nutrition, medicine, and commerce (Trivedy et al., 2008; Karthick et al., 2019; Sharma et al., 2022). The silk reeling process generates waste such as pupae and leftover unreliable silk.

The SWP, as the main by-product of sericulture, could be considered a well-balanced source of nutrients in terms of

proteins, lipids, minerals, vitamins (Herman et al., 2022; Tassoni et al., 2022) and various bioactive substances such as fatty acids, peptides, and polyphenols with antioxidant, anticancer, cardiovascular, hepato-protective properties (Sadat et al., 2022).
According to Valerie et al. (2015), the SWPs are usually referred to by a variety of names, including silkworm pupae meal, silkworm meal, defatted silkworm pupae meal, spent silkworm pupae, de-oiled silkworm pupae meal, non-defatted silkworm pupae meal, Eri silkworm pupae meal, and Muga silkworm pupae meal in various locations.
Due to its high protein content, SWP meal has been used to feed animals, especially for monogastric species such as poultry, pigs, and fish, as well as for ruminants (Sheikh et al., 2018).
With an emphasis on pigs, this review provides an overview of the current situation regarding SWP as a sustainable source of animal feed. It was also taken into consideration the mulberry leaves and pupae composition.

MATERIALS AND METHODS

We screened the most relevant and recently published papers available on PubMed, Elsevier, MDPI, and Research Gate, using the keywords "silkworm pupae", "composition", "protein", and "pigs". We also used the bibliographic material regardless of the years of publication when recent papers were not available. In this review, we tried to provide the scientific information reported about nutritional characteristics and the potential of using silkworm (*Bombyx mori* L.) pupae in animal feeding with a focus on pigs.

RESULTS AND DISCUSSIONS

Mulberry leaves nutrient composition

Mulberry (*Morus alba*) plants are adapted to temperate, tropical, and subtropical climates.
In Romania, sericulture developed firstly in Transylvania and Banat in the 14th century (1348). The Turks introduced the practice of rearing silkworms in Moldova and Muntenia later in the 18th century.
To support sericulture, 60,000 mulberry saplings were distributed for free in Moldova in 1845, which were to be planted in the southern areas. The Banat is a region where the mulberry tree is a symbol. Mulberries were introduced to this area by the Habsburg government in the 18th century so that farmers could feed silkworms. The adoption of the trees was so widespread that one of the region's primary exports was silk. Dolis, (2008) specified that the old mulberries were still growing along Banat's roads. According to Tanase (2007), the Romanian vegetal sericulture patrimony has had 64 mulberry varieties, with increased productive potential (up to 30 leaf tonnes/ha) depending on the maintenance and exploitation technologies. Pau et al. (2008) cited by Pop et al. (2018) stated that Romania has had a diversity of mulberry species, about 10 local breeds and 49 foreign breeds and hybrids from Japan, China, Russia, Bulgaria and India. But in recent years in Romania, as far as we know, there are no clear evidence regarding the area cultivated with these mulberries, neither variety. Moise et al. (2018) and Dezmirean et al. (2018) reported the set-up of a mulberry plantation from Kokuso 21 variety (Japanese origin), at the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca in the Global Centre of Excellence for Advance Research in Sericulture and Promotion of Silk Production which is recognised since 2014 by the International Sericulture Commission. However, according to Sarkar et al. (2017), Rohela et al. (2020). mulberry trees are widely distributed across the continents and in a variety of environments, which suggests that it is more tolerant of changing environmental circumstances, being adapted to a variety of climates, soil types, and altitudes up to 4000 m above sea level.
The mulberry leaves become crucial to the sericulture sector since mulberry silkworms (*Bombyx mori* L.*)* exclusively eat mulberry leaves (Sanchez, 2000; Thaipitakwonga et al., 2018). However, due to compounds in mulberry leaves that may be sequestered by silkworms, such as essential oils, flavonoids, and terpenoids, the decomposition of mulberry-fed SWP results in an unpleasant odour. Palatability issues have been attributed to this disagreeable odour (Finke, 2002; www.feedpedia.com). However, mulberry leaves are highly effective in developing high-quality cocoons. Pupae represent approximately

60% of the dried cocoon's weight (Tassoni et al., 2022).

The main nutrients found in mulberry leaves are proteins, carbs, vitamins, sterols, phagostimulants, and minerals (Raghuvanshi & Bukhari, 2019). The dietary nutritional needs of silkworms have an immediate impact on all genetic characteristics, including cocoon weight, silk production, pupation, and reproductive features (Ramesha et al., 2010; Raghuvanshi & Bukhari, 2019).

According to Srivastava et al. (2006), the moisture content of dried mulberry leaf powder ranged from 5.11 to 7.24%, the crude protein (CP) content from 15.31 to 30.91%, the total ash concentration from 14.59 to 17.24%, the neutral detergent fibre (NDF) content from 27.60 to 36.66%, the crude fat (CF) content from 2.09 to 4.93%, the carbohydrate content from 9.70 to 29.64%, as well as the energy content from 113 to 224 kcal/100 g. Generally, CP levels are comparable to those of the majority of legume forages. Sanchez (2000) and Raghuvansh et al. (2019) report that the CP content of leaves varies from 15 to 28%, while Sanchez-Salcedo et al. (2017) found a level of 13.4-19.4%, Iqbal et al. (2012) noticed a content of 18.41-24.63% and Adeduntan & Oyerinde (2010) reported 21.24-21.66%. The composition depends on the variety, leaf age, and growing environment. In comparison to other vegetation, mulberry leaves have a low fibre proportion. The typical Ca, and P concentrations are 0.14 to 0.24% and 1.8 to 2.4%, respectively (Sanchez, 2000).

Moreover, according to Srivastava et al. (2006), mulberry leaves contain a significant source of beta-carotene (14,688 mg/100 g) compared to other frequently consumed green leafy vegetables, including spinach, amaranth, and fenugreek leaves. Furthermore, mulberry leaves are characterized by a high Fe and Ca level and are a source of other antioxidant elements, including Zn and ascorbic acid as well.

Such as Liu et al. (2000) specified spring leaves have significantly more nutritional value than autumn leaves. The silkworm possesses considerable variations in its ability to digest, absorb, and convert to body matter when fed the same quantity of mulberry leaves under various environmental, feeding, and dietary conditions (Rahmathulla & Suresh, 2011). It is generally established that nutritional parameters have a close relationship with feed intake and silk production. The conversion of mulberry leaves into silk is greatly influenced by the silkworms' ability to digest their diet. A more accurate economic indicator to produce cocoons is the efficiency of conversion of ingested mulberry leaves into silk or the rate of leaf silk conversion (Rahmathulla & Suresh, 2011). Only 620.70 kg of the 2472.80 kg of mulberry leaves that are produced by a hectare of mulberry fields are digested by silkworm larvae and turned into 211.20 kg of silk (Priyadharshini et al., 2017).

The haemolymph composition of larvae fed on *Morus alb*a and *Morus laevigata* mulberry leaves consists of 24-30 mg/mL proteins and more than 1500 mg/mL lipids and pupae weight varied between 705-885 mg (Mahmoud, 2017).

Silkworm pupae composition

The primary by-product of the sericulture sector is thought to be SWP which is left over after reeling silk fibre and can be used as animal feed due to its highly nutrient-dense composition (Dong et al., 2017; Lamberti et al., 2019). Literature sources highlighted that SWPs receive all their nutrients from mulberry leaves and convert plant proteins into silk.

Several authors evaluated the chemical composition of silkworm and their by-products. The SWPs nutritional value may change depending on the treatment technique. There were large variations of nutritional composition (Table 1). Thus, protein level ranging from 48 to 94.98% DM, lipid values between 6.2 and 37.1% DM, and fibre variation is between 2.5 to 5.8% DM. The content of mulberry leaves, feed consumption, digestibility coefficients, the bioavailability of nutrients, analytical procedures, sampling, etc. are some potential explanations for these variations.

On a similar note, Kumar & Rajesh (2015) found a variety of bioactive compounds, including 55 g of protein, 8.5 g of fat, 6 g of fibre, 25.43 g of carbohydrates, and 389.60 (Kcal/100 g) of energy which was found in each 100 g of SWP. On the other hand, Kotake-Nara (2002) pointed out the difference in lipid content between males and females, being 46% greater in females (9%) compared to males (4.8%).

Table 1. Proximate composition of SWP

Specification	%, DM bases	%, fresh	References
Dry matter (DM)	-	23.2-25.9	Lamberty et al. (2019)
		81-97.5	Feedpedia
Protein	48-60	-	Herman et al. (2022)
	49-54	21.5	Wu et al. (2021)
	59.52–94.98	13.81-16.83	Lamberty et al. (2019)
	60.7	-	Sheikh et al. (2018)
	51.6-70.6	-	Feedpedia
Lipid	30	-	Herman et al. (2022)
	-	13	Wu et al. (2021)
	6.2-37.1	-	Feedpedia
	25.7	-	Sheikh et al. (2018)
Fiber	2.5-5.8	-	Feedpedia
	3.9	-	Sheikh et al. (2018)
Ash	5.8	-	Sheikh et al. (2018)
	-	1.16-1.33	Lamberty et al. (2019)
	-	3.3-10.6	Feedpedia
Chitin	3-4	-	Herman et al. (2022)
Gross Energy - (MJ/kg)	-	5.09-6.82	Lamberty et al. (2019)
- (MJ/kg DM)	25.8	-	Feedpedia

Apart from the main nutrient in all the analyzed bibliographic sources, SWP has a high quality of protein due to the concentration of essential amino acids (Tomotake et al., 2010; Rafiullah & Khan, 2016; Wu et al., 2020). According to a study led by Zhou & Han (2006), silkworm pupae contain all 18 recognized amino acids, including the essential amino acids, mainly methionine, which is a limiting amino acid, especially for poultry. As seen in Table 2, a detailed composition of amino acids of the defatted and non-defatted SWP was provided by Mahata et al. (1994), quoted by Raja et al. (2019) and Lin et al. (1983), and by Longvah (2011) cited by Jeyaprakashsabari & Aanand (2021). Table 2 also shown the amino acids composition of SWP, expressed as g/100 g protein, reported by Roa et al. (1994), Zhou et al. (2006) and Longvah (2011), cited by Kumar & Rajesh (2015).

Table 2. Amino acids composition of SWP

Specification	g/16 g N[1]		g/100 g protein[2]
	Defatted	Non-defatted	
Alanine	4.4	5.6-5.8	5.5
Arginine	5.1	5.8-5.6	6.8
Aspartic acid	7.8	10.4	10.9
Glutamic acid	8.3	13.9	14.9
Cystine	0.8	1.0	1.4
Methionine	3.0	3.5	4.6
Lysine	6.1	7.0	7.5
Isoleucine	3.9	5.1	5.7
Leucine	5.8	7.5	8.3
Phenylalanine	4.4	5.1	5.1
Threonine	4.8	5.2-5.1	5.4
Tryptophan	1.4	0.9	-
Histidine	2.6	2.6	2.5
Proline	5.2	5.2	4.0
Serine	4.5	5.0	4.7
Glycine	3.7	4.8	4.6
Tyrosine	5.5	5.9	5.4
Valine	4.9	5.5	5.6

References: [1]Lin et al. (1983); Mahata et al. (1994); Raja et al. (2019); Longvah (2011) quoted by Jeyaprakashsabari, and Aanand (2021); [2]Roa et al. (1994); Zhou et al. (2006), and Longvah (2011) cited by Kumar & Rajesh (2015).

With regards to the fatty acids profile of SWP oil, Nakasone et al., (1967) and Kotake-Nara (2002) and presented composition differentiated by sex as is described in Table 3.

Table 3. Fatty acids composition of SWP[1]

Fatty acids (% of total lipids)	Male	Female
C16:0 (palmitic)	28.60	22.80
	24.90	19.50
C16:1n-7 (palmitoleic)	3.10	1.80
	0.80	0.60
C18:0 (stearic)	2.60	4.30
	5.40	6.30
C18:1n-9 (oleic)	29.0	27.20
	24.30	22.60
C18:2n-6 (linoleic)	7.30	8.50
	6.30	7.70
C18:3n-3 (alpha-linolenic)	29.20	34.90
	36.00	40.70

[1]References: Nakasone & Ito (1967); Kotake-Nara et al. (2002).

Comparative to SWP oil, the same authors described soybean oil and linseed oil fatty acids composition (wt % of total lipids) as follows: soybean oil C6:0 10.6, C18:0 3.5, C16:1n-7 0.1, C18:1n-9 20.5, C18:2n-6 54.4, C18:3n-3 6.5, C20:3n-3 0; linseed oil C6:0 5.5, C18:0 3.1, C16:1n-7 0.1, C18:1n-9 14.8, C18:2n-6 14.2, C18:3n-3 56.2, C20:3n-3 0.1. A significant concentration of omega-3 (including α-linolenic), omega-6 (including linoleic fatty acids), docosahexaenoic (DHA) and eicosapentaenoic (EPA) acids, was found as well by Kumar and Rajesh (2015) in the lipid structure. This statement was also supported by Payne et al. (2016), who reported low levels of saturated fat and significant levels of monounsaturated and polyunsaturated fatty acids.

According to Kumar et al. (2015), another important aspect is the SWP's excellent minerals and vitamins composition (Table 4).

On the other hand, Priyadharshini et al. (2017) noticed that approximately 8% of dried SWP are nitrogen, 0.29% are calcium, and 0.58% are phosphorus, whereas wet pupae contain 0.65% calcium, 1.22% phosphorus, 0.30% natrium, 0.80% potassium, 0.325% magnesium, 230 mg/kg iron and 285 mg/ kg zinc.

Table 4. Minerals and vitamins composition of SWP[1]

Minerals	Concentration	Vitamins	Concentration
Calcium (mg/100 g)	102.31	Vitamin A (µg)	273.99
Potassium (mg/100 g)	1826.59	Vitamin E (IU/kg)	51.45
Magnesium (mg/100 g)	287.96	Vitamin C (mg)	<5.78
Phosphorus (mg/100 g)	1369.94	Vitamin B1 (mg)	1.91
Natrium (mg/100 g)	274.57	Vitamin B2 (mg)	5.43
Iron (mg/100 g)	9.54	Vitamin B3 (mg)	15.20
Zinc (mg/100 g)	17.75	Vitamin B5 (mg)	12.49
Manganese (mg/100 g)	2.08	Vitamin B7 (µg)	144.51
Copper (mg/100 g)	2.08	Vitamin B12 (mg/100 g)	0.50
Selenium (mg/100 g)	0.08		

[1]Reference: Kumar et al. (2015).

Silkworm pupae for animal feeding

Similar to other insects, silkworms are cold-blooded, quick-growing, and an essential component of the natural diets of many species. Their varying protein contents and protein digestibility (76%-98%), which highlight their importance in contemporary trends in food science and related fields, led to an increased interest in terms of potential application as animal feed.

Sheikh et al. (2018) mentioned that animals, particularly monogastric (poultry, pigs, and fish), but also ruminants, can be fed with SWP meal. As stated by Asimi et al. (2017) and Herman et al. (2022), only 25-30% of waste pupae have been used for livestock feeding.

Despite this, a significant amount of SWP waste is discarded every year. A series of trials were running to determine the impact of the dietary addition of SWP, as a replacement of soybean meal, on growth parameters and carcass characteristics, apparent nutrients and energy digestibility, haematological profile in the broiler (Rafiullah and Khan, 2016) and laying hens (Saikia et al., 1971 and Aruga, 1994 quoted by Priyadharshini et al., 2017). Although it is slightly lower quality than fish meal, Sheikh et al. (2018) confirmed that SWP meal is a valuable and less expensive alternative protein source that can be utilized in feeding chickens. Numerous studies carried out around the world have demonstrated that it is safe to partially replace (50%) the main protein source (fish meal) in most experiments, albeit it may be necessary to supplement with minerals. While total replacement is sometimes achievable, the performance is more likely to be affected in broilers. Inclusion percentages often range between 5 to 10% (Valerie et al., 2015). Hence, as Fagoonee (1983a; 1983b) and Purushothaman and Thirumala (1995) mentioned, growth performance and feed efficiency were not negatively impacted when SWP replaced 50% of the fish meal but was negatively affected by 100% replacement. In 2020, Miah et al. conducted a trial to determine the impact on growing chickens' performance and meat traits of the partial replacement of soybean meal and oil with full-fat silkworm (*Bombyx mori* L.) meal. The findings demonstrated that full-fat silkworm meal could partially replace soybean meal/oil in the chickens' diet, maintaining appropriate performance and meat qualities and meat with a healthier n-6/n-3 ratio.

When utilized SWP as a protein supplement, hens' egg characteristics were improved, yolk's colour as well (Saikia et al., 1971; Priyadharshini et al., 2017). Layer chicken body weight, feed intake, hen day production (%), egg weight, feed conversion ratio, blood profile, and egg quality parameters did not change significantly when soybean meal was substituted with SWP meal (0, 25, 50, or 100%) (Ullah, 2017). Similarly, Khatun et al. (2005) found that layer chicks of the Rhode Island Red pure line grew more rapidly, produced more eggs, and were more profitable if fed one of three isonitrogenous and isoenergetic diets: D1 (6% protein concentrate+0% SWP), D2 (0% protein concentrate+6% SWP), and D3 (0% protein concentrate+8% SWP). These authors demonstrated that SWP is a less costly option to protein concentrate, which increased profitability. On the other hand, lysine and methionine amino acids have a high digestibility (94% and 95%, respectively) in geese (Penkov et al., 2002, quoted by Sheikh et al., 2018).

In Japan, SWP meals are fed to cattle, pigs, and poultry. Despite having a high percentage of indigestible protein and a favourable amino acid composition, feeding SWP meals to calves is restricted because of its high oil content (Sheikh et al., 2018). SWP meals *in situ* nitrogen degradability is not very effective. According to numerous researchers (Chandrasekharaiah et al., 2002; Sheikh et al., 2018), the effective degradability values (5%/h outflow rate) for undefatted SWP were 29% and 25%, and only 20% for the defatted meal FCR (Chandrasekharaiah et al., 2004). As a result, a significant amount of protein was not degradable, especially from the defatted meal, which was higher in protein.

The rabbits fed SWP recorded a noticeably higher rate of fat deposition and fur growth (Priyadharshini et al., 2017).

In aquafeed, the SWP can replace partially or totally fish meal without adverse effects on fish. Shakoori et al. (2013) replaced the fish meal with SWP in rainbow trout considering for their trial 4 diets groups: T1 with 100 % fish meal, T2 with 5 % SWP + 95 % fish meal, T3 with 10 % SWP + 95 % fish meal, and T4 with 15 % SWP + 95 % fish meal and one control group. The findings showed that SWP can induce some anaemia-related symptoms while stimulating the immune system in rainbow trout.

Silkworm pupae for pigs feeding

The volume of knowledge on using SWP in pig diets is modest. The majority of pigs farmers complete soybean meal in growing phases 1, 2, and 3 with fish meal due to the high protein requirement of pigs. The issues arise when it is necessary to replace classically fed ingredients with more sustainable sources of protein and oil. Interestingly, pupae's protein is superior to that of soy and fish. Due to its high protein content, the pupal powder is recommended to be used as food for pigs (Trivedy et al., 2008), although the higher oil content can determine a negative response.

Table 5. Effects of dietary addition of SWP in pigs' diet compared to classical fish meal (FM) protein rich source

References	SWP level	Pigs' category and breed	Period	Performances
Ramamoorthi and Mercy (2003)	0, 3% and 4% and 6.7% (substitute for FM protein 0, 50 and 100%)	Growing-finishing Large White Yorkshire ♀	90 days	- weight gain (kg): 45.9 and 44.6 vs. 43.3 kg; - average daily gain (g/day): 510.1 and 495.7 vs. 481.4 g; - feed conversion ratio (kg feed to kg gain): 3.63 and 3.62 vs. 3.78.
Medhi et al. (2018)	0, 3% and 7% (0, 50 and 100% replacement of FM, with or without enzymes supplementation at the rate of 65 g/100 kg feed).	Growing crossbred (Hampshire Ã - Assam local pigs)	70 days	No significant differences were observed for average daily gain, dry matter intake, digestibility of nutrients as well as balance of energy and nitrogen, except that the digestibility of ether extract increased by supplementation of enzyme in the diet.
Choudhury et al. (2021)	SWP muga, 0, 2% and 4% as substitute for FM	Grower pigs Large White Yorkshire	45 days	- average daily gain (g/day): 127 and 146 vs 125; - feed conversion ratio (kg feed to kg gain): 3.16 and 2.87 vs 3.45.

Coll et al. (1992), cited by Sheikh et al. (2018), mentioned that a non-defatted SWP meal could partially replace soy oil meal in growing and finishing pigs' diets without significantly affecting growth performance or carcass traits. However, there was noticed a negative effect on intake when the substitution rate exceeded 50%. The lower intake was compensated, though, by a higher feed conversion rate. Medhi (2011) carried out an investigation on finishing cross-breed pigs to assess the alteration of certain blood parameters as reference markers for health status. No significant differences were observed. According to a study conducted by Choudhury et al. (2021), Table 5, feeding Large White Yorkshire grower pigs 2% and 4% of Muga SWP enhanced overall production performance while lowering production costs.

CONCLUSIONS

This review revealed the various applications of one of the main silkworm by-products for the livestock industry, emphasising pig feeding. While looking through more than 60 papers online, there are few comprehensive scientific studies on using SWP in pig diets. Most of them target fish and poultry, but they also target cattle. Mulberry leaves, the single component of the diet of silkworms *Bombyx mori*, have a strong correlation with the SWP composition. All authors agree that SWP is a remarkable source of nutrients for animal feeding, with protein constituting the predominant compound which provides a valuable amino acid composition. Additionally, the structure of the lipids is advantageous to health due to their high content of essential fatty acids, particularly n-3. The vitamins, minerals, and other bioactive compounds complete this nutritional value of SWP. Due to the SWP composition, this could be an important ingredient for animal feed. There were no detrimental effects on environmental pollution, meat and egg quality, animal health, or livestock productivity. However, to complete the informational package, the subsequent pig research should be performed.

ACKNOWLEDGEMENTS

This study was funded by the Ministry of Agriculture and Rural Development and supported by the Academy of Agricultural and Forestry Sciences, Romania.

REFERENCES

Aart, K.W.P. (2020). How to develop insect-based ingredients for feed and food? A company's perspective. *Journal of Insects as Food and Feed*, 6(1), 67-68. Special Issue: Insects to feed the word. doi.10.3920/JIFF2018.x008.

Adeduntan, S.A., & Oyerinde, A. S. (2010). Evaluation of nutritional and antinutritional characteristics of obeche (*Triplochition scleroxylon scleroxylon*) and several mulberry (*Morus alba*) leaves. *African Journal of Biochemistry Research,* 4, 175–178.

Asimi, O. A., Bhat, T. H., Nasir, H., & Irfan, K. (2017). Alternative Source of Protein "Silkworm Pupae" (*Bombyx Mori*) In Coldwater Aquaculture. *International Journal of Poultry and Fisheries Science,* 1, 1-4.

Banaszkiewicz, T. (2011). *Nutritional Value of Soybean Meal.* EBOOK (PDF) doi: 10.5772/23306

Chandrasekharaiah, M., Sampath, K. T., & Thulasi, A. (2002). Rumen protein degradability of certain feedstuffs in cattle determined by nylon bag technique. *Indian Journal of Dairy Bioscience*, 13, 18-21.

Chandrasekharaiah, M., Sampath, K. T., Praveen, U. S., & Umalatha, I. (2004). Chemical composition and in vitro digestibility of certain commonly used feedstuffs in ruminant rations. *Indian Journal of Dairy Science*, 57, 114-117.

Choudhury, M., Barman, K., Banik, S., & Das, P. J. (2021). Effect of dietary inclusion of muga silkworm pupa meal on the growth performance of Large white Yorkshire grower pigs. *International Journal of Creative Research Thoughts, 9 (5).*

Coll, J.F.C., Crespi, M.P.A.L, Itagiba, M.G.O.R., Souza, J.C.D., Gomes, A.V.C., & Donatti, F.C. (1992). Utilization of silkworm pupae meal (*Bombyx mori* L.) as a source of protein in the diet of growing finishing pigs. *Rev. Soc. Bras. Zootec*., 21, 378-383.

Dev, P., Ramappa, V. K., Gopal, R., & Sangeeta, M. (2017). Analysis of chemical composition of mulberry silkworm pupal oil with fourier transform infrared spectroscopy (FTIR), gas chromatography/mass spectrometry (GC/MS) and its antimicrobial property. A*sian Journal of Agricultural Research*, 11, 108-115.

Dezmirean, D., Mărghitaş, L.A., Bobiş, O., Urcan, A.C., Dezmirean, H., Paşca, C., & Moise, A.R. (2018). Multidirectional activities for gene pool conservation in GCEARS-PSP. *Bulletin UASVM Animal Science and Biotechnologies*, 75(1), 5-10.

DiGiacomo, K., & Leury, B. J. (2019). Review: Insect meal: a future source of protein feed for pigs. *Animal,* 13(12), 3022-3030.

Dolis, M. (2008). *Sericiculture*. Bucharest, RO: Alfa Publishing House.

Dong, H. L., Zhang, S. X., Tao, H., Chen, Z. H., Li, X., Qiu, J. F., Cui, W. Z., Sima, Y. H., Cui, W. Z, & Xu, S. Q. (2017). Metabolomics differences between silkworms (*Bombyx mori*) reared on fresh mulberry (*Morus*) leaves or artificial diets. *Scientific Reports,* 7(1), 1–16.

Fagoonee, I. (1983a). Inclusion of silkworm pupae in poultry rations. *Tropical Veterinary Journal*, 1, 91-96.

Fagoonee, I. (1983b). Possible growth factors for chickens in silkworm pupae meal. *British Poultry Science,* 24, 295-300.

Finke, M. D. (2002). Complete nutrient composition of commercially raised invertebrates used as food for insectivores. *Zoo Biology*, 21(3), 269–285.

Food and Agriculture Organization of the United Nations (FAO) (2013). *Edible insects' Future prospects for food and feed security*. Accessible at: https://www.fao.org/3/i3253e/i3253e.pdf

Herman, R. A., Yan, C.H., Wang, J.Z., Xun, X. M., Wu, C.K., Li Z. N., Ayepa, E., You, S., Gong, L. C., & Wang J. (2022). Insight into the silkworm pupae: Modification technologies and functionality of the protein and lipids. *Trends in Food Science & Technology,* 129, 408-420.

Iqbal, S., Younas, U., Sirajuddin, Chan, K. W., Sarfraz, R. A., & Uddin, K. (2012). Proximate composition and antioxidant potential of leaves from three varieties of mulberry (*Morus* sp.): A comparative study. *International Journal of Molecular Science,* 13, 6651–6664.

Jeyaprakashsabari, S., & Aanand, S. (2021). Silkworm Pupae Meal - A Promising Fish Meal Substitute in Aqua Feed. *AgriCos e-Newsletter,* 02 (07), 17.

Karnjanapratum, S., Kaewthong, P., Indriani, S., et al. (2022). Characteristics and nutritional value of silkworm (*Bombyx mori*) pupae-fortified chicken bread spread. *Scientific Reports.* 12, 1492.

Karthick, R. P, Aanand, S., Sampathkumar, J.P., & Padmavathy, P. (2019). Silkworm pupae meal as alternative source of protein in fish feed. *Journal of Entomology and Zoology Studies,* 7(4), 78-85.

Khatun, R., Azmal, S. A., Sarker, M. S. K., Rashid, M. A., Hussain, M. A., & Miah, M. Y. (2005). Effect of Silkworm Pupae on the Growth and Egg Production Performance of Rhode Island Red (RIR) Pure Line. *International Journal of Poultry Science,* 4 (9), 718-720.

Kotake-Nara, E., Yamamoto, K., Nozawa, M., Miyashita, K., & Murakami, T. (2002). Lipid profiles and oxidative stability of silkworms pupal oil. *Journal of Oleo Science,* 51(11), 681-690.

Kumar, D., & Rajesh, K. R. (2015). Biomedical Applications of Silkworm Pupae Proteins. *Biochemistry and Molecular Biology. Biomedical Applications of Natural Proteins.* (Chapter 3), 41–49.

Lamberti, C., Gai, F., Cirrincione, S., Giribaldi, M., Purrotti, M., Manfredi, M., Marengo, E., Sicuro, B., Saviane, A., Cappellozza, S., Giuffrida, M. G., & Cavallarin, L. (2019). Investigation of the protein profile of silkworm (*Bombyx mori*) pupae reared on a well-calibrated artificial diet compared to mulberry leaf diet, *PeerJ,* 7:e6723, doi 10.7717/peerj.6723.

Liu, J. X., Jun, Y., Yan, B. J., Shi, Z. Q., Wang, X. Q., & Yu, J. Q. (2002). Mulberry leaf supplement for sheep fed ammoniated rice straw. In: Sánchez, M. D. (Ed.), Conf. paper "Mulberry for animal production". Proc. e-conf., May-Aug. 2000. *FAO Animal Prod. and Health Paper*, 147, 189-201.

Łochyńska, M., & Frankowski, J. (2018). The biogas production potential from silkworm waste. *Waste Management,* 79, 564-570.

Mahmoud, K. M. (2017). Impact of nutritional composition of wild and cultivated mulberry varieties on productivity and some biochemical parameters of silkworm *Bombyx mori* L. (Bombycidae: Lepidoptera). *Journal of Applied Plant Protection; Suez Canal University*, 6 (1), 25-30.

Medhi, D., Bhuyan, R., Bhuyan R., Ahmed H.F., & Saikia, B.N. (2018). Effect of Inclusion of Silk Worm Pupae Meal in the Diet with or without Enzyme Supplementation on Nutrient Utilization and Growth

Performance in Crossbred Pigs. *Indian Journal of Animal Sciences,* 33, 3.

Medhi, D. (2011) Effects of enzyme supplemented diet on finishing crossbred pigs at different levels of silk worm pupae meal in diet. *Indian Journal of Field Veterinarian,* 7(1), 24-26.

Meng, X., Feifei, Z., & Chen, K. (2017). Silkworm: A Promising Model Organism in Life Science. Silkworm. *Journal of Insect Science*, 17(5), 97, 1–6.

Miah, M., Singh, Y., Cullere, M., Tenti, S., & Zotte, A. D. (2020). Effect of dietary supplementation with full-fat silkworm (*Bombyx mori* L.) chrysalis meal on growth performance and meat quality of Rhode Island Red Fayoumi crossbred chickens. *Italian Journal of Animal Science*, 19 (1), 447-456.

Moise, A.R., Marghitas, L.A., Bobis, O., Copaciu, F.M., & Dezmirean, D.S. (2018). *Morus Spp*. Material Conservation and Characterization and its Importance for Romanian Sericulture and GCEARS-PSP Development - A Review. *Bulletin UASVM Animal Science and Biotechnologies*, 75(2), 57-63.

Nagaraj, G., & Basavanna, H. M. (1969). Proteins from silkworm pupae. *Silkworm Info. Bulletin*, 1, 29-30.

Nakasone, S., Ito, T. (1967). Fatty acid composition of the silkworm, *Bombyx mori* L. *J Insect Physiol*, 13(8), 1237–1246.

Payne, C. L. R., Scarborough, P., Rayner, M., & Nonaka, K. (2016). A systematic review of nutrient composition data available for twelve commercially available edible insects, and comparison with reference values. T*rends in Food Science & Technology*, 47, 69–77.

Pau, E., & Constantinescu, M. (2008). Solutions for Sericulture Reorganization in Romania. *Proceedings of The First International Conference „Sericulture – From Tradition to Modern Biotechnology", Cluj-Napoca,* 133-140.

Pop, L.L., Mărghitaș, A.L., Dezmirean, D., Bobis, O., Moise, A., & Pasca, C. (2018). Sericiculture industry in Romania - Analysis on current situation and prospects of development. *Scientific Papers. Series D. Animal Science, LXI*(1), 251-258.

Priyadharshini, P., Joncy, M. A., & Saratha, M. (2017). Industrial utilization of silkworm pupae – A review. *Journal of international Academic research for Multidisciplinary,* 5 (7).

Purushothaman, M. R., & Thirumala, S. (1995). Silkworm pupae meal as protein supplement in chick ration. I*ndian Veterinary Journal*, 72, 826-828.

Rafiullah, I. & Khan, S. (2016). *Replacement of soybean meal with silkworm meal (Bombyx mori) in poultry ration.* A dissertation thesis submitted to the University of Agriculture, Peshawar for the degree of doctor of Philosophy in Poultry Science.

Raghuvanshi, T., Bali R.K., & Bukhari, R. (2019). Effect of Different Feeding Frequencies on the Commercial Characters of Silkworm (*Bombyx mori* L.). I*nternational Journal of Current Microbiology and Applied Sciences,* 8(6), 3193-3203.

Rahmathulla, V. K., & Suresh, H. M. (2011). Seasonal variation in food consumption, assimilation, and conversion efficiency of Indian bivoltine hybrid silkworm, *Bombyx mori*. *Journal of Insect Science,* 12.82, available online: insectscience.org/12.82.

Raja, P. K., Aanand, S., Sampathkumar, S.J., & Padmavathy, P. (2019). Silkworm pupae meal as alternative source of protein in fish feed. *Journal of Entomology and Zoology Studies,* 7(4), 78-85.

Ramamoorthi, S., & Mercy, A.D. (2003). Evaluation of silk worm pupae meal on growth performance in large white Yorkshire pigs. *Journal of Veterinary and Animal Sciences*, 34, 6-11.

Ramesha, C., Anuradha, M. C., Lakshmi, H., Kumari, S. S., Seshagiri, V. S., Goel, M., & Kumar, S. C. (2010). Nutrigenetic trait analysis for the identification of nutritionally efficient silkworm germplasm breedings. *Asian network for scientific information,* 9(2), 131-140.

Rohela, G.K., Shukla, P., Muttanna, Kumar, R., & Chowdhury, S.R. (2020). Mulberry (*Morus spp.*): An ideal plant for sustainable development. *Trees, Forests and People,* 2 100011. https://doi.org/10.1016/j.tfp.2020.100011.

Sadat, A., Biswas, T., Cardoso, M.H., Mondal, R., Ghosh, A., Dam, P., Nesa, J., Chakraborty, J., Bhattacharjya, D., Franco, O.L., Gangopadhyay, D., & Mandal, A.K. (2022). Silkworm pupae as a future food with nutritional and medicinal benefits. *Current Opinion in Food Science,* 44, 100818. https://doi.org/10.1016/j.cofs.2022.100818.

Saikia, A., Das, P. C., & Sutradhar, R. (1971). Systematic study of by-products of agro-industrial origin for evolvement of economic poultry rations-layers rations. *Indian Veterinary Journal,* 48, 941-946.

Sanchez, M. D. (2000). Mulberry: an exceptional forage available almost worldwide! *World Animal Review,* 93, 1–21.

Sanchez-Salcedo, E. M, Amoros, A., Hernandez, F., & Martinez, J. J. (2017). Physicochemical properties of white (*Morus alba*) and black (*Morus nigra*) mulberry leaves, a new food supplement. *Journal of Food Nutrition and Research,* 5, 253–261.

Sarkar, T., Mogili, T., & Sivaprasad, V. (2017). Improvement of biotic stress adaptative traits in Mulberry (Morus spp.): an update on the biotechnological interventions. *Biotech*, 7 (3), 214.

Shakoori, M., Gholipour, M., & Naseri, S. (2013). Effect of replacing dietary fish meal with silkworm (*Bombyx mori*) pupae on hematological parameters of rainbow trout *Oncorhynchus mykiss*. *Comparative Clinical Pathology.* doi 10.1007/s00580-013-1872.

Sharma, A., Gupta, G. K., Sharma, P., Duwa, Kapil A., Bandral, R.S., & Bal, K. (2022). Silkworm as an edible insect: A review. T*he Pharma Innovation Journal,* SP-11(2), 1667-1674.

Sheikh, I.U., Banday, M.T., Baba, I.A., Adil, S., Shaista, S. N., Bushra, Z., & Bulbul, K.H. (2018). Utilization of silkworm pupae meal as an alternative source of protein in the diet of livestock and poultry: A review. *Journal of Entomology and Zoology Studies,* 6(4), 1010-1016.

Srivastava, S., Kapoor, R., Thathola, A., & Srivastava, R. P. (2006). Nutritional quality of leaves of some genotypes of mulberry (*Morus alba*). *International*

Journal of Food Sciences and Nutrition, 57(5/6), 305313. doi: 10.1080/09637480600801837.

Tănase, D. (2007). The agro productive characterization of the mulberry varieties used in the amelioration programs. *Lucrări ştiinţifice Zootehnie şi Biotehnologii*, 40(2), 141-149.

Tassoni, L., Cappellozza, S., Zotte, A. D., Belluco, S., Antonelli, P., Marzoli, F., & Saviane, A. (2022). Systematic Review. Nutritional Composition of *Bombyx mori* Pupae: A Systematic Review. Insects. 13, 644. https://doi.org/10.3390/insects1307064.

Thaipitakwonga, T., Numhomb, S., & Aramw, P. (2018). Mulberry leaves and their potential effects against cardiometabolic risks: a review of chemical compositions, biological properties and clinical efficacy. *Pharmaceutical Biology*, 56, 1, 109–118.

Tomotake, H., Katagiri, M., & Yamato M (2010). Silkworm pupae (*Bombyx mori*) are new sources of high-quality protein and lipid. *Journal of Nutritional Science and Vitaminology,* 56, 446–448.

Trivedy, K., Kumar, S. N., Mondal, M., & Bhat, C. A. K. (2008). Protein banding pattern and major amino acids components in de-oiled pupal powder of silkworm, *Bombyx Mori* L. *Journal of Entomology,* 5, 10-16.

Ullah, R., Khan, S., Khan, N. A., Mobashar, M., & Lohakare, J. (2017). Replacement of soybean meal with silkworm meal in the diets of White Leghorn layers and effects on performance, apparent total tract digestibility, blood profile and egg quality. *International Journal of Veterinary and Health Science Research*, 5(7), 200-207.

Valerie, H., Tran, G., Giger-Reverdin, S., & Lebas F., 2015. *Silkworm pupae meal.* Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Available at: http://www.feedipedia.org/node/199.

Wu, X., He, K., Cirkovic Velickovic T.C., & Liu, Z. (2021). Nutritional, functional, and allergenic properties of silkworm pupae. *Food Science Nutrition,* 9, 4655–4665.

Zhang, X., Xue, R., Cao, G., Pan Z., Zheng X., & Gong, C. (2012). Silkworms can be used as an animal model to screen and evaluate gouty therapeutic drugs. *Journal Insect Science,* 12, 4. doi: 10.1673/031.012.0401.

Zhou, J., & Han, D. (2006). Proximate, amino acid and mineral composition of pupae of the silkworm *Antheraea pernyi* in China. *Journal of Food Composition and Analysis*, 19(8), 850-853.

Observatory of Economic Complexity (OEC; https://oec.world/

Animal feed resources information system, Feedpedia. www.feedpedia.ro