University of South Bohemia in České Budějovice

Faculty of Economics

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Summary of the dissertation thesis

Waste as a source of business opportunities for circular economy and bioeconomy

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České Budějovice, 2024

Bibliographic data

Author	Ing. Anna Marouškova Faculty of Economics Department of Regional Management and Law
Dissertation title	Waste as a source of business opportunities for circular economy and bioeconomy
Study program	Economics and Management
Study field	P6208 Management and Business Economics
Supervisor	doc. Ing. Eva Cudlínová, CSc.
Year	2024
Keywords	Bioeconomy; circular economy; competitiveness; feed; insect protein

Abstract

This dissertation thesis underlines the promising potential of biowaste processing using Black Soldier Fly (BSF) larvae with the subsequent production of value-added products such as feed components, fertilizers, cosmetics, etc. The concept is gaining global popularity, although legislative challenges initially hindered EU companies, resulting in delays in the placement of BSF products on the market. Nevertheless, EU enterprises, leveraging the time afforded by evolving legislation, emerged with cutting-edge technologies, positioning them to produce high-quality protein for animal feed and other value-added products. The study reveals a significant correlation between business development and scientific achievements in the field of BSF rearing in the EU and EFTA Member states. Another finding of this study was that countries with established Bioeconomy strategies at the national level show higher numbers of publications and established companies in the field of BSF rearing compared to those with Bioeconomy strategies under development or other bioeconomy-related policies. However, the biggest finding of this study is the results of the BSF meal, soybean meal and fish meal competitiveness analysis for the first time conducted in the Czech Republic. The comprehensive analysis showed that BSF meal has the potential to compete with products like soybean meal and fish meal despite its current market price is still a major drawback. The main benefits of the BSF meal are well-balanced nutritional properties and demonstrated positive ecological impact. It was also discovered that under the current conditions, the key bottlenecks are insufficient BSF products supply and the overly strict EU legislation which causes challenges in the price competitiveness. However, based on the review accompanied by the competitiveness analysis results and taking into account political trends, it can be concluded that industrial insect rearing represents a significant commercial potential.

Content

1. Introduction

The continuously growing amount of various types of biowaste represents one of the most frequently mentioned untapped economic opportunities in academic literature. Especially, food waste represents a challenge that needs an immediate solution, since a significant part of this biowaste is still being landfilled even in the EU (Di Maria et al., 2018) which causes many environmental and economic issues. Environmental concerns include (but are not limited to) release of greenhouse gases due to the organic matter decay in the landfill and landfills' bodies collapse (Huang and Fan, 2016). Economic negatives can be interpreted as increasing the production costs of agricultural commodities, which are unnecessarily burdened by operations related to waste management (Agovino et al., 2020). On the other hand, the global population growth increases the need for food and feed which not only worsens the issue of food waste but also causes food insecurity and malnutrition in a significant part of the world (FAO, 2021). Therefore, the transformation towards more sustainable food systems is crucial. Ensuring less waste and making sustainable products the norm while promoting the circular economy (CE) concept - are priorities of the EU Circular Economy Action Plan, which is one of the main building blocks of the European Green Deal (EC, 2020). Implementation of innovative food waste management technologies that are in accordance with the circular bioeconomy economy principles is essential for mitigating negative environmental and economic impacts (Vea et al., 2018). One such method is food waste reduction via its utilization using insects. Moreover, this method allows turning biowaste into various value-added products such as protein for animal feed, fertilizers, oil, and many others (Cappellozza et al., 2019).

It's important to note, that developing alternative protein sources, including insect-based protein, is a keystone of the EU's Farm to Fork strategy which aims to enhance the transition to more sustainable food production and consumption (Jensen et al., 2021). According to various studies (Cortes et al., 2016; van Huis and Oonincx, 2017; Madau et al., 2020) insect-based protein has a great potential to substitute conventional protein sources like soybean meal or fish meal, and contribute to the transition to environmentally more sustainable food systems. Moreover, insects are considered as an important component for enhancing the circularity of the bioeconomy since industrialized insect rearing can transform food waste into valuable food and feed products (Jensen et al., 2021). According to the Updated Bioeconomy Strategy (2018), a significant reduction of food waste by 2030 and its transformation into valuable sources represents the key challenge of the European Bioeconomy Strategy and its Action Plan. Thus, this work, inter alia, deals with an overview of existing Bioeconomy Strategies on different

levels and their possible influence on the development of the insect industry in the EU and EFTA (European Free Trade Association) Member states. Business development in general is affected by the state of knowledge in particular field, therefore a correlation analysis on the number of published publications, patents, and established companies in the field of one selected insect species namely Black Soldier Fly (BSF, *Hermetia Illucens*) rearing is conducted in the EU and EFTA Member states. Last but not the least, a competitiveness analysis of selected BSF product available on the EU market was carried out to learn the potential of this product to substitute products such as soybean meal and fish meal, and therefore the potential to promote the transition to a more sustainable business models and circular bioeconomy concept.

2. Aim of the work and research hypotheses

The first objective of this work is to investigate if there is a correlation between the achievements of the academic sector and the business sector in the field of Black Soldier Fly rearing in the EU and EFTA Member states. Any business development is also highly dependent on the state of the knowledge in a particular field Thus, the correlation analysis between the number of companies and patents (representing the business sector), and scientific publications (representing the academic sector) in the field of BSF rearing is conducted across the EU and EFTA Member states. The following hypothesis resulted from this objective:

H1: There is a significant correlation between business development and the scientific achievements of the academic sectors in the BSF rearing in the EU and EFTA Member states.

The second objective is to review Bioeconomy strategies in the world and find out if countries with Bioeconomy strategies adopted on the national level have better achievements both in the academic and business sectors in the field of BSF rearing with the focus on the EU and EFTA Member states. The following hypothesis resulted from this objective:

H2: Established Bioeconomy strategies on the national level positively affect the development of the business and academic achievements in the field of BSF rearing in the EU and EFTA Member states.

The third objective is to analyze the competitiveness of BSF biorefining products and their potential to transform the current waste management practices towards a more sustainable business model. The following hypothesis resulted from this objective:

H3: BSF products are competitive substitutes for products such as fish meal and soybean meal, and therefore BSF business concept has the potential to promote the transition to a more sustainable business model and support the development of circular bioeconomy concept.

3. Methodology

Firstly, assessment of the current state of the academic and business development in the field of BSF rearing was performed in the EU and EFTA Member states. Obtained data were statistically analyzed. For purpose of this study Poisson regression model was chosen to analyze the relation between number of publications, patents, and companies in the field of BSF rearing. Secondly, current Bioeconomy strategies in the EU Member states and the rest of the world were reviewed. In the next step numbers of publications and companies were compared in countries with Bioeconomy strategies at the different levels. Thirdly, a survey was conducted to analyze the competitiveness of BSF products and their potential to promote the transition to more sustainable economic model.

3.1. Academic and business development assessment (H1)

First, the number of published publications, published patents and established companies in the EU and EFTA Member states were quantified according to the procedure described in 3.1.1. Data from the United Kingdom were also incorporated since all companies included in the research were established before 31. 12. 2020, therefore before Brexit, and a significant number of publications and patents were published before that date as well. Obtained data were statistically analyzed via the Statistica® (version 13.6.0) analytics software (TIBCO Software Inc., CA, USA). In order to evaluate the relationship between the number of publications, patents and companies based on pairwise combinations, a nonparametric correlation estimator, namely Spearman correlation (Croux and Dehon, 2010) was used. Then, the relation between the number of publications and patents was analyzed via the Poisson regression model (Nussbaum et al., 2011), which is a type of generalized linear model, where the dependent variable is not continuous and is far from being normally distributed. As an independent variable was selected the number of publications and the number of patents was selected as the response variable. The relation between the number of publications and the number of companies was analyzed in the same manner, picking the latter as a response variable.

3.1.1. Quantification of publications, patents, and companies

The quantification of publications was conducted via the Web of Science research database (Clarivate, USA) according to the following parameters: 1/topic: "Hermetia Illucens" OR "Black Soldier Fly"; 2/publication years: 2010 – 2022; countries: EU + EFTA Member states that contributed to the research (Italy, Netherlands, Germany, Belgium, Spain, United Kingdom (England, Scotland, Wales, and Northern Ireland), Switzerland, Poland, Norway, Portugal, France, Sweden, Denmark, Czech Republic, Greece, Austria, Finland, Bulgaria, Romania,

Slovakia, Slovenia, Ireland, Hungary, Iceland, Croatia, Lithuania, Estonia, Latvia, Luxembourg)

The quantification of patents was conducted via the Google patents database (Alphabet, Inc., USA) according to following parameters: 1/ search terms: "*Hermetia Illucens*" OR "Black Soldier Fly"; 2/ search fields: publication date from 01.01.2010 to 31.12.2022 (each year during this period was evaluated separately); and patent office: EP (The European Patent Office), BE, BG, CZ, DE, DK, EE, IE, FR, GB, IT, LT, LU, LV, HU, MT, NL, AT, PL, PT, RO, SI, SK, SE, FI, GR, CY, NO, CH, IS, LI, WO (World Intellectual Property Organization). The WO patent office affiliation was added due to the fact that in the majority of cases patents with WO affiliation at the same time had affiliation in one of the EU or EFTA member states, but the EP affiliation was not indicated. Moreover, mostly those patents were assigned to one of the companies based in the EU (Ynsect, Protix B. V, InnovaFeed).

The quantification of companies was conducted via: 1/ Google search engine (Alphabet, Inc., USA); 2/ LinkedIn a social media platform for business; 3/ literature (Wang and Shelomi, 2017; Skyquest, 2022; Grossule et al., 2023) and 4/ International Platform of Insects for Food and Feed (IPIFF, 2023). The year of establishment of each company was searched via Amadeus database of comparable financial information for public and private companies across Europe (Bureau van Dijk – A Moody's Analytics Company, Belgium).

3.2. Bioeconomy strategies comparison (H2)

A review of existing Bioeconomy strategies around the world was performed based on the data from the Web of Science research database (Clarivate, USA) and published Bioeconomy strategies of different EU Member states as well as other countries around the world. Subsequently, numbers of publications and companies in the field of BSF rearing were compared in the EU and EFTA Member states with Bioeconomy strategies at the different levels. The quantification of companies and publications included in the comparison is explained in the subsection 3.1.1.

3.3. Competitiveness analysis (H3)

Competitiveness analysis was conducted through a survey specially designed for this study, followed by a thorough evaluation of the outcomes in line with the recent scientific advancements. The main objective of the survey was to explore the degree of importance of the key parameters that influence decision-making in the selection of feed components. The questionnaire aimed mainly at feed manufacturers or sellers and farm animal producers, but also at the academic staff and experts with the focus on animal nutrition.

The keywords “poultry feed”, “fish feed”, “pig feed”, “petfood”, and “protein” were entered into the search fields of scientific databases (Web of Science, Scopus and Google Scholar), with the time span set to last 10 years. The most cited publications from each database were scanned for the Abstract to assess relevance (possible substitutes for BSF products in the feed industry). Also, colleagues within the University of South Bohemia in České Budějovice, as well as independent experts working in feed science, were approached personally. Key players in the local feed market were contacted. Those who agreed to participate in the research were interviewed in a controlled manner to independently ascertain what the current state of the feed market is and what the main sources of protein are in the most traded pig, poultry, fish feed and petfood. Based on the results of literature research and consultation with experts, from a wide range of BSF products for the purpose of this survey defatted BSF meal (hereinafter BSF meal) was picked as a potential substitute for soybean meal and fish meal. Therefore, the survey compares those three main protein sources and analyses the possible replacement of soybean meal and fish meal with a BSF meal for feed purposes.

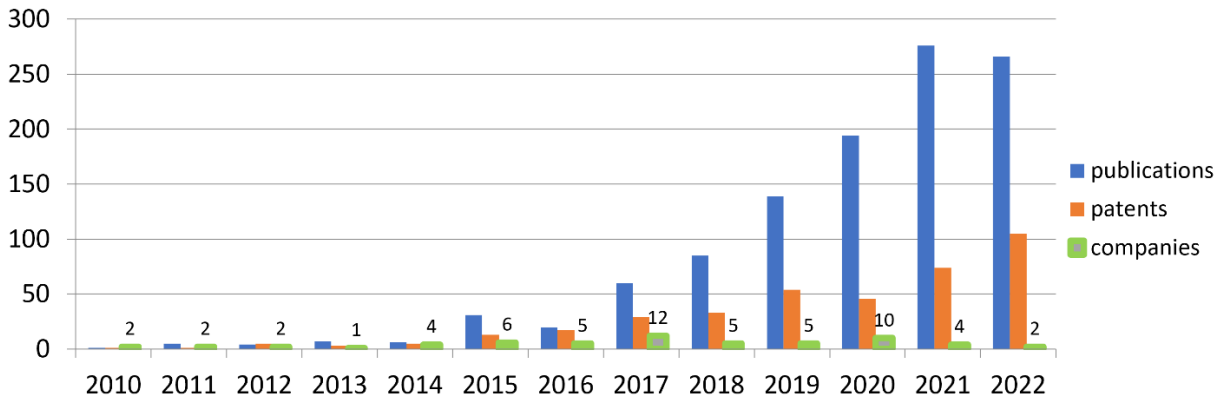
The paid version of the Survio® online survey service was purchased, which allows to create advanced questionnaires and subject them subsequently to a number of complex analyses. The online questionnaire was designed in the Survio® system based on the knowledge obtained through literature research, market research and a controlled discussion with experts and key players on the feed market. Each of the 14 questions of the questionnaire was designed with respect to different groups of stakeholders in order to gain a deeper awareness of the opinions of the professional public and to obtain supporting arguments to confirm or refute H3.

4. Results and discussion

4.1. H1

In total, more than 1000 publications, almost 400 patents, and at least 60 companies in the field of BSF rearing in the EU and EFTA Member states were included in this research.

Figure 1: Annual increases in the number of publications, patents, and established companies in the field of BSF rearing in the EU + EFTA Member states (2010-2022)



Source: own elaboration

A significantly increasing trend in the number of publications, patents, and companies in the field of BSF rearing during the last decade can be seen in Figure 1. As for the number of companies, Figure 1 shows there are some fluctuations in its development. This could be caused by a variety of factors. First of all, very likely not all companies engaged in BSF rearing were included in this research since some of them couldn't be easily found in the procedure described in 3.1.1., for instance, due to the lack of a website in the English language. Nevertheless, all major players in the EU and EFTA such as Ynsect (France), Protix (Netherlands), Bioflytech (Spain), etc. (Skyquest, 2022; Grossule et al, 2023) were included in the analysis. A relatively higher amount of newly established BSF companies in 2017 and 2020 can be connected with the expectations of more favorable legislative changes in the EU. In 2017 the protein originating from seven insect species including BSF was allowed as feed for aquaculture and in 2021 it was fully approved as poultry and pig feed (Montanari et al., 2021). The exponential increase in the number of publications about BSF and the growing number of companies interested in its commercialization is also pointed out by Tomberlin and van Huis (2020).

The results of statistical analysis of the collected data using Spearman correlation based on pairwise combinations between three investigated indicators (number of publications, number of patents and number of companies) showed a significant relationship between the number of publications and the number of patents with a coefficient of almost 0.95. The correlation

coefficient between the number of publications and the number of companies was almost 0.45 which is also considered as significant. Results of the Poisson regression also showed a statistically significant relationship between the number of publications and the number of patents with a p-value equal to 0 indicating high statistical significance. Similar relation has the number of publications and the number of business entities with a p-value around 0.014, which is less than the significance level of 0.05 and thus is considered statistically significant (Myers et al., 2010).

Based on the results of this study it can be stated that all three indicators (the number of publications, patents, and companies in the field of BSF rearing) are interconnected and develop together. Although at first glance it seems that the H1 has been confirmed, the limitations connected with the chosen data shouldn't be neglected. As the most substantial limitations could be stated: 1/ time delay in the publication of patents and scientific papers; 2/ patent assignment to a specific country; 3/ companies' geographic allocation (many companies, decide to move their business to other countries due to the business environment).

4.2. H2

It is noteworthy that the highest number of publications and BSF companies (including major players) are in countries with established Bioeconomy strategies on the national level such as Italy, Netherlands, Germany, France, etc. (Table 1). Moreover, most of those member states' Bioeconomy strategies, especially their latest updated versions, consider insects as a potential solution for various sectors, including food and feed production, waste management, and alternative protein sources. For instance, in the National Bioeconomy Strategy of Germany (BMBF, 2020) the use of insects and also algae, fungi, and microorganisms is stated as a necessary step to achieve sustainable production in both agriculture and industry. Therefore, the German Federal Government commits to supporting such practices with appropriate funding measures.

As well a New Bioeconomy Strategy for a Sustainable Italy (BIT II, 2019) mentions that insects, algae, etc. have the potential for developing alternative protein sources. Also, Bioeconomy a Strategy for Austria (2019) has recommended the insect protein produced from biowaste as an attractive source of protein for the future. It is stated in the Strategy that the production of insect protein could decrease dependence on imported feed, and it could be achieved without using additional land, also the concept could contribute to better utilization of otherwise unused nutrients. Even though Austria is not among those member states with the highest number of publications or companies in the field of BSF rearing, it has adopted its

Bioeconomy strategy as one of the last, therefore the latest solutions and achievements in the insect industry could be incorporated in the strategy.

Table 1: The list of countries with established Bioeconomy strategies at the national level and with the highest number of publications and companies.

	Number of publications	Number of companies	Number of major players
Italy	274	4	2
Netherlands	118	8	2
Germany	103	9	2
Spain	65	4	2
UK	63	6	3
Norway	48	0	0
France	38	8	4
Portugal	38	1	1
Austria	17	3	2
Finland	4	3	1
Estonia	2	0	0
Ireland	0	1	1

Source: own elaboration

In Table 1 were included EU and EFTA Member states with the highest number of publications and companies in the field of BSF rearing and at the same time with established Bioeconomy strategies at the national level. The UK was also included in the Table 1 since at the time of the research it was still a member of the EU and even after the Brexit and its national Bioeconomy strategy was withdrawn another strategy related to the bioeconomy was adopted at the national level.

As can be seen from Table 2, among Member states with dedicated Bioeconomy strategy at national level under development or other policy initiatives related to the bioeconomy, there are only few countries with high publication numbers and only 1 or 2 BSF companies in most of them. Moreover, those are rather small or medium enterprises with a little influence on the market. Noteworthy are one located in Poland and the one in Bulgaria, both can be considered as a major player. Regarding EFTA member states, only Norway has established Bioeconomy strategy on the national level which, by the way, mentions insects as a renewable biological resource for new advanced production opportunities (Norwegian Ministries, 2016).

Table 2: Numbers of publications and companies in the field of BSF rearing in the member states with dedicated Bioeconomy strategy at the national level under development or other policy initiatives related to the bioeconomy

	Number of publications	Number of companies	Number of major players
Belgium	89	1	
Switzerland	58	3	
Poland	51	2	1
Sweden	34	1	
Denmark	29	2	
Czech Republic	14	0	
Greece	11	0	
Bulgaria	8	1	1
Romania	7	1	
Slovakia	6	0	
Slovenia	6	0	
Hungary	4	2	
Lithuania	3	1	
Croatia	3	1	
Lichtenstein	0	1	

Source: own elaboration

Based on the above-mentioned results, it can be stated that having established a dedicated Bioeconomy strategy on the national level positively affects the development of the business and academic achievements in the field of BSF rearing in the given country. Therefore, it's possible to consider the H2 as confirmed. However, further research is needed to investigate whether the high numbers of publications and companies in countries with dedicated Bioeconomy strategy on the national level is conditioned by the fact of having the strategy itself or another reasons like government financial support or other more favorable conditions. Nevertheless, as the insect production sector grows and regulatory restrictions are eased, it is anticipated that the insect industry will play an increasingly significant role in advancing the bioeconomy concept (Skrivervik, 2020). This is particularly likely once the use of food waste as a substrate for feeding insects becomes permissible.

4.3. H3

The survey named Feed ingredients competitiveness analysis was sent out among nearly one hundred potential respondents in the Czech Republic. The questionnaire was disseminated among feed manufacturers, feed sellers, local farmers, other relevant stakeholders and in the local scientific community with the focus on animal nutrition. Such kind of a survey related to BSF products competitiveness analysis was conducted for the first time in the Czech Republic. Overall feedback of the respondents was quite positive, which looks promising in case of an effort of placing BSF products for farm animals on the local market. In total forty-three answers were collected, twenty-three (54%) of which were from feed manufacturers and sellers, eleven (25%) from animal producers, five (12%) from the academic staff of experts with a focus on the animal nutrition and four (9%) from other stakeholders (mostly teachers or technicians in the field of animal nutrition). The respondents were asked to evaluate feed ingredients' key parameters which were divided into four groups:

1. **Nutritional properties** (protein content, amino acids, fatty acids, carbohydrates, minerals, vitamins, fiber, energy MJ/kg, digestibility, palatability)
2. **Ecological aspects** (energy consumption, water consumption, land use, carbon footprint, use of agrochemicals, load on water bodies, deforestation)
3. **Logistical aspects** (delivery time, storage time, local availability)
4. **Price** (price per protein content and price per unit of weight)

Respondents had to assign one of the five types of the degree of importance to each key parameter: "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure". The comparison of soybean meal, BSF meal, and fish meal based on the respondents' answers on degree of importance of nutritional properties, ecological aspects, logistical aspects, and price and the literature review regarding each parameter of those three products is presented in Table 3. The data in the blue cells show parameters of a similar value for soybean meal, BSF meal, and fish meal. The data in the green cells represent competitive advantages and the data in orange cells competitive disadvantages of each product. The value of the data in the grey cells cannot be clearly determined. The values of the degree of importance for each parameter given in the last column represent the ratio of respondents stated in the questionnaire that these parameters are "Very important".

Table 3: Key parameters for soybean meal, BSF meal and fish meal production

Evaluation criteria	Soybean meal	BSF meal	Fish meal	Degree of importance (%)
Nutritional properties				
Protein content (%)	50	60	70	**65**
Amino acids	well-balanced	well-balanced	well-balanced	**49**
Fatty acids	low content of omega-3	Lauric acid	high content of omega-3, EPA, DHA	28
Carbohydrates (%)	20 - 30	22	less than 5	26
Minerals	Cu, K, P	Ca, Cu, Fe, Mn, P, Zn	Ca, P	**42**
Vitamins	choline, niacin, E	B1, B2, C, E	A, B12, D, E, choline, biotin, selenium, iodine	40
Fiber (% of DM)	3 - 7	5 - 10	less than 5	**42**
Energy MJ/kg	15 - 18	21 - 24	20 - 25	**56**
Digestibility (%)	82 - 91	85 - 99	90	**88**
Palatability				**51**
Ecological aspects				
Energy consumption (GJ/t)	high level			**56**
Water consumption (L/t)				**47**
Land use (ha/t)				35
Carbon footprint (kg CO2 eq./t)				30
Use of agrochemicals	high level			28
Load on water bodies			high level	**42**
Deforestation				**44**
Logistical aspects				
Delivery time				**54**
Storage time (months)	6 - 24	12	6 - 24	**56**
Local availability		N/A		**51**
Price				
Price per protein content (EUR/% in kg)	0.01	0.07	0.02	**63**
Price per unit of weight (EUR/kg)	0.5	4	1.5	**58**

Source: own elaboration based on the survey results and literature research

As can be seen from the values of the degree of importance of each parameter (Table 3), the most important (with value more than 50%) for the survey respondents are: protein content, energy, digestibility, and palatability (from the nutritional properties), energy consumption (from ecological aspects), all parameters from logistical aspects (delivery time, storage time, local availability) and both price parameters (price per protein content, price per unit of weight).

In terms of **nutritional parameters** all three protein sources have similar properties. The exact composition of each meal varies depending on different factors such as the processing method, the type of substrate, which was fed to larvae, the origin destination where it comes from in case of soybean, the origin and type of fish the fish meal was produced from, etc. Each of the three meals is suitable for an animal diet depending on the specific animal need. And it can be stated that BSF meal is a highly competitive product when compared to soybean and fish meal.

As for **ecological aspects**, soybean meal has the highest number of orange cells in Table 3, which reflects higher negative impact on the environment (all ecological parameters except the “load on water bodies”, which is difficult to determine). In case of fish meal “energy consumption”, “carbon footprint”, and “load on water bodies” are the parameters with negative impact on the environment, thus they are given an orange color. BSF meal has all ecological parameters in green color, except of “energy consumption” which in some cases can be high if the heating is needed for BSF larvae rearing. However, in comparison with energy consumption related to soybean meal production the energy consumption needed for BSF meal production is still low. Therefore, this parameter has a grey color for BSF meal.

In terms of **logistical aspects**, the disadvantage of both soybean and fish meal is that they are not locally available in the Czech Republic and are imported. This could be the advantage of BSF meal in case of the local mass production. Due to the fact that the BSF products market is not yet established in the Czech Republic and suppliers of BSF meal are missing, it isn't possible to estimate delivery time and local availability. Nevertheless, in the case of mass production BSF meal could gain a competitive advantage because it would be produced locally and the need of the import from long-distance related to the soybean and fish meal could be eliminated.

As for the **price** factor, soybean is currently the first-choice feed due to its relatively low price (wholesale 0.4 – 0.5 EUR / kg). The cost-effectiveness of soybean production is driven by various factors beyond subsidies, geographic locations, and fuel prices. Fish meal prices can be influenced by various factors, and they may fluctuate over time based on market conditions, global fish stocks, demand from various industries (such as aquaculture and animal feed), and other economic factors. Even though fish meal has 40% higher protein content in comparison with soybean meal, the current price of fish meal (1.5 – 1.7 EUR / kg) is 300% higher than the price of soybean meal (Indexmundi 2024a and Indexmundi 2024b), which results in an effort to replace fish meal by soybean meal. However, the demand for fish meal is still and 75% of global fish meal usage goes to the aquaculture sector (IFFO, 2022). The price range of BSF meals produced in the EU or EFTA Member states varies from 3 - 9 EUR/kg. However, companies selling BSF products usually do not reveal their prices publicly and mostly cooperate in B2B (business-to-business) concept. This study calculates with the wholesale price of 4 EUR/kg which was obtained from a company producing BSF meal in Germany. In Table 3 the BSF meal price is marked with orange color since it is 8 times higher than the price of soybean meal and 2.7 times higher than the fish meal price in terms of price per unit of weight. As for price per protein content, the BSF meal price is 7 times higher than the soybean meal price and 3.5 higher than the fish meal price, therefore the price parameter of the BSF meal is marked in orange. Both soybean meal and fish meal prices are marked in green color indicating that these products are cheaper in comparison with the BSF meal. Nevertheless, it can be expected that in case of higher amount of BSF meal available on the market the price will decrease and get more attractive for the feed or animal producers also with respect to the environmental benefits of BSF products.

At first glance, it seems like BSF meal can’t compete to soybean and fish meal in terms of the price. However, considering the environmental benefits of BSF products and rising pressure on enterprises to be more environmentally sustainable, it can be stated that BSF meal has the potential to become a competitive substitute for soybean and fish meal. Moreover, it is expected, that the price of BSF products will decrease with the expansion of production in the EU market. In addition, costs connected with BSF larvae rearing can be reduced by using waste heat (for instance, from biogas plants). Therefore, H3 can be considered as confirmed.

5. Conclusion

Based on the results of this research it can be concluded that biowaste processing using BSF larvae and their use in subsequent production of value-added products is a promising concept in the perspective of circular bioeconomy. The concept is gaining popularity all over the world. However, due to legislative obstacles companies in the EU faced a significant disadvantage and were slowed down in placing their products on the market. On the other hand, the EU enterprises had enough time for deeper research in the field and as soon as legislation allowed BSF companies in the EU were among those with the cutting-edge technologies ready to produce high quality protein for animal feed and other value-added products. Urgent need of better biowaste management and at the same time the necessity of alternative protein sources boosts the development of the insect industry which seems to be a promising solution not only for these two issues. Production of BSF larvae and other insects can have wide-ranging positive economic, environmental, and social impacts such as less greenhouse gas emissions, better food waste/biowaste management practices, waste valorization, job creation in rural areas, less dependence on imported animal feed, fertilizers, etc. In addition, the increase of the competitiveness of the entire agri-food system. Moreover, the concept is in accordance with both the EU Bioeconomy Strategy and the Circular Economy Action Plan and, therefore has the potential to contribute to the achievement of the European Green Deal's objectives. Nevertheless, the support of academic, private, and public sectors is essential for the proper development of the insect industry and thus circular bioeconomy in general.

The results of this study showed that there is a significant correlation between business development and the scientific achievements of local academic sectors in the field of BSF rearing in the EU and EFTA Member states. All three indicators (the number of publications, patents, and companies in the field of BSF rearing) developed together. However, some limitations could affect each of the indicators, for example, 1/ time delay in the publication of patents and scientific papers; 2/ patent assignment to a specific country; 3/ companies' geographic allocation (many companies, decide to move their business to other countries due to the business environment).

Another finding of the study was that in countries with established Bioeconomy strategies on the national level, the number of publications and companies in the field of BSF rearing is considerably higher in comparison to those countries with Bioeconomy strategies on the national level under development or other policies related to bioeconomy. On one hand, it can be interpreted as a government effort to support research and development in the field,

especially in terms of ensuring alternative protein sources. On the other hand, further research is needed to investigate whether there are other circumstances affecting the development of the insect industry in EU and EFTA member states.

Regarding the competitiveness analysis, based on the findings of this work, defatted BSF meal has the potential to become a competitive substitute for products such as soybean meal and fish meal. Even though the actual price of BSF meal is higher, it should be taken into account that the price of BSF products reflects more favorable environmental practices in comparison with soybean and fish meal production. Moreover, due to the UN Sustainable Development Goals, the EU's Green Deal policy and the Corporate Sustainability Reporting Directive, it can be deduced that the major players on the feed market are getting under pressure to look for more environmentally friendly sources for their business activities and to require the same approach from their suppliers or partners. It is also necessary to emphasize, that BSF production includes a wide range of products, so the producers can benefit from portfolio diversification. Along with BSF meal, more value-added products like BSF oil suitable for cosmetics or the pharmaceutical industry will contribute to the total revenue.

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I. Attachment: The questionnaire

1. You are: Choose one answer.
   - o Feed manufacturer or seller
   - o Animal producers
   - o Academic staff or expert with a focus on animal nutrition
   - o Other

2. What kinds of animals are the subject of your activities? Choose one or more answers.
   - o Fish
   - o Poultry
   - o Pigs
   - o Pets
   - o Other

3. According to the currently valid legislation, your activities fall into the category of: Choose one answer.
   - o Microenterprise
   - o Small enterprise
   - o Medium enterprise
   - o Large enterprise
   - o Self-employed
   - o Non-business entity

4. Indicate which of the following ingredients do you use as a main nutritional source (either alone or in a mixture). Choose one or more answers.
   - o Soybean
   - o Fish meal
   - o Insect meal
   - o Cereals
   - o Pea
   - o Other

7. Please rate the degree of importance of logistical aspects. Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".
   - o Delivery time
   - o Storage time
   - o Local availability

8. Please rate the degree of importance of price. Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".
   - o Price per protein content (%)
   - o Price per unit of weight (kg)

9. Are you aware of the possibility of using Black Soldier Fly (*Hermetia Illucens*) larvae as a source of protein in feed? Choose one answer.
   - o Yes, and I use it or recommend it to my customers
   - o Yes, but I don't use it
   - o No

10. What requirements do insect products have to meet for you to be willing to use them (or recommend them to your customers) as a source of protein for animals?

5. Please rate the degree of importance of each nutritional property of the feed (or main nutritional component). Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Protein content
- Amino acids
- Fatty acids
- Carbohydrates
- Minerals
- Vitamins
- Fiber
- Energy MJ/kg
- Digestibility
- Palatability

6. Please rate the degree of importance of ecological aspects (how important is it to you that feed production has the least possible impact on the environment). Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Energy consumption
- Water consumption
- Land use
- Carbon footprint (GHG emissions)
- Use of agrochemicals
- Load on water bodies
- Deforestation

11. If insect products met your requirements, would you be willing to use them (or recommend them to your customers) as a source of protein for animals? Choose one answer.

- Yes
- No
- I'm not sure

12. Whatever your previous answer was, please describe the main reasons.

13. What price range would you be willing to accept for an insect protein source? Choose one answer.

- Lower than current protein source
- Comparable to currently used
- Higher if it is of better quality
- Price is not a relevant criterion

14. Here please write any comments on the possibility of using insects in feed or on the questionnaire itself.