Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Supply Chain Challenges Of Insect Protein

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The study aims to uncover the challenges and opportunities associated with the introduction of new and alternative proteins in the supply chain. The relevance of the topic is driven by several factors - including the growing world population, the demand to reduce the harmful impact of food production on the environment and carbon footprint, waste reduction and improving food safety. This study highlights the challenges faced by the supply chain in the production of insect proteins and develops a conceptual model of the factors influencing consumer behavior along the supply chain. The current study has several limitations. First, it highlights the challenges faced by the insect protein supply chain in Europe and does not include countries that traditionally produce insects. Regarding the scope of the study, the article focuses primarily on consumption behavior along the supply chain, including pre-sale, on-sale and post-sale factors, while end-user preferences are not considered. Due to the large number of items examined, there is scope to extend this study considerably. First, the design of the supply chain will be investigated, followed by the development of a supply chain strategy for protein distribution. This study provides information for producers, traders and managers in the production of proteins to manage the supply chain and offers clarity on the possibilities of supply chain management.

Index Terms—*About four key words or phrases in alphabetical order, separated by commas.*

I. INTRODUCTION

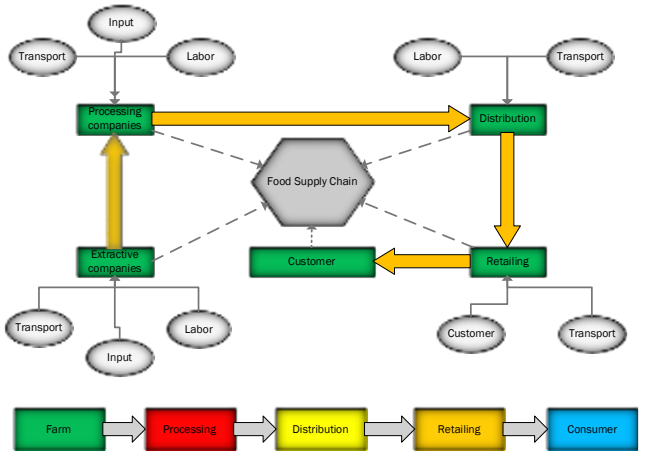
Alternative proteins and innovations in the food sector serve long-term nutrition and the creation of new protein sources (through insects, new plant-based ingredients, microalgae, microorganisms, etc.). All this underlines the importance and relevance of the challenges facing the supply chain in the production and distribution of insect proteins. Proteins from various insect species are considered novel foods under European regulations. Novel foods refer to newly developed foods or foods that are produced using new technologies and production processes. The term "novel food" is also associated with novel food sources or newly developed and innovative foods. The supply chain for novel foods will become

increasingly important due to the growing consumption of proteins. Building a sustainable novel food supply chain requires assessing its sustainability not only for practitioners and companies, but also for the environment and society as a whole.

Despite the increasing interest of entrepreneurs, knowledge about the profitability of insect production on a commercial scale is scarce. This article examines the challenges faced by supply chains, how consumer perceptions and preferences influence the acceptability of insect proteins and how their safety for consumers is ensured.

II. LITERATURE REVIEW

Food production plays a crucial role in climate change due to the use of energy sources. Approximately 14% of global greenhouse gas (GHG) emissions are directly linked to agricultural processes. Digitalization, web services and novel food delivery concepts can help improve food logistics and supply chains by reducing GHG emissions. [8] The food supply chain refers to all processes from production through processing and distribution to consumption and disposal, including cultivation, processing, distribution, retail and consumption [1], [21], [25], [26] A study by Poveda describes that the number of companies working with insects as food and feed worldwide is over 250 in 2019. From a scientific point of view, the use of insects as food and feed provides hundreds of publications every year and is constantly revised by different authors [14]. Insects offer a promising alternative for the future production of animal protein. Their nutritional value combined with their efficiency in feed conversion and low water requirements make them a more sustainable choice for the production of food of animal origin. [2]. Fig. 1 depicts a traditional food supply chain that includes different elements and sub-elements within the food supply chain network.



Fug. 1. Food Supply chain (FSC)
Source: [1]

According to Putten et al., examples of processing techniques that are considered "new" are heat treatment, high-pressure treatment, ultrafiltration and G-irradiation (gamma irradiation). Wu et al. describe freeze preservation, which includes freezing, freezer storage

and thawing to preserve the freshness properties of food. Conventional freezing uses air blast, immersion, fluidized bed and cryogenic freezing, while new freezing uses ultrasound, ultra-high pressure, pulsed electric fields, ultra-low temperatures, high-voltage electrostatic fields and radio frequency. [22]. All of these techniques can be used to improve food safety and quality. In addition, the use of these techniques can reduce or increase allergenicity. [13]. It can be concluded that novel food processing techniques have emerged due to some advantages over traditional techniques.

The new methods aim to maintain the properties of food, including organoleptic and nutritional qualities, at a higher level than conventional processing methods. [19]. In addition, new technologies and innovations can reduce the impact of production on the environment and improve the food supply. According to Djekic et al., LCA is the most important method for assessing the environmental impact of products and is increasingly being applied to products from the food sector. It is a scientific method based on ISO 14040 and includes mapping the process, defining the scope and boundaries, collecting data, calculating, evaluating and interpreting the results to propose environmental improvements (ISO, 2006) [5]. The quality of raw materials supplied, followed by the reliability and flexibility of supply, must play a key role in logistics to maximize profits and ensure high quality end products. This approach focuses on the quality of raw materials that comply with existing standards and regulations. [27]. Insects are most commonly used in feed production as a viscoprotein ingredient. [10] The global demand for animal feed as well as competition for proteins is increasing every year, and this leads to a demand for insects as an irreplaceable source. [6], [4].

In the context of studies looking at alternative protein sources for human and animal nutrition and food waste, edible insects are increasingly appearing as a fully-fledged substitute for animal proteins and the processing of waste. Depending on the species or processing method, insects contain a moderate amount of protein (dry matter, DM), ranging from 50% to 82%, and are rich in nutrients such as calcium, iron and zinc. [10]. For years, many insect species have been part of the diet of some livestock (e.g. chickens, pigs, fish) as they provide high-quality protein.

The authors Jagtap et al. consider the availability of raw materials in larval production as well as the supply chains. They have conducted tests using a life cycle assessment information system and provided new research solutions for the method of resource utilization in the circular economy.[7] Insects have been identified as an alternative in food systems, especially in protein production. Smetana et al. have conducted a life cycle assessment (LCA) study of the use of insects for feed and food purposes based on the collection and processing of insects on an industrial scale. They emphasize several key issues related to the low technological readiness level (TRL) in processes along the entire supply chain [17].

Several researchers [18] are also investigating the use of insects as a source of protein in animal feed. One interesting insect species is Hermetia illucens, commonly known as the black soldier fly. The larvae of this fly can be used in feed for salmon. Black soldier fly larvae (BSFL) are also considered a promising substitute for soy and other proteins in poultry feed, both from a nutritional and environmental perspective. [18].

The nutritional composition of insects can vary greatly depending on the species, but it is the protein and fat content that occurs in large quantities. In addition, edible insects are an

environmentally friendly source of food production. This may be due to their high feed conversion ratio, high fecundity and short life cycles. According to the Food and Agriculture Organization of the United Nations (FAO), edible insects are an underutilized resource with great potential to be an innovative food that offers many benefits to humans. In this way, insects can represent a healthy, nutritious and sustainable food choice for consumers. [3], [15] Mwangi et al. investigated the Fe and Zn content of eleven edible insect species that were mass reared and six species that were collected from the wild. They found that the levels were similar or higher than in other animal food sources. [12].

III. METHODOLOGY

Edible insects can be obtained in three ways: by wild collection, by semidomestication (manipulation of habitats to increase production) and by breeding, which can range from a single small cell to a large factory. [10]. According to Yen [23], captive insects accounted for 92% of the world's total insect supply in 2015, and semi-domesticated insects accounted for 6%. This means that only 2% of insects supplied are currently farmed, demonstrating the great potential of insect farming and the development of new supply chains. After 2023, an increase in the share of agricultural production of edible insects is observed, which requires the optimization and economic efficiency of supply chains for insects and their proteins. This is a complex task given the wide variety of insect species, production scales, feed types, etc.

This study examines the challenges faced by supply chains in the production of insect proteins. It builds on the work of authors Veldkamp et al. who outline the key challenges that need to be overcome to bridge the gap between demand and supply of insect proteins. According to them, the challenges are related to the production and capacity of proteins, sustainability and environmental impact, the consumption of insect proteins and their use in animal feed. This raises the research question: What challenges do supply chains face in the production of insect proteins?

Three sets of criteria were used in this study to shed light on the supply chain challenges in the production of insect proteins:

- Literature review on supply chain management in insect protein production;
- Review of European regulations for the insect protein production supply chain;
- Identify the status and challenges of supply chain management in insect protein production.

Literature sources, journals, scientific articles and reports, internet sources, statistical data and a survey of seven European insect producers were used for this study. In addition, a special study was carried out on European legislation in the field of insect production and marketing. The results of a survey of insect producers in Europe on the state and challenges of the supply chain were used. Basic statistical methods were used to process and analyze the information from the survey conducted.

IV. THE ROLE OF EUROPEAN LEGISLATION IN THE PRODUCTION OF NOVEL FOODS AND INSECTS

According to the FAO, feeding a world population of 9.7 billion people in 2050 will require a 60% increase in total food production from 2005/2007 to 2050. To effectively achieve such significant changes, an economy based on the circular economy principle and taking into

account the limits of resources is required.[20]. In the global sustainable development agenda, Transforming Our World: The 2030 Agenda for Sustainable Development, the United Nations (UN) adopted 17 Sustainable Development Goals (SDGs) that aim to "stimulate action in areas of critical importance for humanity and the planet".[11]. Since the creation of the European Single Market, the European Union has faced a number of challenges arising from the regulation of the free movement of goods. [24]

Currently, the legal framework for novel foods such as insect proteins is laid down in Regulation (EU) 2015/2283 of the European Parliament and of the Council, which entered into force on January 1, 2018. With the implementation of this regulation, a centralized authorization procedure for the placing on the market of novel foods is applied. The regulation makes it possible to obtain a marketing authorization. In addition, safety assessments by the European Food Safety Authority (EFSA) are required. EFSA is working on risk profile assessments related to the production and consumption of insects as food and feed, as safety and hygiene standards are related to the supply of the first stage of the supply chain. It is necessary for the supplier to have a safety system in place. The quality and safety of insects is influenced by the environmental conditions, atmosphere and relative humidity during transportation and storage. Changes in environmental conditions during storage have an impact on product quality. However, only some EU countries (e.g. Belgium, the Netherlands, Denmark, Finland and Germany) have adopted their own internal regulations for the trade of insect foods, which affects the distribution of retailers selling insect products and their availability on the market, which may raise concerns among consumers about the safety and health of these foods.[16] The main principles underlying novel foods are that they must be safe for consumers and properly labeled so as not to mislead consumers.

The European Union allows the introduction of feed derived from certain insects into the diet of animals (EU Rer. 217/893). This regulation allows the use of processed animal proteins (PAPs) from insects in the diet of farmed fish, limited to seven species (Hermetia illucens, Musca domestica, Tenebrio molitor, Alphitobius diaperinus, Acheta domesticus, Grylodes sigillatus and Gryllus assimilis). [10] However, the use of insect PAP to feed poultry and pigs is still banned in the European Union, unlike in China, South Korea, Kenya, Uganda and Canada (in association with Hermetia illucens in poultry feed).[10] The applicant of the novel food has the possibility to apply for an individual marketing authorization using the data protection provisions. Regulation (EU) 2021/1372 of August 17, 2021 allows the use of insect-derived products and in particular their use as an ingredient in pet food, aquaculture feed, poultry feed and pig feed.

The legal framework should apply to the entire production chain, starting from two different sources of primary production: wild collection and farmed insects. Similar to conventional livestock farming, edible insects must also be monitored for food and feed safety. Legislation on insect farming and the use of insect-based products has been introduced in response to the rapid development of the edible insect industry. Many European countries have not introduced legislation for edible insects and must comply with EU legislation.[27] European insect producers must comply with EU environmental legislation. Specifically, Regulation (EU) No. 1143/2014 restricts the insect species permitted for agricultural purposes by establishing a list of "invasive alien species".

Regarding the marketing requirements for individual edible insect species, the European Food Safety Authority requires authorization before they can be placed on the market as novel foods [9]. It should be noted that the challenges associated with industrial insect farming are related to food safety and regulatory requirements for the emerging insect protein market. Producers of food and insect feed are subject to specific labeling requirements. Insect-based foods are subject to all provisions of the 'common' framework for food labeling in the EU (i.e. Regulation (EU) No 1169/2011). In addition, any new edible insect-based food must comply with the labeling requirements that apply to the respective "novel food" A mandatory requirement for foods is that they comply with Regulation (EC) No 1924/2006 on nutrition and health claims. EU Directive 2002/46/EC on food supplements, which are intended to supplement the normal diet of consumers and are potential sources of nutrients, is part of the legal framework. In the traditional food supply chain, these challenges are systematically analyzed through legal provisions, while the knowledge and regulations that apply to commercial insect farming are still in their infancy. Therefore, the numerous challenges in the emergence of the edible insect market need to be overcome, according to Żuk-Gołaszewska et al. The EU regulations allow the following types of insects for human consumption: (Fig. 2.)

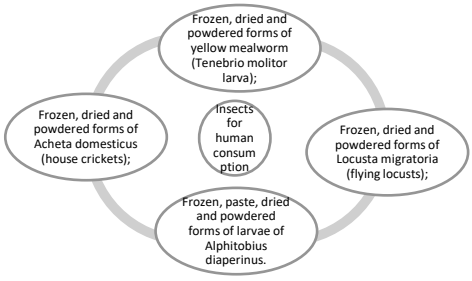


Fig. 2. Insect species authorized for human consumption in the EU

The species described in Figure 2 are classified as safe for human health. Thanks to the requirements of the regulation, both manufacturers and traders or restaurateurs are obliged to clearly label and indicate insect products or parts thereof in prepared foods. The control of insect foods includes all processes carried out to ensure their quality and safety at all stages – from primary production, processing and storage to distribution and consumption.

According to the European Commission's official list of authorizations for foods that are not traditionally consumed in the EU but are part of the usual diet of people in countries outside the EU, 9 applications have been submitted. There are currently 6 novel food authorizations in the European Union for the marketing of foods based on 4 insect species. One of these foods is duckweed, a type of aquatic plant that was approved by the EU as suitable for human consumption in December 2021. It is very rich in proteins, carbohydrates and vitamins and is a plant that grows very quickly and whose protein content exceeds that of wheat. The same applies to the consumption of insects. From January 24, 2023, partially defatted powdered crickets (Acheta domesticus) may be consumed in the EU, and from January 26 of the same year, larvae of the small darkling beetle, a species of beetle (Alphitobius diaperinus).

In summary, compliance with the EU legal framework covers various aspects of supply chain management. All this reinforces the role and increases the need to build partnerships in the production, sourcing, storage, preservation and supply of insects and their proteins.

V. FINDING AND DISCUSSION

The study was conducted in a fast-growing novel food market that is specifically focused on the production of insect proteins. The sector is represented by companies producing proteins and fats from insects for use in animal feed as well as organic fertilizers for agriculture. The companies involved include those that breed mealworms, black soldier flies and silkworms. Insect proteins for aquaculture and animal feed were approved by the EU administration in 2017, and in 2021 they were also approved for use in poultry and pig feed. Globally and in Europe, the number of insect farms has increased significantly over the last ten years. Key players in the European mealworm market include Ÿnsect SAS (France), Protix B.V. (Netherlands), TEBRIO (formerly MealFood Europe SL) (Spain), Tebrito AB (Sweden), Entec Nutrition (UK), Invertapro AS (Norway) and EntoBreed Farming BV (Netherlands). According to the International Platform of Insects for Food and Feed (IPIFF), insect-based feed products will total 9,495 tons in 2022, including 3,928 tons of insect proteins, 2,360 tons of insect oils/fats and 3,207 tons of dried insects.

The total number of European producers is around 50 insect farms, which indicates considerable potential for expanding the supply chain in Europe. Some of these companies are high-tech producers of insect products for the animal feed and agricultural industries. They mainly produce insect proteins and refined oil from black soldier fly larvae. On the Bulgarian market, some companies produce robots and automated solutions for insect breeding.

Another part of the sector breeds mealworms to produce flour, organic silk yarn and alternative proteins from silkworms. An industry organization (Association of Insect Producers and Processors in Bulgaria) has been established to protect the interests of producers in this rapidly developing sector.

This results in challenges for supply chains associated with the imposition of new transportation models that are a direct consequence of technological advances in the sector. The traditional linear model of the supply chain is transforming into Digital Supply Networks (DSN), where functional silos are being broken down and companies are connecting with their comprehensive supply network to ensure transparency, collaboration, flexibility and optimization. In addition, Bulgaria has created a good foundation for insect farming, providing alternative proteins for various purposes and industries, which means an expansion of the supply chain.

The sustainability of the supply chain is ensured by the fact that no temperature regime needs to be maintained throughout the supply chain. Insects are more efficient to farm, especially compared to traditional livestock farming. Around 25 kg of grass is needed to produce 1 kg of beef, but with the same amount of grass, ten times more edible protein can be obtained from insects. This is because up to 90% of the insect's body mass is suitable for consumption, compared to only 40% of the cow's body mass. The supply chain in the production of insect protein is shown in Fig. 3.

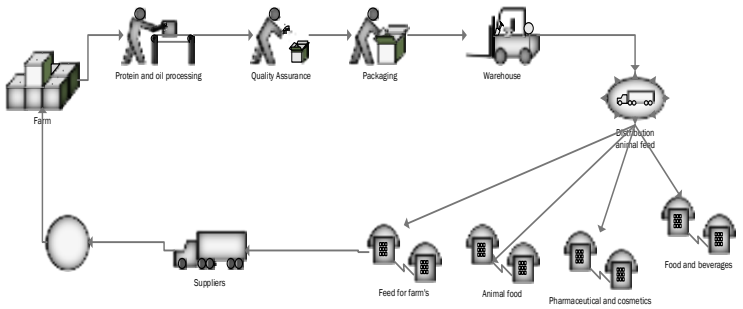


Fig. 3. Insect production supply chain

The supply chain presented begins with insect breeding, followed by protein extraction and quality testing for market distribution. The target market is growing steadily due to the benefits of the products and positive regulatory changes. Once the products are packaged, they are usually distributed from the warehouse, mostly to companies producing animal feed or aquaculture feed. Proteins for pet food production have a significant market share as insects are part of the natural diet of cats, dogs, birds and reptiles kept as pets. Between 5 and 10% of pets are allergic to conventional food, whereas insect-based food is hypoallergenic.

More than 2,100 species of insects are edible. The market for insect proteins is expected to reach 350,000 tons in 2030. This increase will be possible if the legal and regulatory restrictions in European countries are lifted and the price is reduced accordingly. There are still no well-developed supply chains for insects and their protein. (Fig. 4)

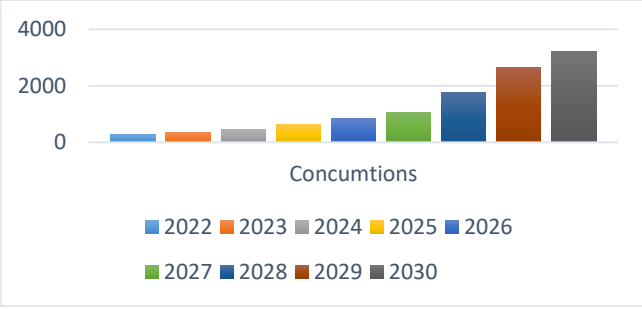


Fig. 4. Consumption (million dollars) and the average price to the protein of insects

As supply chains evolve, markets and prices are regulated. Due to the relatively high price - between 3,500 and 5,000 euros per ton - demand for insect proteins is still low (Fig. 5).

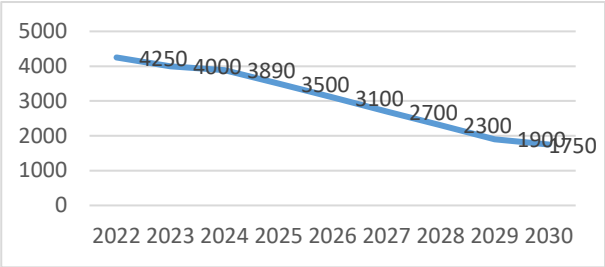


Fig. 5. Average price ($)

Global consumption of insect proteins is expected to increase from 267.8 million dollars to almost 3,217 million dollars. Against the background of the total protein demand in aquaculture, insects will have a share of no more than 1%, with North America and Europe emerging as the main markets (Fig. 6)

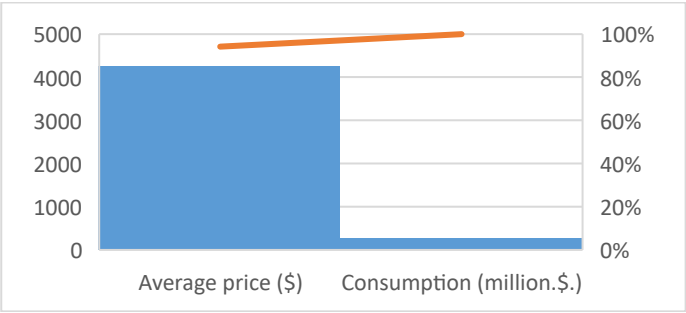


Fig. 6. Protein consumption by insects

Pet food currently accounts for the largest market share, with an estimated capacity of around 150 thousand tons, as pets have no allergies or intolerances to this type of protein. This is followed by pharmaceuticals and cosmetics, with food and beverages in third place. In recent years, cricket flour, which is rich in protein, has been the most consumed, with manufacturers using it in pasta, bread, cookies, potato French fries, chocolate bars and more. The Asia-Pacific region is now one of the leading producers and consumers of edible insects. It recorded a growth of 33.21%. The hot and humid climate in many parts of Asia is good for insect farming.

Insect proteins are a widely used feedstuff in aquaculture. Around 40% of trout feed, for example, contains insect protein, which is a natural food source for the fish. Fish have a higher requirement for animal proteins compared to other farmed species.

Another part of the supply chain is the distribution of the protein for pig and poultry feed. It has been approved in the EU since 2021. Studies show better health and faster growth when only 3-5% insect products are included in the animals' feed. Alternatives such as soy are the main cause of deforestation, the cost of which has tripled in the last 20 years.

The compost from the larval casings of the black soldier fly and the fibers turns into soil conditioner. The resulting compost can be used for soil nourishment and remediation as it is rich in organic matter, essential minerals and chitin. This compost strengthens the plants'

natural defenses and contributes to crop production. The most suitable insects for industrial feed production are the black soldier fly (Hermetica Illucens), the house fly (Musca domestica) and the yellow mealworm (Tenebrio molitor).[6]. The black soldier fly (BSF) reaches sexual maturity 5 times faster than other feeding insects. Insect oil is allowed in all animal feed.

The use of insects as the main component of animal feed can reduce dependence on expensive and imported feed, which represents an opportunity to enter the small animal husbandry market. In addition, by breeding insects in local waste streams, any residues can be used as biofertilizer, increasing farmers' independence from external fertilizer. Insects are highly valued as food in many parts of the world, except in Western countries. In recent years, however, Western cultures have reconsidered entomophagy as part of a healthier and more environmentally friendly diet. This encourages new global research, technology transfer and international cooperation in this field. [11].

The manufacture of other products such as cosmetics, chitin and more is also part of the supply chain derived from insect production. BSF oil is suitable for skin care products due to its antibacterial properties. For the pharmaceutical industry, natural antibiotics can be produced from BSF and incorporated into new medicines. In the chemical industry, BSF can be used to produce chitin and chitosan of the highest purity for industrial applications. And last but not least, energy and biofuels can be produced from BSF oil.

In Europe, there are still few insect producers who can sell insects for human consumption. France is the first European producer of insects to be officially authorized to sell insects as food for humans in the EU. There are currently 37 insect farms in Spain and the world's largest mealworm factory for human and animal consumption is due to open in Salamanca. The European Food Safety Authority states that the defatted powder of the housefly can be used in a variety of foods, including multigrain bread, crackers, cookies, dried pasta products, sauces, processed potato products, legume-based dishes, pizza, soups or soup mixes, corn-based snacks, beer-like drinks, chocolate products, nuts and oilseeds and many others.

The challenges facing the supply chain in the insect farming and insect protein and oil extraction industries are related to increasing the resilience of food systems and the responsibility of all stakeholders along the supply chain. Insect proteins are produced in small quantities for finished products that are mostly supplied to processing plants and rarely to end customers. The equipment is highly specialized and the company's production schedule for the production of proteins is short-term. Usually the production plan is developed on the basis of customer orders.

The next challenge is related to the need to be flexible and change processes on a daily basis in order to achieve greater security in deliveries. This requires stability, flexibility and accuracy in last mile delivery. Edible insects are an attractive food source due to the wide variety of insect species with high nutritional value and appealing taste as well as a clean production process, low production costs, high availability and an environmentally friendly production technology that contributes to the reduction of greenhouse gas emissions. To increase consumer acceptance of edible insects from production to consumption, a good understanding of insect nutrition and their potential to convert low-value organic waste into protein-rich food is required.

Planning and creating effective partnerships can be a key advantage for insect protein producers. The analysis of the research revealed that partner relationships in the supply chain

are weak. Building good partnership relationships requires thorough coordination of deliveries and orders with customers and suppliers. Accepting the challenge of working in partnership will create many opportunities – for joint training and development of new products, for implementing European regulations, for expanding market access and for jointly generating higher profits from the investments made. The main areas of collaboration between organizations involved in the insect protein supply chain relate to the scope of price information, followed by the exchange of information on demand forecasting.

Knowledge and skills are also a potential source of benefits and competitive advantage. Their absence could lead to inefficiencies in production processes and the overall functioning of the supply chain. Partnerships connect companies and inevitably contribute to the sharing of more knowledge and experience, market information and plans, etc. In the next phase of their development, organizations producing insects and derived foods need to develop their collaboration not only with their main suppliers and buyers, but also with all participants in the supply chain. To do this, it is necessary to disclose links to all suppliers and consumers. This means that companies must have a fundamental understanding of the performance, growth potential and profitability of the key players in the supply chain. To meet the new requirements, companies will need to implement a product tracking system. In doing so, they will strengthen their relationships with partners who have supply chain tracking systems in place.

Last but not least, it can be concluded from the analysis of the study that it is necessary to expand distribution channels. According to the organizations studied, each participant in the supply chain uses a different system for encoding and decoding data, which leads to poor communication quality when exchanging information. This results in the need to create communication standards for data. Therefore, organizations must have technical means to encode, read and store data and establish a method for sending, processing and forwarding such data within the information system.

Protein producers have largely focused their efforts on increasing production efficiency, and all have also concentrated on adapting to EU requirements. One challenge for companies in the sector is to establish sustainable distribution channels and develop new markets.

CONCLUSION

Europe is expected to be the fastest growing market for insect proteins in the coming years. There are two reasons for this: On the one hand, it is due to the minimal environmental impact and the low demand for arable land and water compared to livestock farming, as well as the low ecological costs (low greenhouse gas emissions and carbon dioxide). On the other hand, insect farming is becoming increasingly important as a more sustainable alternative in the food and feed industry. The challenges faced by the supply chain are related to the need to adapt to consumer preferences and EU safety regulations. This can be achieved through flexibility and process changes, increasing the resilience of food systems, improving production efficiency and building distribution channels while developing new markets. High costs and limited production capacity are some of the factors inhibiting the growth of the market. Optimization of production processes and supply chain in the extraction of insect proteins is imperative. Issues related to allergic reactions and individual sensitivities to insect consumption also require further research and information.

Several studies have described the benefits of insect proteins and their production. Among the most important are the lower ecological footprint compared to traditional livestock farming and the high efficiency of the food in terms of protein utilization. As in any other sector, the development of insect production in the EU will be determined by accessibility and socio-cultural changes. This article raises a number of issues related to the supply chain that need to be addressed in the future.

Further Research

Future research will investigate how consumer perceptions and preferences influence the acceptance of insect proteins in the food supply chain and how the safety of insect proteins is ensured within the supply chain.

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