Barriers, risks and risk management strategies in European insect supply chains

H.H. Niyonsaba[1*], J. Höhler[1], H.J. van der Fels-Klerx[1], T. Slijper[1], F. Alleweldt[2], S. Kara[2], R. Zanoli[3], A.I.A. Costa[4], M. Peters[5] and M.P.M. Meuwissen[1]

[1]Business Economics Group, Wageningen University, P.O. Box 8130, 6700 EW Wageningen, the Netherlands; [2]Civic Consulting GmbH, Potsdamer Strasse 150, 10783 Berlin, Germany; [3]Department of Agricultural, Food and Environmental Sciences, Università Politecnica delle Marche, Via Lodovico Menicucci 6, 60121 Ancona, Italy; [4]Católica-Lisbon School of Business and Economics, Universidade Católica Portuguesa, Palma de Cima, Edifício Reitoria, 1649-023 Lisboa, Portugal; [5]New Generation Nutrition, Deutersestraat 12, 5223 GV 's-Hertogenbosch, the Netherlands; hilde.niyonsaba@wur.nl

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Abstract

Despite technological developments and regulatory improvements, most actors in the insect sector still face many challenges and uncertainties. While previous research mainly focused on the perception of domain-specific challenges and risks or has been limited to specific stages in the supply chain, this study aims to determine how stakeholders perceive the importance of past barriers and future risks along European insect supply chains, and to identify the applied risk management strategies. Data were collected from stakeholders across four stages of the supply chain (rearers (n=23), processors (n=8), and insect derived feed (n=14), and food (n=12) producers) through an online survey. In total, 60 different barriers and risks, as well as 20 different risk management strategies, were evaluated. We find that stakeholders across all stages of the supply chain perceived 'financial, cost and market' barriers and risks as most important, specifically referring to the lack of financial investments and price and demand uncertainties. In addition, legal restrictions were perceived to constrain upscaling opportunities across all supply chain stages. Worker and food safety barriers were generally perceived as least important. The main risk management strategies across all stages of the supply chain related to investments in technologies enhancing stability of both the quality and the quantity of insects and derived products. Stakeholders were most optimistic about the future reduction of 'operational' and 'financial, cost and market' risks. To further stimulate upscaling of the sector, we recommend to enhance financing opportunities, and to improve authorisations for the use of different substrates and the production of a wider set of insect-based ingredients for feed and food products.

Keywords: dynamic risk perception, stakeholder survey, risk attitude, insect sector, risk preference

1. Introduction

Large-scale insect production for feed and food purposes is gaining interest in Europe and many efforts have been made to improve both the technological and the regulatory landscape (IPIFF, 2019; Montanari *et al.*, 2021a). The insect sector currently consists of many small and medium sized enterprises (SMEs) as well as some large companies (Derrien and Boccuni, 2018). Due to its young and dynamic nature, the European insect sector can be regarded as an emerging sector (Marberg *et al.*, 2017) on the road to scaling up with investment interests on the rise (Montanari *et al.*, 2021a; Rabobank, 2021). In 2020, the International Platform of Insects for Food and Feed (IPIFF), a European non-profit organisation, forecasted that its members will have invested more than 2.5 billion EUR by 2025 (IPIFF, 2020a). The exact number of current operators in Europe is not known, however, in 2022 IPIFF listed 80 members of which 53 were business operators in the insect sector, and the remainder academic institutions so-called observers[1].

European insect supply chains largely consist of four main stages: rearers, processors, and insect-derived feed and food producers. The first stage represents companies that rear

[1] https://ipiff.org/ipiff-members.

insects from egg or larval to maturation phase; the second stage refers to companies processing fresh larvae into meal, oil, protein fraction or other intermediate products; the third and fourth stages involve companies that incorporate the insect-derived intermediate products in, respectively, feed and food. In addition, insect-derived products could be used in non-food and non-feed industrial applications such as cosmetic and textile-based products, however, this is not yet practiced commercially (Van Huis, 2022;Verheyen *et al.*, 2020). In the European supply chain of insects for food, the degree of vertical integration is low. A small number of companies focusses exclusively on the rearing of edible insects (IPIFF, 2020b; Montanari *et al.*, 2021a; Pippinato *et al.*, 2020). Most insect processors buy insects from rearers, process them and sell the derived products (typically insect meal) as raw materials for food manufacturing. Montanari *et al.* (2021a) expected that the gradual opening of the European market will allow insect production for food consumption to expand to 260,000 tonnes by 2030 (IPIFF, 2020c). Feed production and commercialisation are more developed, mainly because the EU legal framework provides more opportunities for insect-based feed than for insect-based food (Montanari *et al.*, 2021b). The production volume for feed may reach up to 2.7 million tonnes by 2030 (IPIFF, 2020a), ten-fold higher than the production volume for food. A rapid succession of authorisations took place since 2021, with full authorisation of the use of insect protein in poultry and swine feed and approval of four Novel Food applications, including 'frozen' and 'dried' *Locusta migratoria*; 'dried', 'ground' and 'frozen' *Acheta domesticus*; and 'frozen', 'dried' and 'ground' *Tenebrio molitor*. Novel food applications allow for data protection and exclusivity, and therefore provide exclusive benefits to the applicant.[2]

With both technical know-how and regulatory landscapes evolving rapidly, European business opportunities are expanding. However, the majority of operators still faces considerable challenges in upscaling, limiting the emergence of a viable, large-scale European insect supply chain (Doberman *et al.*, 2017; Van Huis *et al.*, 2021). Insights into past barriers provide vital information on relevant remediation or prevention measures (Leonidou, 2004). A narrative evidence review conducted by Doberman *et al.* (2017) identified some of the hurdles hindering large-scale rearing and market adoption of insects as feed and food. The main barriers were a lack of knowledge on which species to rear, on optimal rearing conditions, and on the most favourable composition of substrates. Other reported hurdles were a low level of process automation and thus high labour costs. More recently, Yang and Cooke (2020) identified the following five primary challenges for upscaling production capacity of the edible insect industry in the United Kingdom: the need for (often expensive) high quality insect feeding substrates, slowly developing production techniques, challenging product development and marketing, lack of expertise on operational aspects of insect production, and regulatory uncertainty.

While we can measure the impact of past barriers, this is much more difficult to estimate for future risks (Komarek *et al.*, 2020). The perception of occurrence and impact of future risks can inter alia influence the decision making of operators and hence affect current and future business performance (Hardaker *et al.*, 2015). Risk perceptions are domain-specific (Weber *et al.*, 2002). Risks studied for the insect sector include food safety and potential microbiological risks (Vandeweyer *et al.*, 2021), chemical risks (Meyer *et al.*, 2021), allergenicity risks (Ribeiro *et al.* 2018), pest and disease risks (Van Huis, 2017), and technical and legal risks (Dobermann *et al.*, 2017; Marberg *et al.*, 2017). While domain-specific risk studies provide valuable insights, they do not rank the different risks across domains. Furthermore, their scope is typically limited to the barriers and risks posed to individual supply chain actors. To the best of our knowledge, this study is one of the first to study the perceived barriers and risks across multiple domains for European insect supply chains. Simultaneously studying multiple risks across domains is important as it helps producers to prioritise risks and implement appropriate risk management strategies (Komarek *et al.*, 2020).

Enhanced knowledge of past barriers and future risks may improve financial and insurance services, and further enhance business performance and development (Balling *et al.*, 2009; Bosma *et al.*, 2018; Niyonsaba *et al.*, 2021) as insights into how barriers and risks[3] change over time can help map the success of risk management. Risk management can be considered successful if the adopted strategies help reducing future risk perception compared to perceived past barrier, and contributes to the performance and value of enterprises in a dynamic environment (Gordon *et al.*, 2009; Hudáková and Masár, 2018; Mitra *et al.*, 2015). In this regard, Dvorsky *et al.* (2021) recently highlighted the importance of risk identification and application of risk management strategies for smaller companies in young and dynamic sectors in general. Detailed and quantitative research on (the dynamics of) business risks and effective risk management strategies for emerging sectors is, nevertheless, rather scarce, mainly because of a lack of data (Mitra *et al.*, 2015). This study contributes to a better understanding of effective risk management practices by providing insights into dynamic risk perceptions in the European insect sector.

[2] https://ipiff.org/insects-novel-food-eu-legislation-2/#question1.

[3] In the context of this research, identical statements were assessed as both potential past barriers and potential future risks.

This study first aims to identify the perceived importance of different barriers and risks, and to retrieve information on applied risk management strategies by stakeholders in European insect supply chains. Second, it aims to obtain insights into the dynamics of perceived barriers and risks over time.

2. Research methods

Survey design and data collection

Four surveys[4] were designed with a similar set-up, modified for the four main insect supply chain stages of rearing, processing, and insect-derived feed and food producers. An overview of approaches used for the survey design, the data collection process and the main parts of the analysis is shown in Figure 1. Each survey covered four domains: (1) operations; (2) finance, cost and market; (3) worker and food safety; and (4) regulations. A literature-based longlist of different barriers for the commercialisation of insect proteins in Europe (Hartmann and Siegrist, 2017; Payne *et al.*, 2016; Rumpold and Schlüter, 2013) was discussed with a group of researchers and representatives of industrial organisations involved in the European SUSINCHAIN[5] project to produce a final selected list of 60 unique barriers, further finetuned and divided into the four mentioned domains. As a result, 37, 24, 27 and 27 barriers were included in the surveys for rearers, processors, feed and food producers, respectively. As the same barriers were also assessed as future risks, each statement was assessed for two time-dimensions. In addition, a list of 20 risk management strategies was composed, based on, amongst others Spiegel *et al.* (2021) and Slijper *et al.* (2020). In a separate meeting with seven experts from research and industry involved in the SUSINCHAIN project, strategies were adjusted to the insect sector. Finally, a set of five business specific statements was composed to assess risk attitude, based on similar statements used by Meraner and Finger (2019), Meuwissen *et al.* (2001) and Slijper *et al.* (2020).

[4] Surveys can be found in the Supplementary material (1.1-1.4).

[5] These member organisations were taking part in the SUSINCHAIN project (https://susinchain.eu/).

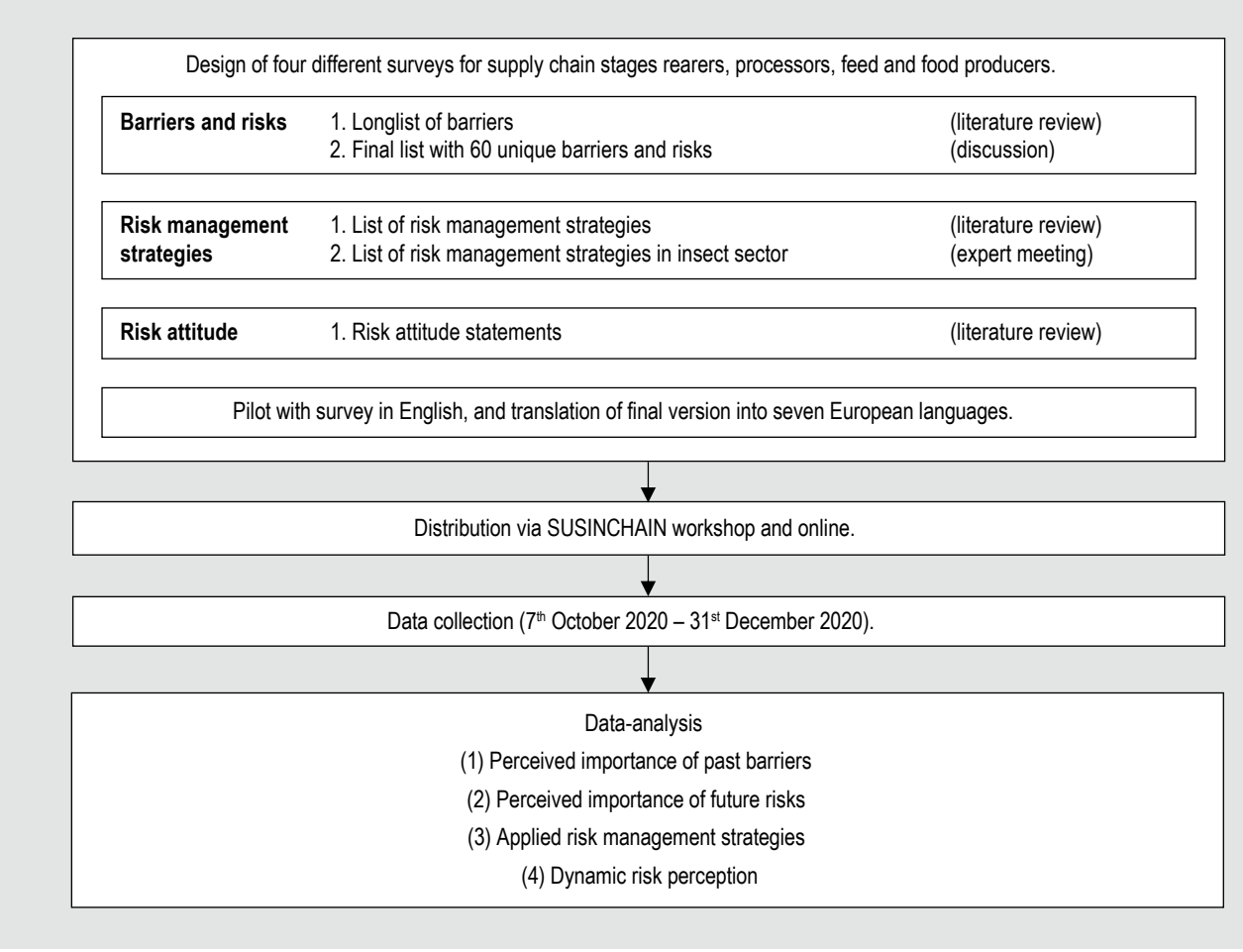

Figure 1. Overview of survey design, data collection and main parts of the analysis.

The first part of the survey collected general information about the stakeholder (demographics) and company, including the produced insect species, number of full-time employees, and production volume. The second part assessed the perceived importance of past barriers and future risks. Respondents were asked to score both the occurrence frequency and the negative impact of each barrier in the past 5 years on a 5-point Likert scale ranging from 1 (never / no negative impact at all) to 5 (always / very severe negative impact). The same scales were used to score future risk (5 years). A Likert scale assessment is often used to measure latent variables using several items. The combination of these items enables researchers to better measure latent variables. Previous studies investigating risk perception also used Likert scales – see for instance Rahman *et al.* (2021), Rizwan *et al.* (2020), and Wauters *et al.* (2014). Respondents were asked to explain their scores and to point out the most important past barrier and future risk for each domain. Furthermore, respondents were requested to explain how they managed the perceived most important past barrier and which strategy they planned to use to manage the most important future risk. The third part of the survey inquired about past and current risk management strategies. At this point, respondents were also given the opportunity to include risk management strategies that were not provided in the questionnaire. Additionally, this third part of the survey assessed respondents' relative risk attitude by asking about their level of agreement on five statements on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). These five statements were framed as follows: I am more willing to take more risks on the aspects of (1) production; (2) marketing; (3) financial matters; (4) management in general; and (5) scaling-up of the business compared to colleagues. Parts 2 and 3 of the survey elicited latent variables, which are variables that cannot be measured using a single item. Latent variables can be measured in formative or reflective way. In contrast with reflective indicators, formative measures imply that changes in items will cause changes in latent variables (Coltman *et al.*, 2008; Diamantopoulos and Siguaw, 2006). All latent variables – i.e. risk perception, the combinations of adopted risk management strategies, and risk attitudes – were measured in a formative way. This makes checks for internal consistency reliability redundant (Diamantopoulos and Siguaw, 2006).

Surveys were designed in English and then piloted by two Dutch insect operators (one insect rearer and one food processor) and one industry representative. After this pilot, the English surveys were translated into seven European languages: Danish, Dutch, French, German, Italian, Portuguese, and Spanish, and reviewed by native speakers with experience in the insect sector. The survey was administered online via Qualtrics (Qualtrics, Provo, UT, USA). The survey was distributed to businesses operating in or organisations connected to the insect sector. Respondents from sector organisations were asked to represent 'average' member companies; researchers and consultancies were requested to base their answers on their expertise. Initial distribution occurred during a workshop facilitated by the SUSINCHAIN project, followed by further dissemination via social media, conferences, and industry organisations. Via a general invitation respondents could choose the survey version for the supply chain stage they felt most connected to. In case a respondent was not familiar with a question or topic of the survey, the particular survey questions(s) could be left unanswered. Responses were collected between 7th of October and 31st of December 2020. During this period, there were no insect related crises or policy changes affecting the insect sector.

Sample characteristics

Table 1 displays the total number of respondents as well as the number of completed and included (at least 50% of the questions related to past barriers and future risks) survey responses per supply chain stage. Three respondents answered the survey for more than one supply chain stage. Response rates could not be calculated as the survey was distributed online and no specific number of respondents was targeted. Convenience sampling is considered sufficient to answer our research questions since due to the small and

Table 1. Number of respondents per supply chain stage.

Supply chain stage	n total responses[1]	n completed surveys[2]	n included responses[3,4]
Rearers	84	25	23
Processors	41	10	8
Feed producers	81	16	14
Food producers	43	15	12

[1] Respondents who started the survey.
[2] Respondents who finished the survey without necessarily answering every question.
[3] Respondents who finished the survey and answered more than 50% of barrier and risk questions; this group is considered for further analysis.
[4] Three respondents (within included responses) answered the survey for more than one supply chain stage.

emerging nature of the insect sector, the pool of potential respondents is rather limited.

A minority of respondents elaborated on their barrier and risks scorings. On average, 65% (rearers: 71%; processors: 70%; feed producers: 60%; food producers: 59%) of the respondents mentioned strategies to overcome the indicated most important barrier or risk. On average, 89% (rearers: 91%; processors: 88%; feed producers: 93%; food producers: 83%) of the respondents indicated which risk management strategies were applied in the respective supply chain stages, and 13 additional risk management strategies were mentioned.

Respondents for the supply chain stages rearers, processors, feed and food producers originated from 12, 6, 6 and 7 different countries, respectively[6]. Included survey responses originated from 11 different European and four non-European countries; the most represented countries were: the Netherlands (n=11), Belgium (n=10), Germany (n=7) and Italy (n=6). On average, 58% of responses came from companies (rearers: 74%; processors: 62%; feed producers: 43%; food producers: 54%), others were from business associations (8.5%), research organisations (16%), or other organisations (17.5%) such as technology suppliers and consultancies. Although researchers are generally not regarded as sector stakeholders, their responses were included as they are considered to have a good understanding of the specific supply chain stages. The size of the companies, in terms of the average FTEs (full time equivalent, 1 FTE = 40 hours per week), was relatively small, except for companies associated to feed production. The dominance of low FTE organisations among survey respondents reflects the dominance of SME and young insect businesses in the European insect sector. The size of research institutes was left out from the analysis. The main insect species reared, processed, or researched included the black soldier fly (*Hermetia illucens*), the yellow mealworm (*T. molitor*) and – though to a lesser extent – the house cricket (*Alphitobius domesticus*) and the lesser mealworm (*A. diaperinus*).

Analysis

Survey responses were analysed using IBM SPSS Statistics for Windows (25th version; IBM Corporation, Armonk, NY, USA). Analyses were performed following the steps specified for each objective below.

Objective 1: to identify the perceived importance of different barriers and risks, and to retrieve information on applied risk management strategies by stakeholders in European insect supply chains.

For each past barrier and future risk, a score (Equation 1 and 2) was computed – per respondent – from the respective frequency and impact score:

$$\text{Past barrier score} = \text{frequency of barrier in the past} \times \text{negative impact of barrier in the past} \quad (1)$$

$$\text{Future risk score} = \text{frequency of risk in the future} \times \text{negative impact of risk in the future} \quad (2)$$

Subsequently, from all respondent scores, the averages and standard deviations were computed for each barrier and risk. These averages thus reflect the perceived importance, averaged over individuals per supply chain stage, for each separate barrier or risk. They were used to rank the five most important barriers and risks perceived by stakeholders for each of the four supply chain stages. Answers to open-ended questions related to strategies to overcome the most important barriers and risks (specified per domain) were used to gain insights into such strategies applied by operators.

Objective 2: to obtain insights into the temporal dynamics of perceived barriers and risks of stakeholders.

The dynamic risk perception was defined as the difference between the future risk score and the past barrier score, for each individual respondent (Equation 3):

$$\text{Dynamic risk perception score} = \text{future risk score} - \text{past barrier score} \quad (3)$$

Paired sample *t*-tests were run to test for statistically significant differences (α=0.05) between future risk and past barrier scores. With regard to data validity used for these paired sample t-tests, we made the following assumptions: (1) the observations (between subjects) are independent; and (2) each paired measurement is taken from the same subject. In addition, the average dynamic risk perception score across all risk domains was computed for each respondent. This average dynamic risk perception score reflects the average difference between future risk scores and past barrier scores for one respondent. Based on this average score, respondents were categorised into one of the following groups: one with a negative average dynamic risk perception (i.e. future risks were perceived to be smaller than past barriers) or one with a positive average dynamic risk perception (i.e. future risks were perceived to be larger than past barriers). These respondent groups were then profiled using descriptive statistics including their applied risk management strategies and risk attitude.

[6] An overview of the number of respondents per supply chain stage per country can be found in the Supplementary material (3.1).

3. Results

Table 2 and 3 show perceived importance of past barriers and future risks. Per supply chain stage, the five most important barriers and risks are highlighted. The complete results can be found in the Supplementary material (2.1-2.2).

Perceived importance of past barriers

Stakeholders in all stages perceived barriers from the 'finance, cost & market' domain as most constraining (Table 2 and 3), followed by barriers from the 'regulations' and 'operations' domains. Barriers from the 'worker & food safety' domain were generally not seen as a major impediment to business performance. For most supply chain stages, top-five barriers comprised different domains, except for the processors' stage, for which all top-five barriers originated from the 'finance, cost & market' domain.

Regarding barriers in the 'operations' domain, the *lack of mass rearing techniques* (14.2) has most severely affected rearers. Hence, feed producers underscored the *insufficient scale of production of insects or insect-based ingredients for commercial use as ingredients in feed* (9.5) for feed producers. For food producers the *limited knowledge on the use of insects as ingredients* (15.9) was regarded as most constraining.

Within the 'financial, cost & market' domain, the most constraining barriers related to the high operational costs of insect production and further processing. These costs included *high labour costs* for rearers (13.5) and processors (14.4), as well as *high unexpected costs* (10.7) and *high prices of insects and insect-based ingredients for further processing* (12.8) for feed producers. In addition, the *lack of possibilities to sell insect frass* (12.6) has limited the business performance of rearers. Furthermore, *the limited access to finance* has affected processors (16.3) and feed producers (10.0), and processors were also constrained by the *unavailability of subsidies for investments* (17.6). Regarding the market for insects and insect-based products, the *lack of social acceptance of production and products* was perceived as most constraining for processors (15.5) and food producers (15.5). Accordingly, the *volatile market demand for produce* (17.9) and *insufficient market demand for insect-based products* (19.3) were considered as important barriers for the business development of processors and food producers, respectively.

Within the 'regulations' domain, barriers including the *legal restrictions on the use of waste and by-products as rearing substrates* (12.7) and *legal restrictions preventing the use of processing-waste or frass* (12.6) were considered as most limiting. More downstream along the supply the chain, feed and food producers were affected by restrictions regarding product development. For feed producers this included *legal restrictions concerning the use of insect meal in feed* (11.5), and for food producers *national legal restrictions concerning the use of insects in food* and *lack of safety data for submission of legal registration* (17.4).

Perceived importance of future risks

'Finance, cost & market' risks were anticipated to be most constraining for the future, followed by 'regulatory' and 'operational' risks (Table 2 and 3). On the contrary, risks related to 'worker & food safety' were not considered to be among the top-five risks across supply chain stages.

With regard to 'operations', rearers anticipated that the *lack of mass rearing or processing techniques* (11.9) will be most constraining in the future, which is anticipated by feed producers to result in an *insufficient scale of production of insects for commercial use as ingredients in feed* (11.5). Feed producers also considered the *lack of consistency in quality of insects* (9.1) as an important risk for the future.

'Financial, cost & market' risks across chain stages comprehended mainly price and demand risks, and – to a lesser extent – risks related to high operational costs. These high operational costs included *high labour costs* (11.9) for rearers and *high prices of insects or insect-based ingredients for further processing* (9.3) for feed producers. In addition, processors feared a *limited access to finance* (11.3) which would affect future business performance. Regarding price risks, the *low market prices of insects or derived products* were perceived as constraining for rearers (12.9) and feed producers (10.4). For processors, the *price fluctuations of insects or insect-based products* (10.9) were regarded as an important risk. With respect to the market for insects and insect-based products, both processors and food producers considered the *lack of social acceptance of production and products* (resp. 13.6 and 15.3) as an important factor affecting future business performance. This perception was also illustrated by the anticipated impact of the *volatile market demand for produce* (12.9) for processors and the *insufficient market demand for insect-based products* (14.1) for food producers.

With respect to 'regulatory' risks, stakeholders anticipated a negative impact from constraints on various aspects for the different supply chain stages. For rearers, the *legal restrictions on the use of waste and by-products as rearing substrates* (13.6) and *legal restrictions preventing the use of processing-waste or frass* (13.6) were anticipated to remain most constraining in the future. Similar constraints included *difficulties to obtain an operating license for the company* (12.0) for processors and *legal restrictions concerning the use of insect meal in feed* (10.5) for feed producers. For food producers, it concerned *national legal restrictions*

Table 2. Average operational and financial, cost & market barrier (B) and risk (R) scores for rearers, processors, feed and food producers.[1,2]

Description	Rearer (n=23)		Processor (n=8)		Feed producer (n=14)		Food producer (n=12)	
Operational barriers and risks	B	R	B	R	B	R	B	R
Lack of information on best species for mass rearing	7.9	4.9						
Lack of information on optimal rearing conditions	11.6	7.7						
Unstable supply of eggs or larvae for rearing	8.8	8.4						
Unstable quality of substrate(s) supply for rearing	9.1	7.7						
Unstable quantity of substrate(s) supply for rearing	6.2	7.7						
Lack of quality standards and best practice guidelines	8.1	9.1	9.3	8.3				
Lack of mass rearing or processing techniques	**14.2**	**11.9**	11.2	8.1				
Insect diseases which infect insect colonies	7.6	9.7						
Pest insects and insect diseases which infect colonies	9.9	8.8						
Presence of rodents in the insect rearing facility	3.3	3.1						
Lower production volumes due to extreme weather	6.2	4.6						
Lack of data on the effect of insect processing techniques on nutritional content			11.4	8.4				
Lack of validated safe methods and guidance for storage, packaging and transport of eggs and larvae			9.8	9.4				
Insufficient scale of production of insects for commercial use as ingredients in feed or food					**9.5**	**11.5**	11.0	8.4
Lack of consistency in quality of incoming insects					5.2	**9.1**	10.4	8.2
The need to source insects with difference in quality					4.5	6.6	10.5	8.0
Limited validation of using specific insect species in diets for livestock under practical conditions					5.2	7.4		
Limited availability of data on sensory perception of consumers regarding insect-based food					4.1	6.4	10.1	9.4
Limited knowledge the use of insects as ingredients					7.8	6.1	**15.9**	9.4
Lack of best practice guidelines for insect-based food production							12.8	9.2
Financial, cost & market barriers and risks								
Unavailability of subsidies for investment	11.4	9.4	**17.6**	9.7	9.3	6.7	14.7	10.4
Limited access to finance	11.1	10.9	**16.3**	**11.3**	**10.0**	5.8	14.9	10.3
Unavailability of business insurance for companies	5.2	7.3	6.4	6.7	2.4	3.8	7.9	7.0
Technological innovations which decrease current asset values	7.7	8.3	9.5	8.9	6.5	5.1	7.8	7.7
High labour costs	**13.5**	**11.9**	**14.4**	10.1				
High prices of young larvae for rearing or insect-based ingredients for further processing	5.3	4.7	10.5	8.7	**12.8**	**9.3**	13.8	8.8
High prices of substrate(s) for rearing	7.2	9.0						
Price fluctuations of young larvae for rearing or insect-based ingredients for further processing	5.0	5.0	9.1	9.7	7.8	8.3	7.9	6.8
Price fluctuations of substrate(s) for rearing	5.5	8.1						
Low market prices of insects or derived products	9.7	**12.9**	9.5	9.1	9.2	**10.4**	8.3	7.1
Price fluctuations of insects or insect-based products	8.1	11.6	6.8	**10.9**	6.1	7.9	7.8	7.7
Lack of possibilities to sell insect frass	**12.6**	9.6	10.4	9.4				
Volatile market demand for produce	12.0	9.7	**17.9**	**12.9**				
Lack of social acceptance of production and products	11.1	8.3	**15.5**	**13.5**	5.4	5.2	**15.5**	**15.3**
Late payment from buyers	5.5	6.1	7.0	7.0	3.3	3.2	6.3	5.5
Seasonal downturns in revenue	6.3	5.1			6.3	5.0	8.8	5.4
High unexpected costs	9.8	7.5	12.6	10.6	**10.7**	7.5	10.7	7.6
Insufficient market demand for insect-based products					7.0	6.8	**19.3**	**14.1**

[1] Top-five scores per supply chain stage are in bold.
[2] Empty cells indicate that this barrier or risk was not included for this stage. Barriers and risks presented in this table are shortened versions. Full phrases are presented in Supplementary material 2.1.

Table 3. Average worker & food safety and regulatory barrier (B) and risk (R) scores for rearers, processors, feed and food producers.[1,2]

Description	Rearer (n=23)		Processor (n=8)		Feed producer (n=14)		Food producer (n=12)	
Worker & food safety barriers and risks	**B**	**R**	**B**	**R**	**B**	**R**	**B**	**R**
Allergenicity potential for workers caused by insects or related products	8.7	7.1	8.3	8.7	3.9	6.2	5.1	5.6
Other health problems for workers due to working with insects	5.3	5.3						
Microbiological hazards in insects related to substrate use	6.2	6.5						
Chemical hazards in insects related to substrate use	4.5	6.0						
Lack of knowledge on the safety of insect production or insect-based products	9.1	6.4			7.6	6.7	7.6	5.8
Microbiological risks related to storage, packaging and transport			9.0	8.4				
Lack of data on the impact of processing techniques on food safety of products			12.3	8.0				
Lack of traceability systems in place for insect transport and logistics			7.7	6.6				
Allergenicity potential of insect-based feed for animals					1.9	3.6		
Lack of data on the impact of insect-based feed on animal performance and health					6.9	7.2		
Allergenicity potential for consumers from insect-based food products							7.3	6.4
Uncertainty regarding the impact of insect-based food products on human health							6.2	7.3
Regulatory barriers and risks								
Legal restrictions on the use of waste and by-products as rearing substrates	**12.7**	**13.6**						
Legal restrictions preventing the use of processing-waste or frass	**12.6**	**13.6**	8.9	10.6				
Difficulties to obtain operating licenses for the company	11.4	8.8	8.9	**12.0**				
Regulations regarding environmental emissions	7.3	7.2						
Lack of safety data for submission of legal registration					8.1	8.7	**17.4**	**11.5**
Legal restrictions concerning the use of insect meal in feed					**11.5**	**10.5**		
Other legal restrictions (e.g. labelling requirements insect-based feed and food)					5.7	6.3	6.3	6.3
Other legal restrictions (e.g. labelling requirements for food from animals fed with insects)					5.3	8.2		
Administrative and financial burden for the authorisation of insects as food at EU level							13.6	**11.8**
National legal restrictions concerning the use of insects in food							**19.2**	**13.9**

[1] Top-five scores per supply chain stage are in bold.
[2] Empty cells indicate that this barrier or risk was not included for this stage. Barriers and risks presented in this table are shortened versions. Full phrases are presented in Supplementary material 2.1.

concerning the use of insects in food (13.9), as well as *lack of safety data for submission of legal registration* (11.5) and related *administrative and financial burden for the authorisation of insects as food at EU level* (11.8).

Applied risk management strategies

Across supply chain stages, *investing in technologies for production and safety thereof* was among the most frequently applied strategies in the domains of 'operations' and 'worker & food safety' (Table 4). With respect to 'operational' strategies, *investing in technologies for consistent quality of production* along with *investing in technologies for consistent quantity of production* were among the top-five strategies applied in most supply chain stages. In addition, rearers and feed producers relied on diversification strategies in production. 'Financial, cost & market' strategies applied by processors and food producers included *ensuring access to loans or external funds* and *minimising debts to keep financial risks low*. Furthermore,

Table 4. Applied risk management strategies in supply chain stages: rearers, processors, feed and food producers.[1,2]

Description	Rearer (%) (n=23)	Processor (%) (n=8)	Feed producer (%) (n=14)	Food producer (%) (n=12)
Operational strategies				
Investing in technologies for consistent quality of production	**87**	**50**	**57**	**42**
Diversifying business activities	22	38	**50**	33
Diversifying insect species for production	17	25	21	33
Producing for feed and food purposes or using different product applications	**52**	25	**50**	17
Having an all-in-all-out system	30	13	7	17
Having multiple production or processing lines	22	25	21	17
Using market information to plan business activities for the next season	35			
Investing in technologies for consistent quantity of production	**78**	**63**	43	**42**
Financial, cost & market strategies				
Ensuring access to loans or external funds	43	**63**	36	**58**
Keeping financial reserves for possible financial downtimes in the future	39	38	43	33
Minimising debts to keep financial risks low	13	25	29	**58**
Having an additional job outside the insect business	13	25	21	25
Buying insurance	26	38	0	25
Using contracts	13	25	**50**	17
Improving labour flexibility	17	25	29	33
Purchasing inputs or selling outputs jointly with other rearers or processors	0			25
Worker & food safety strategies				
Investing in technologies to control environmental risks	**57**	38	21	33
Investing in technologies for hygiene control	**57**	**50**	**57**	**58**
Other strategies				
Being a member of a cooperative	17	**63**	0	8
Being a member of a business association	35	13	43	33

[1] Top-five strategies per stage are in bold. Numbers reflect percentage of respondents who apply the strategy.
[2] Empty cells indicate that this risk management strategy was not included for this supply chain stage. Risk management strategies presented in this table are shortened versions. Full phrases are presented in Supplementary material 2.3.

using contracts to guarantee consistency in quantity or quality was frequently applied by feed producers. Regarding 'worker & food safety' strategies, *investing in technologies for hygiene control* was among the top-five strategies applied in all supply chain stages. 'Other' strategies, such as *being a member of cooperatives or business associations* were not very popular risk management strategies for operators, except for processors for whom the strategy *being a member of a cooperative* was among the top-five.

Answers to the open question on stakeholders' perception of the capacity among business operators to overcome barriers and risks revealed a large heterogeneity across individual respondents and domains. In this regard, stakeholders were especially positive about overcoming 'operational' risks, in contrast to 'regulatory' risks. Stakeholders indicated for instance that operators felt quite able to overcome the barrier of *lack of technologies*, *small scale production* and *high labour costs*. Main strategies used in this respect included *doing research*, *experiments* and *developments of automated systems, both in-house and in collaboration with other start-ups.* Regarding strategies for 'financial, cost & market' risks, *cooperating with other businesses* along with *doing market research* were frequently applied in the sector to improve and enlarge the market for insects. Furthermore, stakeholders observed the desire *to set up long-term relationships* and *make use of contracts* to keep price and demand risks as low as possible. With regard to improvement of the social acceptance of insect products, the main applied strategy across stages included *educating consumers*. With respect to 'regulatory' risk strategies, the most important strategy was to *provide more clarity*

about production and processing and *to invest time and efforts into lobbying with the authorities.* In addition, stakeholders indicated that *cooperating with other businesses or stakeholders* was more frequently applied to overcome 'regulatory' risks compared to other types of risks.

Dynamic risk perception

Looking at multiple risk domains simultaneously, the perceived risks were considered smaller in the future as compared to the past for processors and food producers, which can be seen from the significantly negative dynamic risk perception scores of -1.39 (P=0.001) and -1.90 (P=0.000), respectively, in Table 5 (bottom row). This result is in line with those listed in Table 2 and 3, indicating sometimes large differences between barrier and risk perception. Stakeholders expected risks to reduce in the future, especially in the case of 'operational' and 'financial, cost & market' risks, with a score of 0.74 (P=0.001) and 0.76 (P=0.020) (final column), respectively. Again, this is in line with results presented in Table 2 and 3, showing a decline in risk perception. In addition, it is noteworthy that for all supply chain stages except for food producers, 'regulatory' risks are expected to increase in the future, an observation that could be related to the difficulties stakeholders foresee in overcoming this type of risk. We realise that the small sample size for the supply chain stage processors is not representative to provide conclusive evidence on the dynamic risk perception for this chain stage. We believe, however, that our results do provide suggestive evidence. Comparing the individual dynamic risk perception between operators, 31 of 55 stakeholders perceived future risks on average to be smaller compared to the past. With regard to risk management, operators with a predominantly positive dynamic risk perception applied fewer strategies, but risk attitude was nearly equal between the groups. Details on respondents' risk attitude per supply chain stage can be found in Supplementary material 2.4. Details on profiles for the two groups are shown in Supplementary material 2.5.

4. Discussion

Comparison to previous research and other sectors

Since research on barriers and risks for the insect sector is rather limited, we do not only compare our findings with observations from previous studies in the same sector but also with those from other emerging sectors. In addition, we interpret our results in the context of barriers and risks which are typically experienced by small companies.

An important 'operational' barrier for rearers was the lack of automation techniques for large scale production, which inter alia leads to insufficient quantities of insects and insect-based ingredients for further processing as perceived by feed producers. These results confirm previous findings for the insect and other sectors. Rumpold and Schlüter (2013) already emphasised the need for automated and cost-effective production processes in the insect industry. In addition, Sogari *et al.* (2019) suggested in their review that automation techniques will help to increase production scale and reduce labour intensity allowing for stable product quality and competitive product pricing. Comparable observations were made for the algae sector, where the costs of raw materials, the required labour, and the small-scale operations resulted in high production costs (Fernández *et al.*, 2019). High operational costs, also affected the mussel sector (Gren and Tirkaso, 2021). Concerning other 'operational' matters, Van Huis *et al.* (2021) highlighted potential pathogen infection as a major concern for insect rearing. In our study, this risk was considered of medium concern relative to other 'operational' barriers.

'Financial, cost & market' barriers and risks were consistently ranked as most important among all domains and across chain stages. The volatile and insufficient market demand, due to factors such as high sales prices of insects and insect-based feed products as well as limited social acceptance of food products, were main concerns. The low social acceptance of insect-based food products in particular has been thoroughly discussed before by, for instance, Onwezen *et al.* (2021), who concluded that

Table 5. Dynamic risk perception scores per supply chain stage and per risk domain.[1]

	Rearers (n=23)	Processors (n=8)	Feed producers (n=14)	Food producers (n=12)	All supply chain stages
Operations	**-0.91 (0.035)**	-1.88 (0.059)	**1.46 (0.021)**	**-2.53 (0.014)**	**-0.76 (0.020)**
Finance, cost & market	0.14 (0.693)	**-1.78 (0.003)**	**-1.15 (0.007)**	**-1.59 (0.001)**	**-0.74 (0.001)**
Worker & food safety	-0.28 (0.604)	-1.39 (0.093)	0.60 (0.188)	0.38 (0.665)	-0.23 (0.477)
Regulations	0.23 (0.777)	2.43 (0.090)	0.84 (0.144)	**-3.25 (0.009)**	-0.27 (0.596)
All risk domains	-0.25 (0.295)	**-1.39 (0.001)**	0.04 (0.874)	**-1.90 (0.000)**	

[1] P-values of paired sample t-tests are between brackets. Significant differences (P<0.05) are in bold.

insects have the lowest consumer acceptance among various alternative protein sources. Intensive consumer education and new product development efforts are required to reach higher consumer acceptance (Naranjo-Guevara *et al.*, 2021; Ngo and Moritaka, 2021). The observed importance of 'financial, cost & market' risks as perceived by stakeholders correspond to those commonly experienced by smaller companies (Ali *et al.*, 2017; Yang, 2017) and in other emerging sectors (Ahsan and Roth, 2010). Ahsan and Roth (2010), for instance, obtained similar findings for the mussel industry where market risks regarding future demand and volatile prices were perceived as important by stakeholders. The difficulty for small companies to obtain financing has also been described before. Enzing *et al.* (2014), for instance, identified access to finance as one of the main non-technological barriers for companies operating in the algae sector. The difficulty to obtain financing is often related to information asymmetry between small companies and finance providers on firm performance and financial statements (Moro *et al.*, 2015). For companies operating in emerging sectors, information provision and symmetry become even more relevant as they operate in a fast-changing business environment, often characterised by a high level of uncertainty, with changing regulations and market conditions.

In our study, 'worker & food safety' barriers and risks were consistently regarded as least important. This result is in contrast to findings by Skotnicka *et al.* (2021), who mentioned the relevance of food safety concerns for consumers and their role in the social acceptance of insect-based products. The difference could be explained by the focus on consumers versus supply chain operators. Apparently, insect operators feel they can handle safety problems for workers and their products quite well.

'Regulatory' barriers and risks were perceived as highly relevant for all chain stages. Dobermann *et al.* (2017) and Yang and Cooke (2020) obtained similar findings, as did Araújo *et al.* (2021), Rumin *et al.* (2021), and Ahsan and Roth (2010) for other emerging sectors; the former two studies in the context of the algae- and the latter one of the mussel sector. These emerging sectors face(d) comparable regulatory barriers, specifically in relation to changing regulations and the high complexity of administrative procedures and licensing. The large impact of regulatory constraints for SMEs in young and innovative sectors has been described before as a barrier for business model innovation to enhance firm performance (Ulvenblad *et al.*, 2018). In the context of the current study on European insect supply chains it is, however, important to note that European regulations have further progressed since the time of data collection. Although the implemented changes were foreseeable when the survey was conducted, respondents still regarded 'regulatory' risks as highly relevant and as limiting factors for many different aspects of production. European regulations pertaining to the use of different substrates did not change so far. The approval of cheaper substrates and the permission to sell insect by-products could benefit the profitability of rearing companies (Beesigamukama *et al.*, 2021). Regulations related to the use of insect ingredients for feed and food have changed, but were still ranked as important risks for feed and food producers. We believe that the recent new authorisations create further opportunities for business operators in European insect supply chains.

Stakeholders emphasised the importance of investing in new technologies to scale up production capacity and to ensure continuous high-quality production as an 'operational' risk management strategy in all supply chain stages. This finding corresponds to the high scores on perceived risk regarding the lack of automation for rearers and its consequences for upscaling the production for feed producers. Respondents mentioned that these investments not only included financial investments in technology, but also in-house and project-related research and development. We also observed efforts to create more financial security and financial opportunities by ensuring access to funds or loans for companies. Again, this reflects the high perceived risks related to the lack of subsidies or finance.

Regarding further management of 'financial, cost & market' risks, we found that diversification strategies to mitigate for instance the high perceived supply and demand risks were not often applied across chain stages. Other strategies, such as obtaining insurance or buying or selling jointly, were also not widely applied. With regard to insurance, this could be related to the lack of available insurance specific for insect companies and/or to the low relevance that stakeholders ascribed to the lack of insurance. The use of insurance is suggested as an important risk management tool for smaller companies, but requires detailed knowledge on company risk and incurred costs (Falkner and Hiebl, 2015). Remarkably, only feed producers made frequent use of contracts to determine price and quality. This might be explained by the fact that larger companies, with a stronger representation in feed production, were more familiar with this strategy. 'Regulatory' risk management strategies were not included in the survey, since most regulatory restrictions represent external risks upon which business operators have little influence. Additional comments from stakeholders revealed that many of them continue to communicate, connect, and lobby with governments and associations to address these 'regulatory' risks. These actions are in line with the suggestion of Marberg *et al.* (2017) for small companies to focus on collective lobbying operations.

Actions needed by operators and third parties

In general, it is important for both insect business operators as well as third parties to acknowledge that the nature and relevance of barriers and risks are different for individual actors and stakeholders. Hence, different actions could be taken by business operators and third parties in each of these supply chain stages. For rearers, efforts to mitigate risks should be channelled into automation techniques to reduce labour (costs) (Heckmann *et al.*, 2019) and into lowering of operational costs by using cheaper substrates (Van Huis, 2020). Capital is needed to make these investments in technologies and, therefore, the sector needs more legitimacy from finance providers. Furthermore, insect processors should mainly focus on the marketing of insect products, for instance by public education to improve social acceptance of insect-based products (Stull and Patz, 2020). To mitigate most relevant risks for insect-based feed producers, attempts should be made to realise a consistent quality and quantity of incoming insects or insect-based ingredients. Feed producers are rather dependent on rearing facilities in this regard, but the use of contracts could provide more certainty for large scale feed producers. Insect-based food producers should primarily target a reduction of market and consumer risk. Most important in this regard is the improvement of social acceptance, including the collection of (sensory) data on insect-based food products to adapt products based on consumer preferences (Wendin and Nyberg, 2021). Eventually, forces of all supply chain actors should be bundled to facilitate further easing of regulations and create hereby a less uncertain regulatory landscape in Europe.

From the information collected through the survey, it was clear that intra-chain collaboration is not often practiced but regarded as essential for further development and scale up of the sector. In our view, collaboration in such an emerging sector is key to strengthen its financial position and increase resilience, especially for the commonly experienced barriers and risks. For third parties, including governmental agencies and financial institutions, initiating subsidy schemes or enhancing access to finance would allow for more large-scale investments and increased production volumes. Furthermore, actions to facilitate authorisation procedures of new insect-based products would enable small insect businesses to expand their product range and increase sales on the food market.

Limitations

The representativeness of our results in view of the number and characteristics of the businesses operating in the different countries surveyed could not be estimated, since the exact number of operating companies is unknown. As Belgium, Germany and The Netherlands are regarded as the sectors' front-runners and are also best represented in our survey, we believe that we covered a relevant part of the sector. Furthermore, we recognise that the risk management strategies covered in this study mainly focused on business aspects and on the rearer stage, and not on marketing or other strategies commonly used more downstream in the supply chain. Even though including those could have enriched our results, the currently used strategies enabled us to compare across stages. In this regard, we believe to have covered relevant strategies to provide a first insight into risk management for insect businesses. Lastly, we realise that in comparing past barrier and future risk perception, the former has a larger certainty component compared to the latter. However, we believe that even though the scores have a slightly different certainty component, both are based on perception, which is eventually one of the main driving factors for behavioural change and decision making when it comes to business and risk management strategies.

5. Conclusions

Our study showed that most past barriers and future risks for insect operators were encountered or anticipated in the 'finance, cost & market' domain, particularly for insect processors. Other chain stages were also hampered by 'regulatory' barriers and risks and – though to a smaller extent – 'operational' ones. The highlighted barriers and risks included a lack of automation for large-scale rearing, the volatile demand for insect products, the limited access to finance and subsidies, and the constraints imposed by strict legislation. For rearers, perceived barriers and risks concerned those impacting profitability of businesses, specifically limitations to increase operational scale and lower operational costs by using cheaper substrates due to restrictions in legislation. Marketing barriers and risks, including low and volatile demand as well as limited social acceptance of insect-based (food) products, were especially important for processors and food producers, whereas price and quality of inputs were regarded as most constraining for feed producers. Regarding risk management, the most frequently applied strategies included investing in technologies with the aim of ensuring high and consistent quality of production, and this was true for all four chain stages. Based on our findings, we recommend to further enlarge opportunities for insect operators in obtaining finance for investments to enhance sector growth. Risk management should primarily focus on mitigation of 'financial, cost and market' risks. In addition, approval of alternative and possibly cheaper substrates as well as the authorisation of insect-based feed and food products should be further facilitated to enlarge sales and market opportunities.

Supplementary material

Supplementary material can be found online at https://doi.org/10.3920/JIFF2022.0100

Supplementary Material 1: Surveys

S.1.1 Supply chain stage: rearer

S.1.2 Supply chain stage: processor

S.1.3 Supply chain stage: feed producer

S.1.4 Supply chain stage: food producer

Supplementary Material 2: Results

S.2.1 Overview of multiplied barriers and risks scores

S.2.2 Average scores of barriers and risks

S.2.3 Risk management strategies

S.2.4 Risk attitude

S.2.5 Dynamic risk perception

Supplementary Material 3: Respondents

S.3.1 Origin of respondents

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Conflicts of interest

The authors declare no conflict of interest.

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