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From waste to wealth: Challenges and opportunities in agricultural side-stream utilization for circular bio-economy in Kosovo

Hysen Bytyqi[1], Arben Mehmeti[2], Muhamet Zogaj[2], Kaltrina Berisha[3]*, Labinot Kryeziu[4] and Rainer Waldhardt[4]

[1] *Department of Animal Science, Faculty of Agriculture and Veterinary, University of Prishtina "Hasan Prishtina", Prishtina, Republic of Kosovo*
[2] *Department of Plant Production, Faculty of Agriculture and Veterinary, University of Prishtina "Hasan Prishtina", Prishtina, Republic of Kosovo*
[3] *Department of Food Technology with Biotechnology, Faculty of Agriculture and Veterinary, University of Prishtina "Hasan Prishtina", Prishtina, Republic of Kosovo*
[4] *Division of Landscape Ecology and Landscape Planning, Faculty of Agricultural Sciences, Nutritional Sciences, and Environmental Management, Justus Liebig University Giessen, Giessen, Germany*
**Corresponding author:* kaltrina.berisha@uni-pr.edu

Abstract

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This study examines the potential of agricultural by-products such as residues from tomatoes, peppers, potatoes, watermelons, melons, and apples as a sustainable feed source for insect farming, contributing to circular bio-economy efforts in Kosovo. By assessing the availability of these by-products in two key agricultural regions, Dukagjini and Kosovo Plain, the research identifies significant variations in yield, with tomatoes plants producing the highest amount (8.1 t/ha), followed by watermelon, apple, potato, and melon. The findings suggest that these often-discarded agricultural residues, typically overlooked due to market constraints, can be repurposed as insect feed, providing an eco-friendly approach to waste reduction and nutrient recycling. This approach not only addresses the environmental challenges posed by organic waste, but also supports the production of value-added products like insect-based proteins. The study underscores the feasibility of integrating agricultural side-streams into insect farming, contributing to a closed-loop system that aligns with circular bio-economy goals. This research is novel in its focus on Kosovo's agricultural context, providing localized data and insights that can inform sustainable practices in similar regions. By transforming agricultural waste into valuable resources, the study offers a pathway to enhance sustainability, reduce environmental impact, and promote economic resilience in the agricultural sector.

Keywords: agricultural side-streams; insect feed; circular bio-economy; waste reduction; sustainable protein production

Introduction

In Kosovo, around 19 571 hectares are dedicated to cultivating various vegetables, primarily potatoes (3 884 ha), peppers (3 154 ha), watermelons (1 316 ha), tomatoes (805 ha), and melons (329 ha), alongside other crops. Additionally, fruit tree crops occupy a substantial portion of land, with 3 091 hectares allocated (Ministry of Agriculture, Forestry and Rural Development –MAFRD, 2023). Yet, primary agricultural production also generates significant quantities of organic refuse during the stages leading up to harvest.

These agricultural products, often comprising surplus materials, residues, or by-products, pose both challenges and opportunities for sustainable resource management and environmental protection (Arancon et al., 2013; Pleissner and Lin, 2013). The emergence of organic by-products within the context of agriculture aligns with the principles of the circular bio-economy, advocating for the reduction of waste and environmental consequences through resource reuse, recycling, and regeneration (Jurgilevich et al., 2016). However, effectively addressing these organic side-streams remains a formidable task, particularly concerning food security and environmental sustainability (Kennard, 2020).

The concept of "organic side-stream emergence" involves recognizing, applying, and managing surplus materials generated during organic farming to establish a sustainable and closed-loop agricultural framework (Ojha et al., 2020). Agricultural and culinary by-products, commonly known as agriculture side-streams, encompass the secondary outputs produced throughout and after the harvest process of organic fruits and vegetables. These by-products, often deemed unsuitable for sale or consumption due to factors like size, shape, or ripeness, contribute to the estimated one-third of global food waste discarded annually (FAO, 2017).

With global demand for animal-based proteins rising due to population growth, interest in alternative, environmentally sustainable protein sources like edible insects is increasing (Vassileios, 2019). According to Grau et al. (2017), edible insects, notably the yellow mealworm, offer a promising solution due to their high protein, vitamin, and mineral content, as well as their efficient conversion of feed into edible biomass. Moreover, compared to conventional livestock, edible insects have a smaller environmental footprint in terms of land use, greenhouse gas emissions, and overall environmental impact (Oonincx and De Boer, 2012; Thévenot et al., 2018). In order to map side-stream supply from different crops in Kosovo, the German Federal Ministry for Economic Cooperation and Development (BMZ) and the European Union (EU), being implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (Society for International Cooperation) (GIZ) Kosovo, funded The Faculty of Agriculture and Veterinary partnering with GoBeyond to implement an innovative project "Feasibility Study for Production & Application of Insect Frass".

Thus, exploring the potential of utilizing agricultural side-streams as feed for insect production aligns with the principles of a circular bio-economy and presents an opportunity to address agriculture side-stream while promoting sustainable protein production. Therefore, this research aims to assess the economic feasibility and quantity considerations associated with utilizing agricultural side-streams from Kosovar crop production such as tomatoes, peppers, potatoes, watermelons, melons, and apples – as feed for insect production. By investigating insects' capacity to digest a wide range of agricultural crop wastes, this study seeks to contribute to the development of sustainable solutions for transforming organic side-streams into valuable proteins within a circular bio-economy framework.

Materials and Methods

Research background

The research methodology used in this study aimed to assess the feasibility of utilizing agricultural side-streams as insect feed to promote circular bio-economy principles in Kosovo. The study was conducted from September to December 2023, coinciding with the harvesting season of key crops, including tomatoes, peppers, potatoes, watermelons, melons, and apples. Data collection focused on two primary agricultural regions in Kosovo: Dukagjini and Kosovo Plain (Figure 1).

A total of 108 watermelons, 69 melons, 284 apples, 77 tomatoes, 136 peppers, and 90 potato fields were randomly selected for sampling (Table 1). Data collection methods varied by crop: side-streams from peppers, tomatoes, and potatoes were sampled from 2×2 m plots, while watermelons and melons were sampled from 2×5 m plots. For apples, every 10^{th} plant in a row was selected for sampling. Side-streams, defined as surplus materials or by-products unsuitable for sale or consumption, were weighed using technical scales at multiple points within each plot. Data on production type (open field or greenhouse), region, and farm details were recorded.

Agriculture (vegetable and fruit tree) production in Kosovo

Cultivation of vegetables and orchards is considered for self-use and commercial purposes. Traditional farming techniques prevail, with a gradual adoption of new technologies, particularly in greenhouse farming. However, at the end of the growing season, significant portions of fruits often remain unharvested due to various factors, including small size, poor quality, damage by pests and diseases, and fluctuating market demands.

Data recording

The collected data were analyzed using the Duncan test GLM procedure in the JMP software package (2022). Univariate fixed effects were applied to evaluate the impact of different variables on side-stream production, with statistical significance set at $p \leq 0.05$. Side-stream yields were calculated per hectare for each crop, and regional variations were assessed to identify significant differences.

Results

Table 2 shows the overall mean, standard deviation, and significance level for each agricultural side-stream crop. Statistical analysis revealed significant differences between crops ($p < 0.0001$). Among the crops, tomato exhibited the highest average side-stream, followed by watermelons, melons, peppers, potatoes, and apples, in descending order.

Although numerical variations in agricultural side-stream were observed across tomatoes and peppers production methods (open field vs. greenhouse), the differences were not statistically significant (Table 2).

Table 1. Sample of study fields' number for agriculture side-stream in two regions in Kosovo

Agriculture Product	Region	N*	Region	N*
Apple	Dukagjini	91	Kosovo Plain	167
Watermelon	Dukagjini	38	Kosovo Plain	68
Melon	Dukagjini	35	Kosovo Plain	34
Peppers (greenhouse)	Dukagjini	38	Kosovo Plain	54
Peppers (open field)	Dukagjini	24	Kosovo Plain	30
Potato	Dukagjini	13	Kosovo Plain	75
Tomato (greenhouse)	Dukagjini	18	Kosovo Plain	20
Tomato (open field)	Dukagjini	16	Kosovo Plain	23

*N = Number of study fields.
Source: Authors' own elaboration

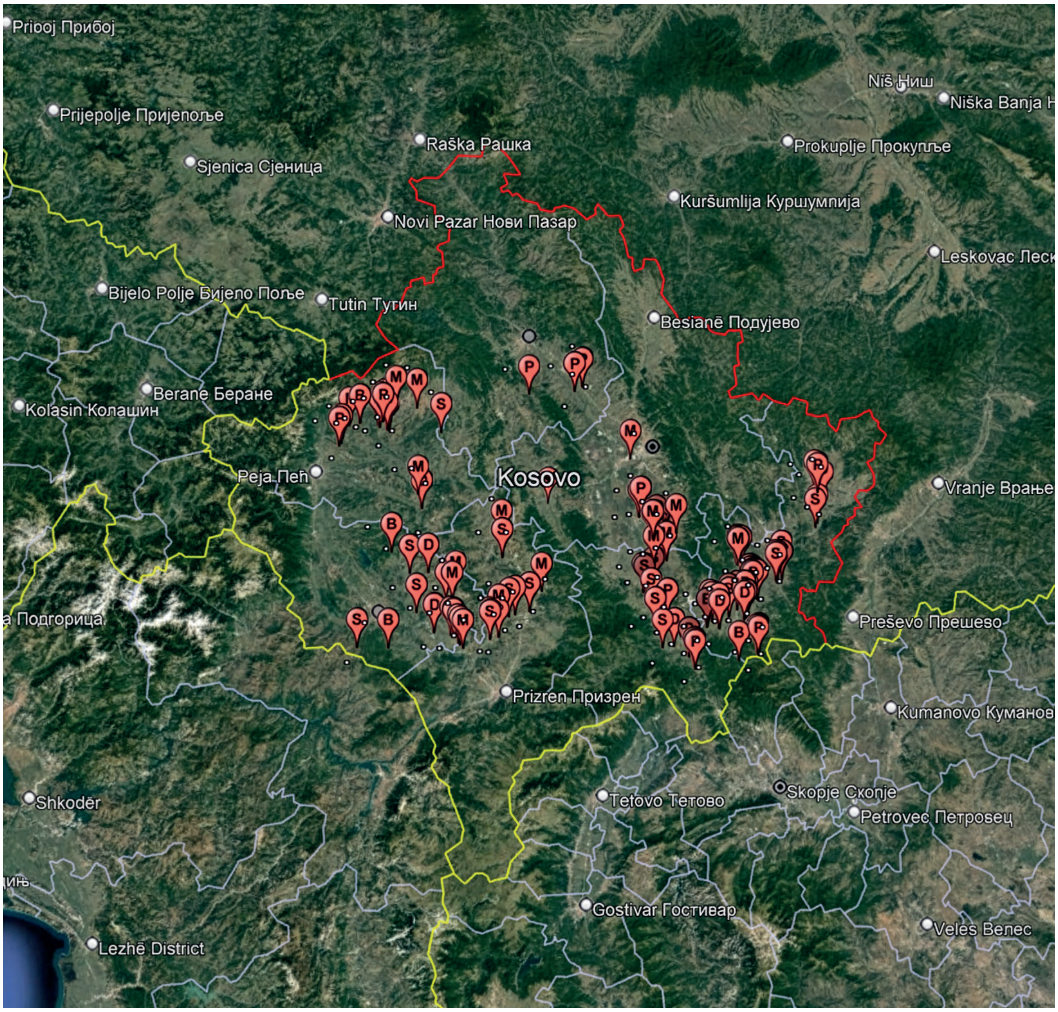

Fig. 1. Study sample collection including Dukagjini and Kosovo Plain region using google map earth
Source: Authors' own elaboration

Table 2. Summary of agricultural side-stream production for each crop and production type

Agriculture Crop	N	Agriculture side-stream	
		$\bar{X}$ ± SE	SD
Apple (kg/tree)	258	0.80 ± 0.06cd	1.02
Watermelon (kg/5m^2)	106	2.51 ± 0.13b	1.33
Melon (kg/5m^2)	69	1.53 ± 0.13c	1.12
Pepper (greenhouse) (kg/2m^2)	68	0.45 ± 0.02c	0.25
Pepper (open field) (kg/2m^2)	66	0.50 ± 0.02c	0.25
Potato (kg/2m^2)	88	0.80 ± 0.03cd	0.50
Tomato (greenhouse) (kg/2m^2)	36	1.67 ± 0.03a	0.31
Tomato (open field) (kg/2m^2)	41	1.68 ± 0.03a	0.35
Analysis of Variance ($p \leq 0.05$)*	0.0001		

*Levels not connected by the same letter are significantly different at ($p \leq 0.05$); Number of records – N; mean – $\bar{X}$; standard error – SE; standard deviation – SD.
Source: Authors' own elaboration

Table 3 shows the influence of region on various agricultural crop side-stream production. The only substantial regional effect was observed in watermelon production, with a difference of 0.39 kilograms per square meter. In other cases, regional variations did not yield meaningful differences.

The agriculture side-stream for various crops, measured in tons per hectare, is provided in Table 4, along with the comparable production for the same agricultural area. With about 33.5% and 12.8% of their farming in the open field and approximately 32.3% and 11.2% for their farming in greenhouses, respectively, the data demonstrate that the most noticeable losses are shown in tomatoes and peppers crop production per same farming land. These losses are almost twice as large (statistically significant) as the losses that are recorded in other crops. The agricultural side-stream for watermelon was 12.01%, followed by the side-stream for melon (11.21%), potato (10.49%), and apple (9.3%).

Table 5 shows the annual losses of agricultural side-streams out of the overall studied crop production in the country. These results highlight significant variations in agricultural side-stream production among different crops, regions, and production methods. According to the assessed data, the potato crop generates the greatest side-stream, which is about twice to ten times bigger (7 928 t). Compared to other agricultural products, the crop with the highest side-stream was pepper, producing around 7 528 tons per year, followed by tomato of about 6 648 tons, apples of about 3 723 tons, watermelon and melon with about 3 299 and 501 tons, respectively.

Discussion

Statements from the introduction and results sections should not be repeated here. The final paragraph should highlight the main conclusions of the study. The results and discussion sections may be combined.

The current trajectory of food production and consumption is unsustainable, necessitating innovative solutions to improve the sustainability of our food systems. One such solution, as proposed by Jurgilevich et al. (2016), is the

Table 3. Influence of region on agricultural side-stream production

Agriculture Crop	Region	N	$\bar{X}$ ± SE	SD	($p \leq 0.05$)*
Apple	Dukagjini	91	0.82 ± 0.09 de	0.81	NS
	Kosovo Plain	167	0.79 ± 0.07 de	0.80	
Watermelon	Dukagjini	38	2.78 ± 0.15a	2.77	0.0481
	Kosovo Plain	68	2.37 ± 0.11b	2.34	
Melon	Dukagjini	35	1.62 ± 0.15c	1.62	NS
	Kosovo Plain	34	1.43 ± 0.15c	1.43	
Pepper (green house)	Dukagjini	38	0.46 ± 0.03f	0.15	NS
	Kosovo Plain	54	0.44 ± 0.04f	0.12	
Pepper (open field)	Dukagjini	24	0.49 ± 0.04f	0.15	NS
	Kosovo Plain	30	0.51 ± 0.04f	0.12	
Potato	Dukagjini	13	1.28 ± 0.05cd	0.67	NS
	Kosovo Plain	75	0.72 ± 0.04de	0.32	
Tomato (green house	Dukagjini	18	1.63 ± 0.08a	0.56	NS
	Kosovo Plain	20	1.63 ± 0.08a	0.53	
Tomato (open field)	Dukagjini	16	1.68 ± 0.07a	0.56	NS
	Kosovo Plain	23	1.68 ± 0.06a	0.53	

*Levels not connected by the same letter are significantly different at ($p \leq 0.05$); Number of records – N; mean – $\bar{X}$; standard error – SE; standard deviation – SD.
Source: Authors' own elaboration

Table 4. Approximate mean side-stream percentages and p-value for variations in agricultural products

Agriculture Crop	N	Yield (t/ha)*	Agriculture side-stream (t/ha)	Percentage of agriculture side-stream Analysis of Variance (P ≤ 0.05)
Apple	258	12.95	1.20	9.3e
Watermelon	106	20.89	2.51	12.0cd
Melon	69	13.56	1.52	11.2cd
Pepper (greenhouse)**	68	17.55	2.25	12.8bc
Pepper (open field)	66	17.55	2.50	14.3bc
Potato	88	19.44	2.04	10.5d
Tomato (greenhouse)**	36	25.10	8.10	32.3b
Tomato (open field)	41	25.10	8.40	33.5a

*The information on the yield for different crops was obtained from ASK, 2023;
**The information on the yield for the pepper and tomato crop received by ASK at the country level are aggregated for open field and greenhouse production.
Source: Authors' own elaboration

Table 5. Production side-stream from total agricultural production (2023)

Agriculture Crop	Total land cultivated year 2022 (h)*	Yield (t/ha)*	Total production per year (t)*	Agriculture side-stream total production 2023 (%/ha)	Total agriculture side-stream generated (t)
Apple	3.091	12.95	40.029	9.3	3.723
Watermelon	1.316	20.89	27.491	12.0	3.299
Melon	329	13.59	4.471	11.2	501
Pepper**	3.154	17.55	55.353	13.6	7.528
Potato	3.884	19.44	75.505	10.5	7.928
Tomato**	805	25.1	20.206	32.9	6.648

*The information on the farmed areas, the crops that were grown, the yield, and the overall production was obtained from ASK, 2023.
**There is a sharing of information concerning the growing method for pepper and tomato crops, which can be either open field or greenhouse.
Source: Authors' own elaboration

concept of a circular bio-economy, which holds promise in optimizing resource use and reducing waste. Over the past decade, the notion of a circular bio-economy has gained prominence worldwide, aiming to foster sustainable and resource-efficient policies for long-term socioeconomic and environmental gains (Milios, 2018).

The concept of a circular bio-economy seeks to transcend the linear model of production and consumption by implementing circular or "closing the loop" strategies in production systems (Maina et al., 2017). This paradigm shifts presents opportunities for addressing sustainability challenges in the food system (Table 6). This is accomplished by employing strategies of a circular or "closing the loop" system in production systems. The circular system is the means by which this objective is attained.

Over the course of many centuries, insects have been an essential component of the cuisines of a number of different cultures around the world. In order to overcome the cultural hostility that exists about the consumption of insects, advocating for these actions might be of assistance (Yen, 2015). In addition, insects may be converted into animal feed, which provides a sustainable alternative to traditional feed sources (Oonincx and De Boer, 2012; Salomone et al., 2017; Thévenot et al., 2018). Despite cultural resistance to insect consumption, as in in Western societies, particularly in Europe (La Barbera et al., 2020), promoting the inclusion of insects in diets and converting them into animal feed can offer sustainable alternatives to traditional feed sources, mitigating the environmental impact of livestock husbandry. Integrating edible insects into food side-stream management aligns with sustainability principles and addresses both food waste and protein production challenges.

Effective implementation of these concepts requires collaboration among consumers, companies, and governments. Stakeholders across various sectors, including farmers, industries, policymakers, and academics, must collaborate to address challenges associated with organic side-stream production and maximize associated benefits. In agriculture, this collaboration aims to establish a broad and sustainable circular bio-economy (Van Itterbeeck and Pelozuelo, 2022; Jongema, 2015; Morales-Ramos et al., 2014). The establishment of agricultural side-streams has the potential to lessen the reliance on conventional methods of waste disposal (Figure 2), therefore, contributing to the alleviation of the economic and environmental effects that are associated with landfills and incinerator operations.

Based on the preliminary findings, it appears that the agricultural products that are produced by those who engage in side-stream agriculture have the potential to be exploited as a source of feed or substrate for insects. Insects have the capacity to transform the organic matter that is contained inside these agricultural leftovers into proteins and nutrients that are beneficial to the body. The concept of a bio-economy, which has beneficial effects on both the economy and the environment, is supported by this process with its positive effects. Furthermore, it encourages the use of environmentally responsible agriculture techniques (Figure 2). However, the practicality and effectiveness of such systems depend on various factors, including production volume, the local circumstances, the particular agricultural requirements, and the amount of knowledge among stakeholders regarding the notion of a circular bio-economy.

The implementation of new production technologies and techniques, efficient planning, improved harvesting methods, and strategies to synchronize production with market demand will continue to strengthen the global efforts to increase production capacities and reduce agricultural crop production side-stream. These efforts will continue to be strengthened. A variety of factors, including cultivation techniques, adherence to quality standards, mechanical damage, size differences, harvesting methods,

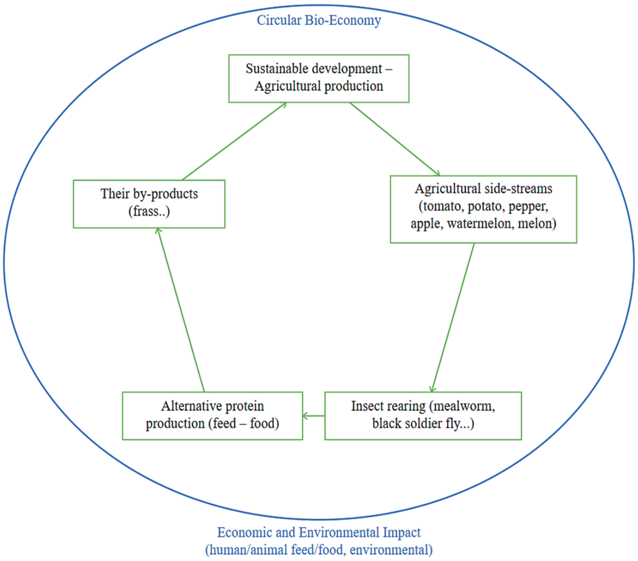

Fig. 2. Integrated system of organic leftovers, Insect Production, Circular Bio-economy, and Addition value.
Source: Authors' own elaboration

insect and pathogen infestations, and market dynamics, can all contribute to the development of crop production side-streams in the field. Consequently, conducting research into alternative opportunities and challenges for their usage might potentially be of assistance in the implementation of approaches for the management of trash that are sustainable (Figure 3).

To effectively manage agricultural by-products and incorporate them into a circular bio-economy, it is necessary to apply methods that prioritize the optimization of resources, the reduction of side-stream, and the generation of value. Through its incorporation into insect farming, it is possible to construct a closed-loop system that can transform organic side-stream into beneficial resources, such as frass, which is rich in both protein and nutrients (Figure 2).

One method that is both environmentally friendly and consistent with the principles of a circular bio-economy is the utilization of agricultural by-products as a source of nutrition for insects. It is of the utmost importance to recognize that these side-stream commodities from agriculture, which are left in the field, may not meet certain market standards, but they have value in and of themselves. The concept of bio-economy makes it possible to repurpose these resources for a variety of applications, including the rearing of insects, among other things.

By facilitating the repurposing of agriculture that would otherwise be abandoned, the utilization of agricultural leftovers to produce insects can be a method that is favourable to the environment. Insects have the potential to serve as a valuable and sustainable supply of protein for a variety of applications, including animal feed, due to their high efficiency in converting organic matter into protein. Before putting such methods into effect, it is necessary to further research and take into account a variety of factors, including the type and welfare of animals, the safety of food, and the duties imposed by regulations, etc. Agricultural extension services should be prepared and after consulted in order to gain guidance that is specifically adapted to the specific conditions of crop cultivation, pest control, and particular purpose use of them. Additionally, it is vital to develop expanded skills and seek assistance from these services.

To reiterate, crop production side-stream in the field can occur for a variety of causes (connected to cultivation, quality standards, mechanical damage, size variation, harvesting, insect and pathogen infections, and market dynamics). These reasons can be broken down into many categories. It is common knowledge that increasing production capacity and reducing agricultural crop production side-streams will continue to be a focus of global efforts, and that these efforts will continue to strengthen continually. This will be done by the implementation of new production technologies and techniques, as well as through the improvement of planning, the implementation of enhanced harvesting techniques, and the implementation of strategies to integrate production with market demand. It is possible that doing research into the possibilities and challenges that are linked with alternative applications for their goods might be of assistance in the process of implementing sustainable agriculture side-stream management practices.

When it comes to the management of agricultural side-streams in the field and the absorption of these products into a circular economy, it is necessary to adopt methods that place an emphasis on the development of value, the reduction of waste, and the efficiency with which resources are utilized. Through the incorporation of organic side-stream into insect farming, it is possible to build a closed-loop system that is capable of transforming organic side-stream into beneficial resources such as insects and their frass that are rich in protein and nutrients for food-feed and as natural fertilizer (Figure 2).

It is possible to establish this system by including them into insect farming processes. By utilizing agricultural side-streams from the field to feed insects, an approach that is both ecologically friendly and in keeping with the principles of a circular economy may be used. Even though these agricultural side-streams that are left in the field might not

Fig. 3. Challenges and opportunities presenting of organic side-stream production
Source: Authors' own elaboration

satisfy certain market standards, they might nevertheless have value. Keeping this in mind is necessary if one is talking about agriculture. Within the scope of bio-economy, they are capable of being repurposed for a range of purposes, including insect rearing. Since it helps upcycle organic material that would otherwise be wasted, insect farming has the potential to be a very sustainable method. Because they can convert organic matter into protein in an efficient manner, insects have the potential to supply a key source of sustainable protein for a range of reasons, including the consumption of animal feed.

However, before putting such methods into practice, it is necessary to consider a number of different issues, such as the state of the animals, the safety of the food, and the standards that are imposed by the law. In addition, the expansion of the relevant knowledge and interaction with agricultural extension services to obtain direction that is dictated by the specific conditions of crop and insect production (Oonincx and De Boer, 2012; Salomone et al., 2017).

Conclusion

This study highlights the importance of integrating agricultural side-streams into agriculture and the circular bioeconomy. It emphasizes the need for technical innovation, regulatory support, and market expansion to enhance the resilience and sustainability of agricultural systems. Preliminary findings suggest the use of agricultural by-products for cultivating edible insects, but further investigation is needed to develop diets for large-scale insect production. This includes analysing the nutritional composition of reared insects, evaluating the technology's economic feasibility, assessing the feed-to-feed chain's safety, and conducting life cycle assessments of farmed insect species. Future research should focus on addressing research gaps and advancing our understanding of the potential of utilizing agricultural side-streams in insect cultivation. By leveraging innovation and collaboration, we can unlock the full potential of agricultural side-streams, leading to more sustainable and resilient agricultural practices.

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