SYNERGIES & TRADE-OFFS OF WAGENINGEN CLIMATE SOLUTIONS IN PRIMARY PRODUCTION SYSTEMS

CASE STUDY: AGRICULTURE

USING MYCOTOXINS-CONTAMINATED CROPS AS SUBSTRATES FOR INSECT REARING

KB 34 Circular and climate neutral society

CASE STUDY
ASSESSMENT REPORT
DECEMBER, 2024

Introduction

Mycotoxin contamination is a multi-faceted problem affecting not only human and animal health but also economic and environmental aspects. Mycotoxins are formed by certain fungal species during pre- and post-harvest stage. Weather condition largely influences fungal contamination in crops during cultivation and climate change is expected to have a profound impact in mycotoxin formation (Moretti et al., 2019). Previously mycotoxin contamination in crops mainly occurs in tropical and subtropical countries since mycotoxin-producing fungi (e.g., *Aspergillus spp.*) are well-adapted to warm temperature and humid environment. However, multiple studies showed that climate change and the effects thereof, e.g., rising temperature, precipitation pattern changes, drought and flood, will also increase the likelihood of mycotoxin contamination in Europe. For example, high aflatoxin level were measured in Italy, Croatia, Serbia and some Southern European countries (Dövényi-Nagy et al., 2020).

Photo of a Moldy Ear of Corn Vegetable by Steven Depolo (Flickr)

In 2012, hot and dry weather in Serbia resulted in maize contaminated with high levels of aflatoxins whereby the contaminated maize were fed to cattle, consequently resulting in high aflatoxin levels in milk (Popovic et al., 2017). Furthermore, a recent study combining a mycotoxin prediction model and a land use model predicted that in 2050 aflatoxin contamination in maize cultivation in Europe will dramatically increase, particularly in Central and Southern Europe (Focker et al., 2022).

As one of major food/ feed safety hazards, the presence of mycotoxins in food is heavily regulated worldwide and in Europe via the enforcement of maximum levels, aiming to protect public health (EC, 2023). A recent study indicated that mycotoxin occurrence above the EU and Codex limits reached 25% of global food crop production whereas the occurrence above detectable levels reached up to 60-80% (Eskola et al., 2020). Due to public health concerns, heavily contaminated crops exceeding EU maximum limits cannot be legally used for food production, consequently contributing to food loss, and exacerbating climate change crisis due to the significant carbon footprint. One of the proposed solutions to prevent food loss from heavily contaminated crops is by using them for insect rearing as feed for livestock production. In recent years, insect rearing for food and feed has been gaining increased attention in Europe as an alternative protein source and particularly to transition towards a circular economy since insects can be fed on various residual/ side streams (e.g. food waste, vegetable scraps and even manure) (Ojha et al., 2020; Van Peer et al., 2021).

This case study explores the potential of using highly contaminated cereals as substrates for insects rearing for feed as a proposed solution to mitigate climate change. An overview of the enablers and barriers as well as questions to multiple disciplines (e.g., food safety, animal welfare, economic and environmental perspectives) are elaborated below to assess the synergies and trade-offs of this solution.

Climate mitigation solution

Insect farming is considered effective and more environmentally-friendly for a number of reasons, i.e. high feed conversion rate from low-nutrient biomass into nutrient-rich body mass, low greenhouse gases and ammonia emission, lower use of water and land (van Huis & Oonincx, 2017). Considering these aspects, this solution may tackle climate change in two ways: (1) reducing environmental impacts of food loss (i.e., contaminated crops), (2) reducing environmental impacts from using insects for livestock feed in comparison to using conventional feed ingredients (e.g., soybean and fishmeal).

Research showed that the nutritional value of insects is comparable to that of conventional feed ingredients such as soybean and fish meal. According to EU Regulation 142/2011, eight insect species have been allowed to use for animal feed and pet food, with three species are currently for commercial production, i.e., black soldier fly (BSF or *Hermetia illucens*), yellow mealworm (*Tenebrio molitor*) and common housefly (*Musa domestica*). There are different possibilities of using insects for feed depending on the insect species and their forms (e.g., live insects, whole dead insects, hydrolyzed protein). For example, in the Netherlands it is allowed to feed live insects to poultry, pigs, and aquaculture animals. But it is not allowed to feed these food-producing animals with whole dead insects (treated or untreated (e.g., freeze dried)), thus insects need to be processed into other forms, e.g., hydrolyzed insect proteins or insect fats. At the moment, it is not allowed to feed insects to cattle due to BSE (bovine spongiform encephalopathy) concern.

Photo of Black soldier fly larvae by Tomasz Klejdysz (GettyImages)

Current commercial insect production mainly uses substrates that can be directly fed to livestock, making insect production less competitive in terms of production cost. Therefore, ongoing studies mainly focus on searching for alternative substrates to reduce production cost. EU legislation only allows the use of materials from vegetal origins as insects substrates, although studies showed that insects can also be fed with various residual/ side streams including manure (Ojha et al., 2020; Van Peer et al., 2021).

The safety aspect is a crucial consideration when rearing insects from residual streams as these substrates may contain microbiological and chemical contaminants which might transfer and accumulate in the insects (Hoek-van den Hil et al., 2022; Meyer et al., 2021; Schrögel & Wätjen, 2019). Multiple studies investigating the presence of mycotoxins in insect larvae reared with mycotoxins-contaminated substrates showed that insects are generally tolerant to mycotoxins, with tolerance level varying depending on the insect species and types of mycotoxins (Camenzuli et al., 2018; Meyer et al., 2021; Niermans et al., 2021).

Furthermore, a recent study investigating the potential of rearing insects with grains contaminated with high level of mycotoxins (higher than EU limits) showed that only very low level of mycotoxins (below EU limit) was found in insects, corroborating previous findings that insects can either metabolize or possibly degrade mycotoxins (K. Niermans and E. Hoek-van den Hil, personal communication, 21 March 2023). At the moment, research on safety of insects grown on mycotoxins-contaminated substrates is still on going and to guarantee their safe use for feed, it is also important to include different metabolites of mycotoxins in the analyses.

Figure 1. Potential effects of the climate mitigation solution

Using heavily mycotoxin-contaminated crops which are otherwise discarded with current estimates of 25% global crop production exceeds EU and Codex limit will reduce food loss and carbon footprint while simultaneously contributing to a circular economy.

Depending on the type of substrate, insect rearing uses fewer resources (e.g., land use, water and energy) and produces higher feed to mass conversion rate compared to producing other feed ingredients (e.g., soy and fishmeal), consequently reduces greenhouse gas emission and contributing to climate neutral objective.

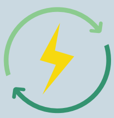
Potential uses of insect by-products, e.g., insect frass for fertilizer and other applications, also contribute to circular economy.

Figure 2. Potential challenges of the climate mitigation solution

Ethical issues on insect rearing, e.g., insect welfare, might receive more scrutiny. On one hand, EU Regulation (EC) 1069/2009 considers insects reared for food/ feed as farmed animals, i.e., animals kept producing food, feed or other derived products. On the other hand, EU leaves out invertebrate animals (including insects) from the scope of EU animal welfare legislation (Directive 98/58).

In particular to this case study, a recent study showed that insects fed with substrates contaminated with high concentration of mycotoxins could survive and grow, however, it remained unclear whether insects feel any pain in this rearing condition (K. Niermans and E. Hoek-van den Hil, personal communication, 21 March 2023).

The use of contaminated cereals as insect feed might result in a decrease in consumer trust and acceptance, resulting in declining demands for livestock products.



Depending on the species and production scale, insect rearing may require significant use of energy to maintain favorable growing condition. For example, BSF are more suitable to rear in tropical countries as this species favors temperate climate, while common housefly is more suitable in European climate.

Safety aspects are under research since different insects metabolize/ secrete the toxins differently, e.g.:

- When fed with highly contaminated substrates, larvae (from certain insects) contain low levels of mycotoxins and/or their metabolites
- When fed with highly contaminated substrates and then fed with clean feed, no mycotoxins detected.
- Other concern: mass balance did not match

Enablers and barriers

Figure 3. Enablers of the climate mitigation solution

- Aligned with EU policy (e.g., EU Green Deal) to achieve a more sustainable and circular food production by reducing food loss and food waste through insect production.
- Development in EU legislation on insects for feed and food (e.g., increasing number of permitted insects species).
- Growth of insect industry.
- Insects may partially replace unsustainable protein sources such as fishmeal and soymeal with significant carbon footprints.
- The availability of new high-quality protein source may reduce feed costs (economic opportunity).
- Improve nutrient/feed efficiency in poultry production. Feeding live insects to poultry improves animal health and welfare.

Figure 4. Barriers of the climate mitigation solution

- Current EU legislation doesn't allow the use highly contaminated crops for animal feed in Europe, including for insect production, as insects are regarded as farmed animals. EU legislation requires substrates fed to insect comply to maximum limits of contaminants, including aflatoxins (EU Directive 2002/32/EC).

Stakeholders

Multiple stakeholders along the feed and food chain can be affected by the proposed solution (Saatkamp et al., 2022):

- Cereal growers: providing agricultural waste/raw substrate, e.g., highly contaminated maize.
- Insect breeders: rearing insects for eggs/larvae.
- Insect producers: insect production and collection, killing/ processing of insects into insect products and intermediate insect products.
- Feed producers: production of other feed components into e.g., poultry feed.
- Animal breeders: e.g., breeding day old chicks.
- Animal producers: producing animal products e.g., broilers, eggs, pigs.
- Insect sector-related organization (e.g., International Platform of Insects for Food and Feed (IPIFF), European Research Group for Insect Production (ERGIP)).
- Policy makers/legislators.
- Animal welfare advocates.
- Other stakeholders: processors/ slaughterhouses, retailers / consumers.

Sustainable Development Goals as a framework

The seventeen Sustainable Development Goals (SDGs) came into force on the 1st of January 2016 and have been adopted by world leaders to fulfil the 2030 Agenda for Sustainable Development (see Figure 5).

The SDGs offer a well-known framework for dialogue on international level and a good channel towards circular economy. These goals recognise that ending poverty, inequality, and tackling climate change, must go hand in hand with strategies which build economic growth while addressing social needs, education, health, social protection and job opportunities and environmental protection (van Eijk and van Kruchten, 2020).

The effective incorporation of sustainability is complex and requires all stakeholders in the value chain to be involved, therefore using common frameworks that drives understanding and effectiveness is important. The SDG framework is a shared plan for promoting sustainable economic growth, advancing social inclusion, and safeguarding the natural environment. This framework provides the basis for initiating and developing a common ground and facilitate international, national, or regional dialogues (van Eijk and van Kruchten, 2020, Sustainable Development Goals, n.d.).

Figure 5: Sustainable Development Goals (Source: UN SDG's)

The goals universally apply to all and although they are not legally binding, governments are expected to take ownership and establish national frameworks for the achievement of the 17 Goals. Countries have the primary responsibility for follow-up and review of the progress made in implementing the Goals, which will require quality, accessible and timely data collection. Countries and businesses should mobilize their efforts to end all forms of poverty, fight inequality and tackle climate change, while ensuring that no one is left behind (van Eijk and van Kruchten, 2020, Sustainable Development Goals, n.d.).

Identification of synergies and trade-offs

Identifying synergies and trade-offs of using mycotoxins-contaminated crops as substrates for insect rearing with the SDGs (see Figure 6 and Figure 7) is crucial for informed decision-making. Therefore, a workshop with experts had been organised to discuss synergies and trade-offs of the case on SDG's. The workshop resulted in multiple synergies on the case with all discussed SDG targets (SDG 1-16). Meanwhile, only SDG 1, 2, 3, 6 and 12 resulted in both synergies and trade-offs. Recognizing synergies enables us to harness the potential of insect rearing to address multiple SDGs simultaneously, optimizing resource use and reducing food waste. Understanding the trade-offs will help to identify potential unintended consequences. Therefore, insect rearing practices with mycotoxins-contaminated crops can be aligned better with overarching SDGs, foster inclusive development, and mitigate any negative impacts. This assessment could guide policymakers, stakeholders, and communities in making choices that balance economic, environmental, and social objectives for a more sustainable production and consumption pattern.

Figure 6: Identified synergies of using mycotoxins-contaminated crops as substrates for insect rearing relevant to the SDGs (Selected).
SDG 1 to 7

1 NO POVERTY

Preventing income loss
Using mycotoxin-contaminated crops as substrates for insect rearing instead of waste products, helps to prevent income loss for farmers.

2 ZERO HUNGER

Reduction of food loss
Food loss is reduced as highly mycotoxin-contamined food crops can be converted into feed, and the feed can be used in livestock production to produce e.g. meat, dairy products.

3 GOOD HEALTH AND WELL-BEING

Reduced (public) health risks
Exposure to mycotoxin-contaminated food will be reduced, lowering health risks and long term health effects; which leads to improved life expectancy.

4 QUALITY EDUCATION

Opportunities for community development
The implementation of insect rearing industry (low investment, low technical skills requirements) on a community level, especially in the Global South, can provide opportunities for community development, for example in fostering lifelong learning skills, e.g. counting, reading, management, and other technical skills.

5 GENDER EQUALITY

Empowering women
Insect rearing can be an alternative way to empower women by providing job opportunities. For example, in Colombia widowed women and ex-combatant/ armed resistance forces (FARC) were employed in insect industry as a part of their rehabilitation back into society.

6 CLEAN WATER AND SANITATION

Reduced Water Waste
In cases where crops are wasted when contaminated, which is by far not always the case, a reduced amount of water is wasted because crops are used for insect rearing.

7 AFFORDABLE AND CLEAN ENERGY

Energy Efficient Insect Rearing:
Countries with suitable climates for mycotoxin growth (warm and moist), also have favorable conditions for insect rearing, meaning that less energy is needed compared to insect rearing in colder countries. Also in the future this is expected to happen, as colder countries become warmer with more suitable conditions for both mycotoxins as insect rearing.

Figure 6: Identified synergies of using mycotoxins-contaminated crops as substrates for insect rearing relevant to the SDGs (Selected). SDG 8 to 16

8 DECENT WORK AND ECONOMIC GROWTH

New economic activity
Insect rearing can become a new local/community business model (e.g. in the Global South) which can promote sustainable and inclusive economic growth.

10 REDUCED INEQUALITIES

Economic opportunities
This solution can potentially bring opportunities in developing countries in the insect industry. Through investment flows or creation of jobs, this can reduce inequality among countries, especially economically.

Reduction in exporting contaminated products
As the case provides a suitable solution to process the contaminated products, less contaminated products will be exported to developing countries.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Lower impact than conventional feed production
Fewer resources needed (energy, water, land-use) to produce insects for feed in comparison conventional feed ingredients, leading to a lower impact.

Reduced feed loss
As mycotoxins-contaminated crops are fed to insects instead of becoming waste, feed loss is mostly avoided.

14 LIFE BELOW WATER

Reduce pressure on marine resources
Reduce the fishmeal consumption as feed by replacing it with insects fed with mycotoxins-contaminated crops.

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

Strengthen social inclusion
This case can indirectly promote and enforce corruption reduction (it is essential to prevent mycotoxin-contaminated crops from reaching the black market) and broadens and strengthens the participation of developing countries on the global market. It also helps with rehabilitation of people back into the society, such as in the project 'Insects for Peace'.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Innovations
The insect industry is a relatively new industry with many opportunities for innovations.

11 SUSTAINABLE CITIES AND COMMUNITIES

Sustainable processing of organic waste
Insect rearing can provide a good solution for processing organic solid waste (for contaminated crops, but also other suitable organic waste streams and residues) in cities, urban settlements and rural areas.

Community projects
This case is suitable for community projects. Especially in communities where crime rates are high, having community projects can bring people on small scale together, leading to a more harmonized and safer environment, consequently possibly reducing crime rates

13 CLIMATE ACTION

Reducing impact on climate change
Climate change is expected to worsen mycotoxin-contamination in the field. Using contaminated crops as insect feed is a way to avoid feed and food loss, relying on less resources of planet earth and emissions of greenhouse gasses. This reduces the impact on climate change.

15 LIFE ON LAND

Sustainable use of ecosystems
This case can contribute to a more sustainable use of terrestrial ecosystems by optimizing land use, which indirectly leads to less utilization of land and reducing deforestration.

Figure 7: Identified trade-offs of using mycotoxins-contaminated crops as substrates for insect rearing relevant to the SDGs (Selected). SDG 1-3, 6 and 12

1 NO POVERTY

Decreasing consumer acceptance
Consumer acceptance for livestock fed with insects fed with contaminated feed might be affected (decreased), and can consequently negatively affect the current livestock industry.

3 GOOD HEALTH AND WELL-BEING

Health risks in processing
Exposure to contaminated crops during harvesting, storing & processing may affect workers' health. Good equipment for working protection e.g. protective clothing / masks are required.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Responsible production
Less incentive for change in crop strategy to prevent mycotoxin contamination (e.g. producing other types of crops, different rotation of crops or resistant species for mycotoxins).

Responsible consumption
The availability and affordability of insects as feed might provide an incentive for livestock production, thus this effect seems counterproductive in reducing livestock production and the transition towards a more sustainable, plant-based food consumption pattern.

2 ZERO HUNGER

No year-round feed for insects
Seasonal dependency on mycotoxins-contaminated crops may negatively impact sustainable production and lead to product scarcity (and indirectly feed shortage for animals). Therefore it is important to not build a food chain based on mycotoxins-contaminated crops, but only use them when they cannot be processed anywhere else.

6 CLEAN WATER AND SANITATION

Water use in industry
Water is needed for insect rearing and processing and therefore the industry has a share in the common water supply.

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

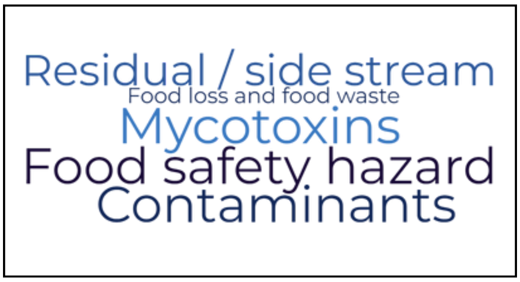
Corruption
This solution provides opportunities for corruption: it is essential to prevent mycotoxin-contaminated crops from reaching the black market.

Research gaps from the case study in relation to the SDGs (Selected)

- Uncertainty of incomplete mass balances: are we sure all harmful mycotoxins are converted by insects?
- Is the nutritional value of insect as feed similar/better/less than regular feed (e.g. soymeal, fishmeal, etc.)? How does this affect safety and nutritional values of the meat? How does the nutritional value of insect-fed meat compare to conventional meat?
- How is the occupational health for workers that work with contaminated crops, e.g. in the insect rearing?
- How many resources are needed for processing and transportation of contaminated products to an insect rearing facilities? And how does this compare to the normal way of producing livestock feed?
- How much water is needed for the process of turning contaminated products into feed compared to normal feed production of soybeans or fishmeal?
- Is the technology present in producing countries?

Terminology for Wageningen climate dictionary

This case study contributes to essential terminology and practical concepts for the Wageningen climate dictionary, enriching the discourse on climate mitigation and adaptation. The terms and definitions can be found in Annex 1.



Conclusions

In conclusion, assessing synergies and trade-offs on the case study of “using mycotoxins-contaminated crops that are not suitable for human consumption to rear insects for feed productions” showed that this case study has significant potential to contribute to achieving different sustainable developmental goals, mainly SDG 2, 3, 8, 12 and 13 (Figure 8). Using contaminated crops as insect rearing substrates will reduce food loss and may improve the availability of livestock products (SDG 2). Moreover, this scenario will reduce and/or prevent the consumption of contaminated crops, thus lowering exposure to the toxic mycotoxins and consequently lowering public health risks, which may lead to improved well-being and life expectancy (SDG 3). Using already available contaminated crops to produce feed instead of exclusively producing ingredients for conventional animal feeds (such as soybean, fishmeal) will reduce food loss and simultaneously put less pressure on resources such as land and water (SDG 12 and 13). In general, insect rearing can also become a new economic activity and business model, including at local/community level, such as the project ‘Insects for Peace’, which can promote a sustained and inclusive economic growth (SDG 8).

Research has to continue on both the safety of feeding those insects to livestock animals and on the occupational health and safety of the workers who process the mycotoxins-contaminated crops to insect feed (SDG 3). This can be considered a prerequisite for further legislation of using mycotoxins-contaminated crops as substrates for insect rearing. It is also important to keep in mind that this case study aims to use contaminated crops in a sustainable way and avoid waste streams due to mycotoxin contamination (SDG 2). However, it should not stimulate increasing production of contaminated crops. In that sense, other efforts should also be put on to prevent and minimize mycotoxins contamination in crops. Lastly, the availability and affordability of insects as feed might provide an incentive for livestock production. Therefore it is important to consider that this case can have a counterproductive effect in reducing livestock production and the transition towards a more sustainable, plant-based food consumption pattern (SDG 12).

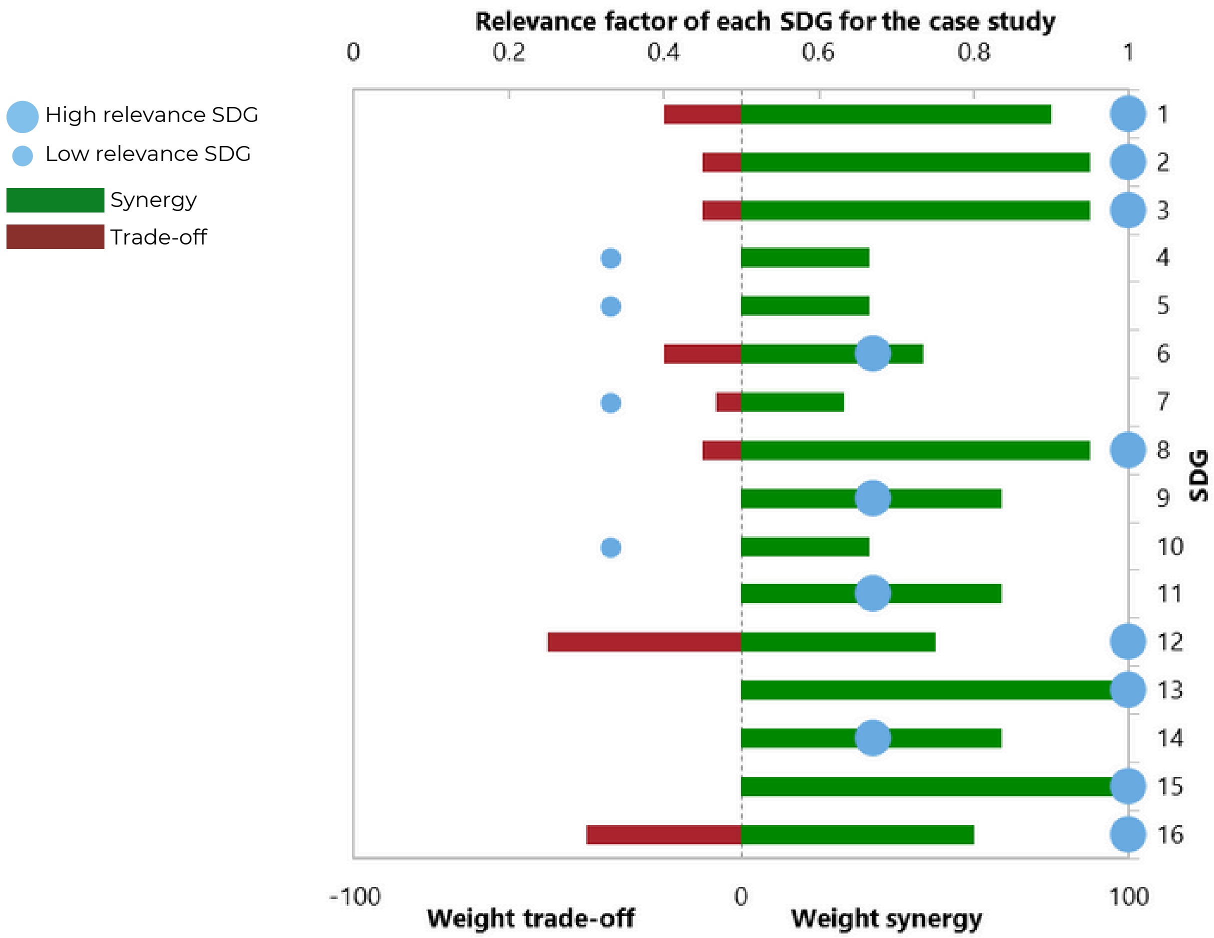


Figure 8. Overview with weight of importance of the synergies and trade-offs, and relevance of each SDG to the case study of using mycotoxins-contaminated crops as substrate for insect rearing. The weight of each synergy and trade-off is a combination of the relevance of the SDG for the case study (blue dots; upper axis) and an expert judgement based weighing between trade-offs and synergies (green and red bars; lower axis).

Overall, using mycotoxin-contaminated crops as a feeding substrate for insect rearing offers significant environmental benefits. It helps reduce food loss through sustainable organic waste processing, mitigates climate change impacts, and reduces the pressure on marine resources by (partly) replacing fishmeal consumption in aquaculture with insects.

However, trade-offs such as the seasonal availability of mycotoxin-contaminated crops, reduced incentives to change crop strategies to prevent mycotoxin contamination, and possible food safety concerns due to mycotoxins being major food safety hazards need to be addressed. Answering the research gaps as mentioned earlier in this factsheet can contribute to further development of the case.

Authors: Liu, C., Safitri, R., Niermans, K., Focker, M. (2024). Case Study Agriculture. Using mycotoxins-contaminated crops as substrates for insect rearing. Project: Synergies & trade-offs of Wageningen climate solutions in primary production systems . Wageningen University & Research. Factsheet, December 2024.

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Annex I Terminology for Wageningen Climate Dictionary

Terminology	Definition	Reference
Food safety hazard	Any biological, chemical, or physical agent in food that can potentially harm human health.	(Codex Alimentarius Commission (CAC), 1969)
Mycotoxins	Toxic metabolites that are naturally produced by certain fungal species infecting various food producing crops, with cereals being one of the most susceptible crops (e.g., wheat, maize). Some of the most important mycotoxins include aflatoxins, fumonisin, zearalenone, deoxynivalenol, ochratoxins A and patulin, with aflatoxins considered as the most dangerous ones.	(Bennett & Klich, 2003)
Contaminants	Substances that have not been intentionally added to food as a result of various stages of its production, packaging, transport or holding as well as from environmental contamination.	(European Commission, n.a.)
Food loss and food waste	A decrease in quantity or quality of food originally intended for human consumption that occurs before the food reaches consumers due to issues in production, storage, processing, and distribution. To distinguish the term between food loss and food waste, food loss occurs at all any points before the food reaches consumer level, whereas food waste occurs at consumer level.	(Teuber & Jensen, 2020)
Residual / side stream	By-product of a production process that are discarded, for example vegetable peelings and scraps, pulps, overripe/rejected fruits and vegetables, wheat bran, brewery by-products, poultry manure, etc.	(Hoek-van den Hil et al., 2022)

Note: All the references and the reference list are available on the complete version of this factsheet.

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