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Farmed insects to create a circular bio-economy in the food and feed industry

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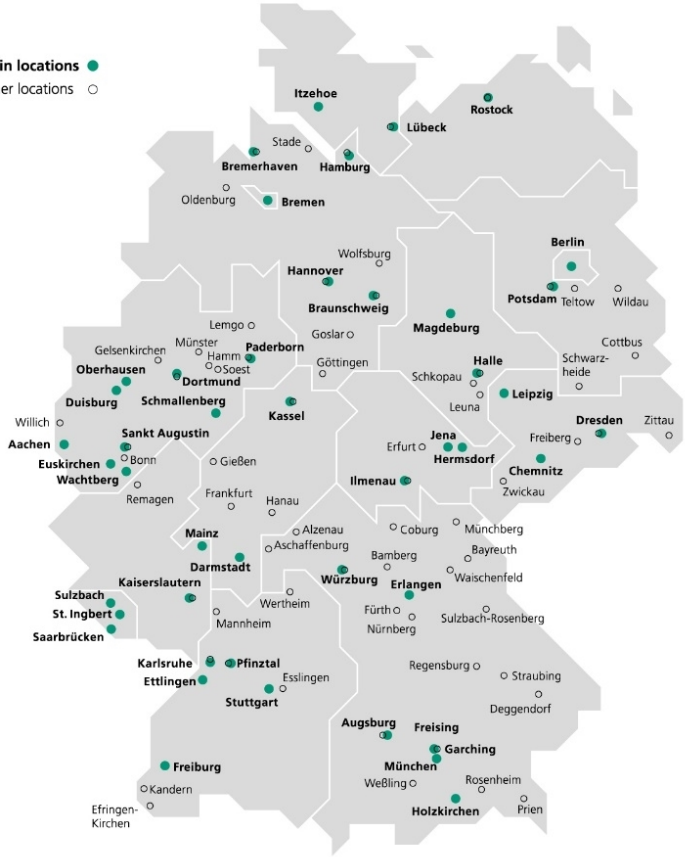
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Fraunhofer IME

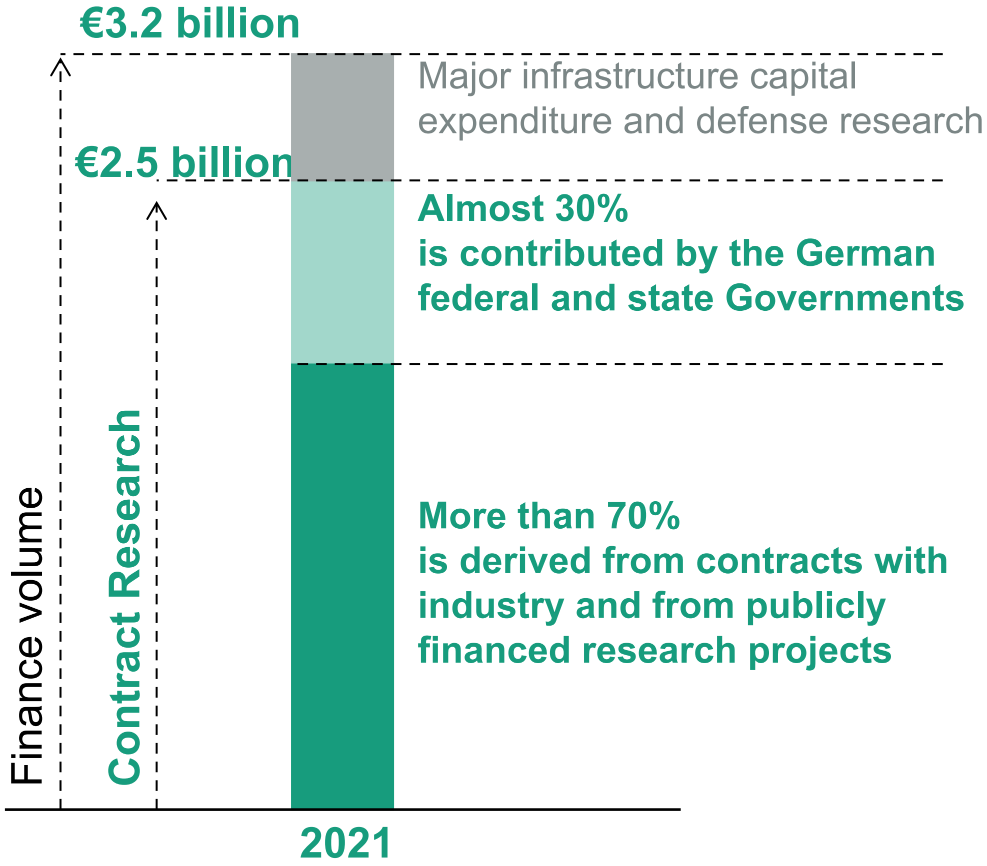
The Fraunhofer-Gesellschaft at a glance

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

30,000 staff



76 institutes and research units



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Intellectual Property Rights of Fraunhofer

Fraunhofer Patents	2015	2016	2017	2018	2019
Active patent families *	6573	6762	6695	6874	7050
Invention disclosures reports p.a.	670	798	756	734	733
Patent applications p.a.	506	608	602	612	623

* Portfolio of active rights (patents and utility models) and patent applications at year end.

2019: Fraunhofer was
Nr. 18 of the most active patent applicants and
Nr. 7 of the most active trade mark registrations
at the German Patent and Trade Mark Office

Deutsches Patent- und Markenamt

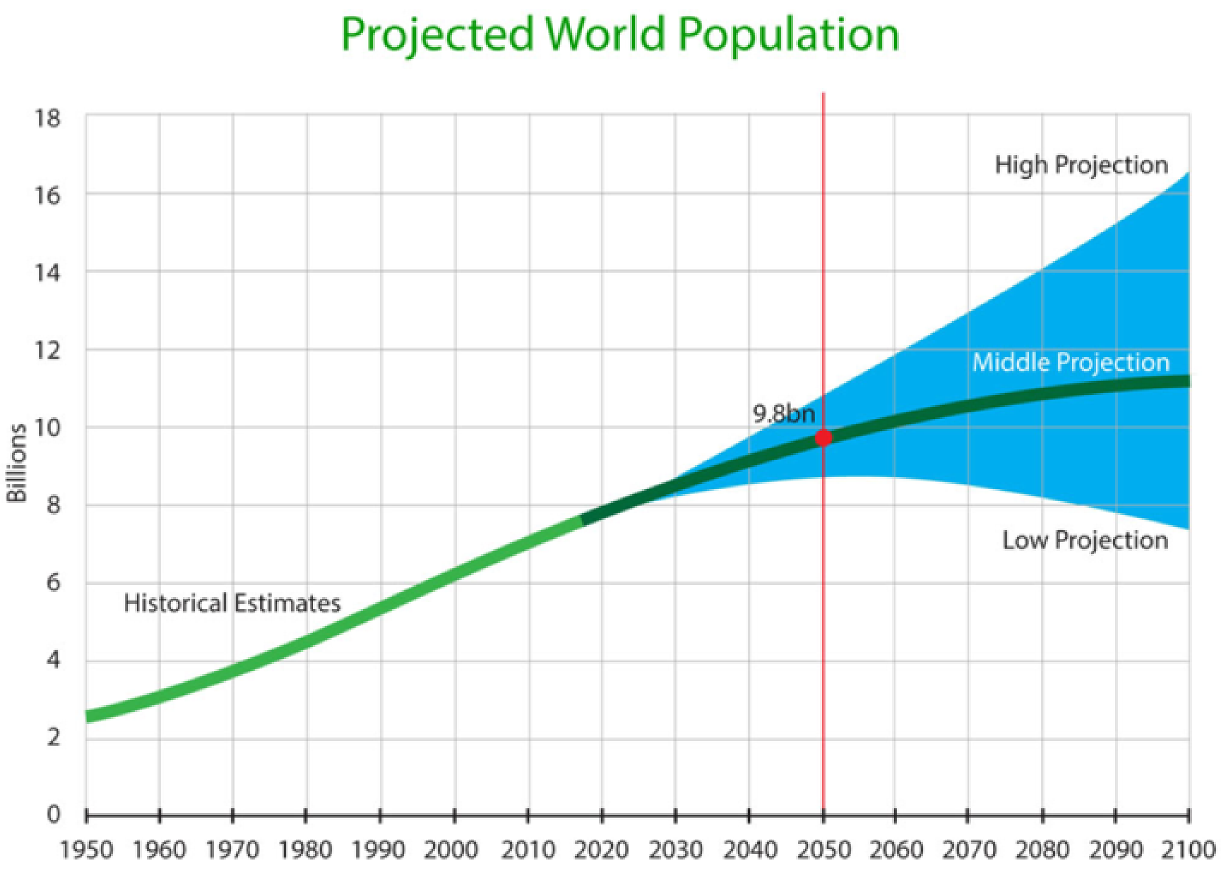
2019: Fraunhofer was
No. 32 of the most active patent applicants
at the European Patent and Trade Mark Office

Europäisches Patentamt
European Patent Office
Office européen des brevets

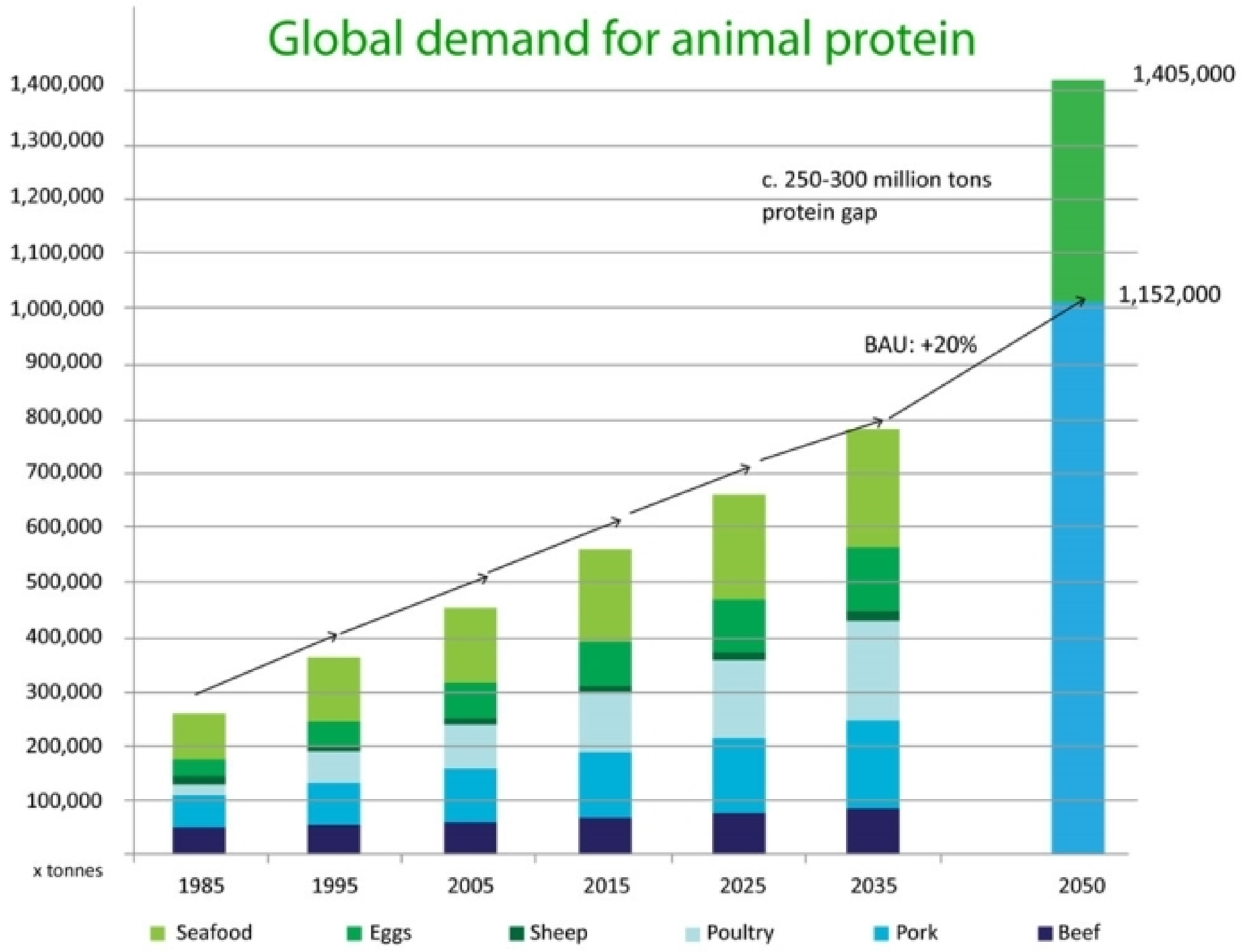
2020: Fraunhofer has been awarded as Top 100 Global Innovator for the years
2014-2020 *according to Clarivate Analytics / Thomson Reuters*

Derwent Top 100 Global Innovator 2020
Clarivate Analytics

The projected world population demands increasing animal protein supply



Data Source: United Nations, "World Population Prospects: 2015 Revision"



Data Source: Rabobank analysis, FAO, OECD, FAPRI, 2016

The Black soldier fly as the economically most important species in insect farming

- Insects such as the Black soldier fly are world-wide used for the bioconversion of organic side streams into protein, lipids and chitin.
- Insect farming is an environmentally sustainable alternative to address the rapidly growing demand for animal-protein.

Resources needed for 1000 kg protein production

	Cattle	Pigs	Broilers	Plant protein*	Insects**
Area needed	7,000 m^2	3,000 m^2	2,000 m^2	4,000 m^2	< 0 m^2
Water needed	17,000 m^3	5,500 m^3	3,800 m^3	2,500 m^3	< 0 m^3

* Soybean
** Waste as feed

Bioconversion with Black Soldier Fly

20 kg of Wet Feed Mix

35,000 Larvae

5 kg of Wet Larvae Product

In 2 weeks

1 gr of Eggs

Dried BSF Larvae	
Protein (%)	53
Fat (%)	38

Farmed insects to create a circular bio-economy in the food and feed industry

Challenges in industrial production of insects

- Large-scale availability of insect feed
- How to prevent the outbreak of diseases?
- Optimization of industrial processes
- Economic competitiveness

Integration of insect farming in the

Controlled Environment Agriculture (CEA)

- Insect feed in sustainable crustacean aquaculture
- Insect feed in animal nutrition
- Insects as a missing link in the circular bio-economy of the food and feed industry
- Insect farming in Controlled Environment Agriculture

Insects as a source of alternative Proteins: reduce costs

- Utilization of agricultural or industrial sides streams
- Large quantities with defined quality
- Challenge: seasonal avalability
- EU-regulations
- Detoxification of side streams
- Diet mixtures for optimized growth of farmed insects

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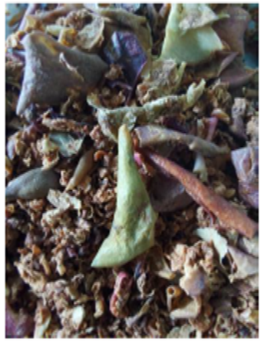
BioBall
Bioökonomie im
Ballungsraum


apple pomace


cocoa bean shell


depectinised
apple pomace

Klüber et al. 2022: Sustainability

Justus-Liebig-Universität Giessen

Fraunhofer IME

Empty fruit bunches of the palm oil industry as a diet for BSF

- The palm oil industry of Malaysia produces app. 25 mio. tons and that of Indonesia 40 mio. tons of EFB per year
- This industrial waste, which is burned or used for land filling, causes tremendous environmental pollution
- The decay of empty fruit bunches results in methane production promoting climate change

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Bioconversion of empty fruit bunches into Black Soldier fly diet

- Fraunhofer-IME has developed a fungus-based fermentation process for the digestion of empty fruit bunches
- and for the enrichment with nitrogen to provide a suitible diet for insect farming
- Enabling the bioconversion of EFB into insect-derived protein, lipids, chitin and frass at industrial scale





Empty fruit bunches of the palm oil industry as a diet for BSF

- Fermentation of empty fruit bunches using specialized fungi
- Degradation of Cellulose and Lignin
- Enrichment of nitrogen and increase of protein content

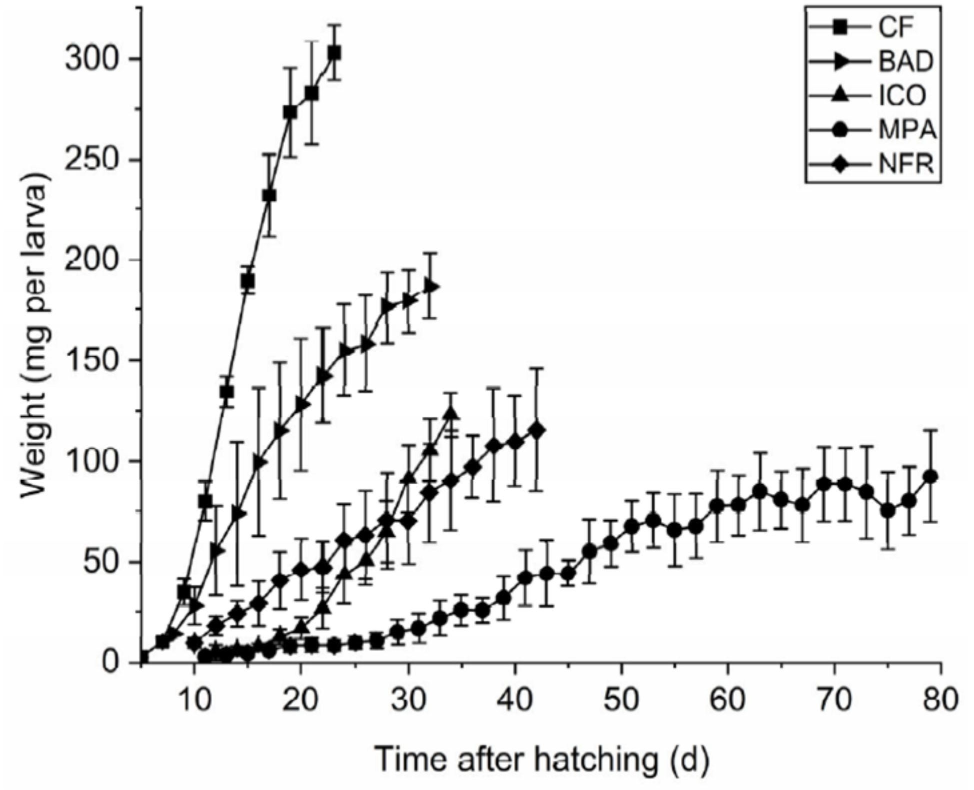

Figure 1. Growth curves of BSF larvae reared on chicken feed (CF), *B. adusta* (BAD), *I. consors* (ICO), or *M. palmivorus* (MPA) fermented EFB + PKM (7:3) mixtures, as well as a corresponding non-fermented reference (NFR). Data are mean larval weights (±SD) of three replicate boxes per diet (n = 25).

Klüber et al. 2022: Sustainability

Large-scale production of Black soldier fly larvae

Empty fruit bunches of the palm oil industry as a diet for BSF

- Fermentation of empty fruit bunches using specialized fungi
- Degradation of Cellulose and Lignin
- Enrichment of nitrogen and increase of protein content

INTELLECTUAL PATENTED PROPERTY

Klüber P, Zorn H, Rühl M, Bakonyi D, Pfeiffer J, and Vilcinskas A. Process for the production of an insect substrate, insect substrate and uses thereof. Application number EP22152265.9.

sustainability

MDPI

Article

Diet Fermentation Leads to Microbial Adaptation in Black Soldier Fly (*Hermetia illucens*; Linnaeus, 1758) Larvae Reared on Palm Oil Side Streams

Patrick Klüber [1], Dorothee Tegtmeier [1], Sabine Hurka [2], Janin Pfeiffer [1], Andreas Vilcinskas [1,2], Martin Rühl [1,3] and Holger Zorn [1,3,*]

Klüber et al. 2022: Sustainability

Insect frass as biofertilizer

- Insect frass (a mixture of excrements, chitin and feed leftovers) represents a valuable biofertilizer
- which can for example double the rice yield
- The benefit of this biofertilizer can be expanded beyond providing nutrients to encompass bacteria that produce plant growth hormones
- Insect frass can replace chemical fertilizers in palm tree agriculture

Beneficial microbes from insect frass

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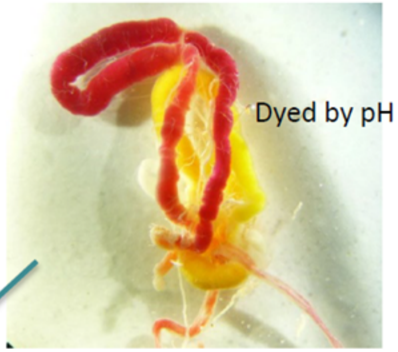
Harvesting the gut microbiota of *Hermetia*

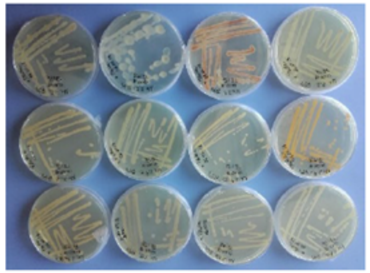
- Pre-digestion of industrial waste products
- Screening for natural products
- Strain collection (cryo bank)

Gut of *Hermetia illucens*

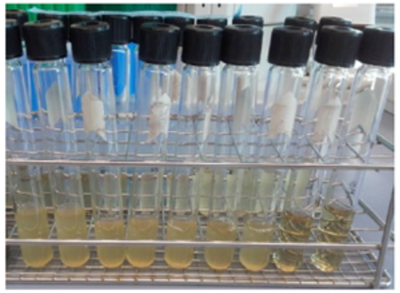


Dyed by pH indicator (phenol rec

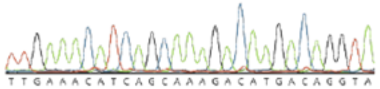
Aerobic cultivation



Anaerobic cultivation



Identification:
16S rRNA sequencing



Dorothee Tegtmeier

Beneficial microbes from insect frass

microorganisms MDPI

Article

Culture-Independent and Culture-Dependent Characterization of the Black Soldier Fly Gut Microbiome Reveals a Large Proportion of Culturable Bacteria with Potential for Industrial Applications

Dorothee Tegtmeier [1,*], Sabine Hurka [2], Sanja Mihajlovic [1], Maren Bodenschatz [1], Stephan
and Andreas Vilcinskas [1,2,*]

Bundesministerium für Bildung und Forschung

frontiers in Microbiology

ORIGINAL RESEARCH
published: 29 March 2021
doi: 10.3389/fmicb.2021.634503

Check for updates

Antonie van Leeuwenhoek
https://doi.org/10.1007/s10482-022-01735-7

ORIGINAL PAPER

Isolation of *Hermetia illucens* larvae core gut microbiota by two different cultivation strategies

Yina Cifuentes · Andreas Vilcinskas ·
Peter Kämpfer · Stefanie P. Glaeser

Cottonseed Press Cake as a Potential Diet for Industrially Farmed Black Soldier Fly Larvae Triggers Adaptations of Their Bacterial and Fungal Gut Microbiota

Dorothee Tegtmeier[1]*, Sabine Hurka[2], Patrick Klüber[1], Karina Brinkrolf[3], Philipp Heise[1]
and Andreas Vilcinskas[1,2]

[1] Department of Bioresources, Fraunhofer Institute for Molecular Biology and Applied Ecology, Giessen, Germany, [2] Institute for Insect Biotechnology, Justus Liebig University Giessen, Giessen, Germany, [3] Department of Bioinformatics and Systems Biology, Justus Liebig University Giessen, Giessen, Germany

Detoxification of diet substrates: Gossypol in Cottonseed press cake

- Gossypol is a natural phenol derived from the cotton plant.
- Plant defense compound mediating infertility in insects.
- Toxic for humans

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frontiers in Microbiology

ORIGINAL RESEARCH
published: 29 March 2021
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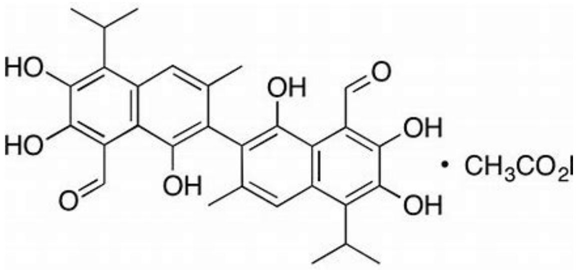

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Molecular pathogen detection in insect farms

Pathogens responsible for more than half of insect production loss

Eilenberg *et al.* 2015

Pathogens detected in **> 80%** of 300 reviewed edible insects farms

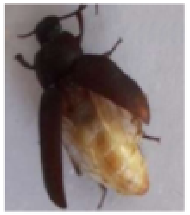
>30% potentially pathogenic for **humans**
>35% potentially parasitic for **animals**

Galecki et al., 2019

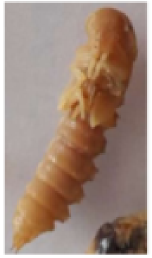
Expect new diseases to emerge in all insect production systems over time

Insect and food borne pathogens

Bacteria



Salmonella enterica
Bacillus thuringiensis
Listeria monocytogenes
Staphylococcus aureus
Serratia marcescens
Pseudomonas aeruginosa

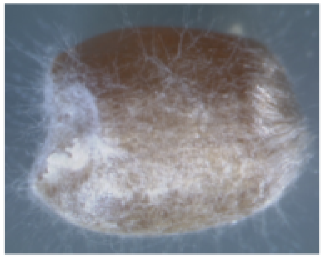


11 target species

farming | food safety

Fungus

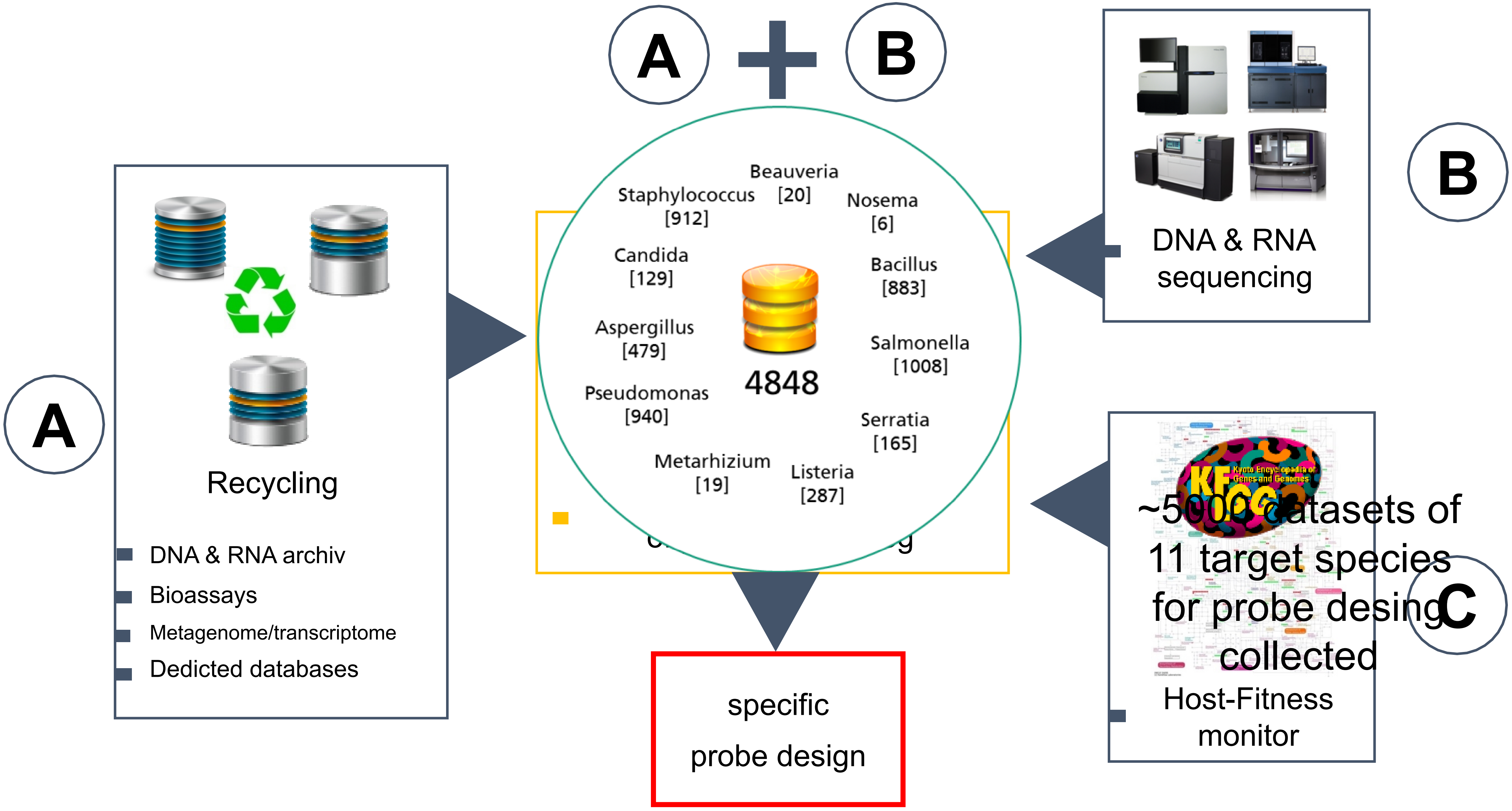
Beauveria bassiana
Metarhizium brunneum
Candida albicans
Aspergillus flavus



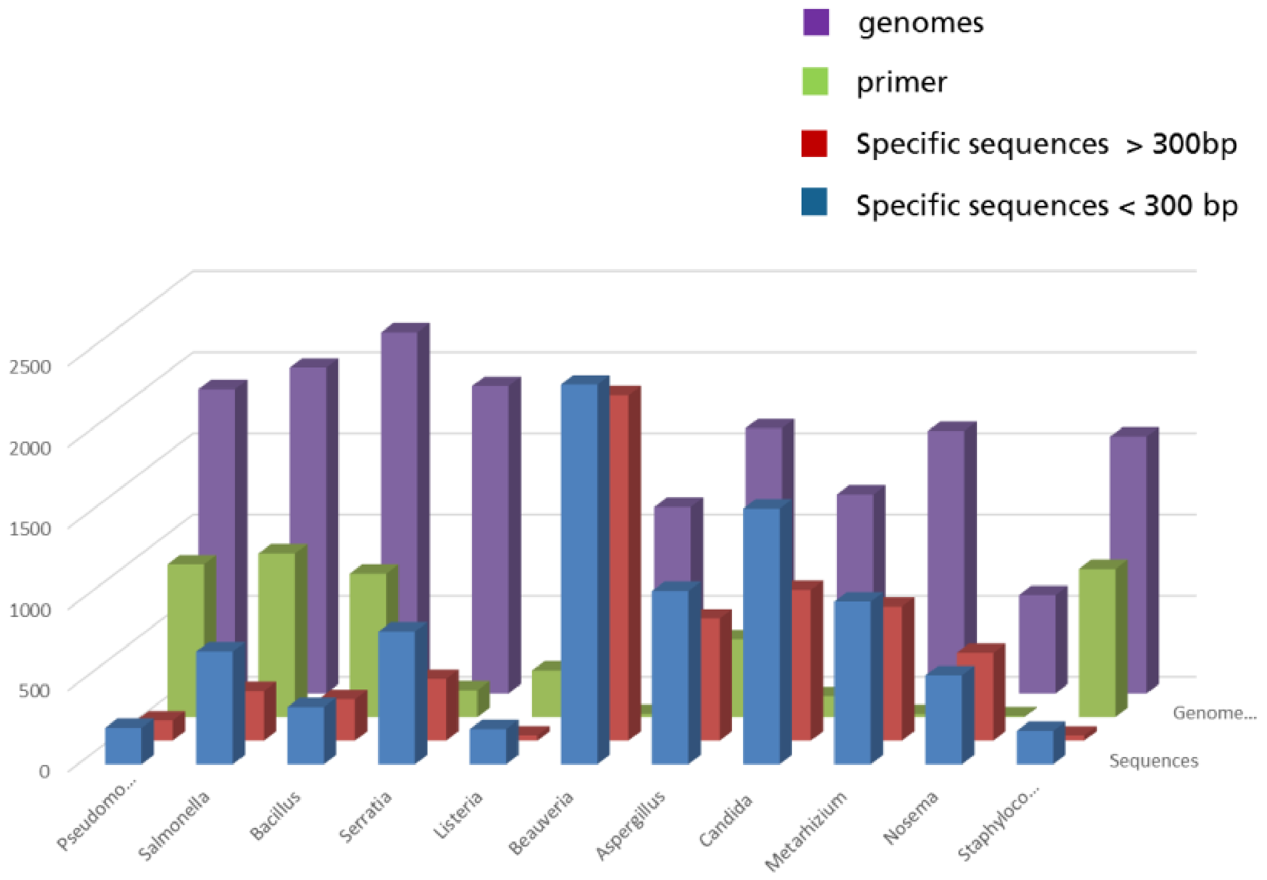
Parasites

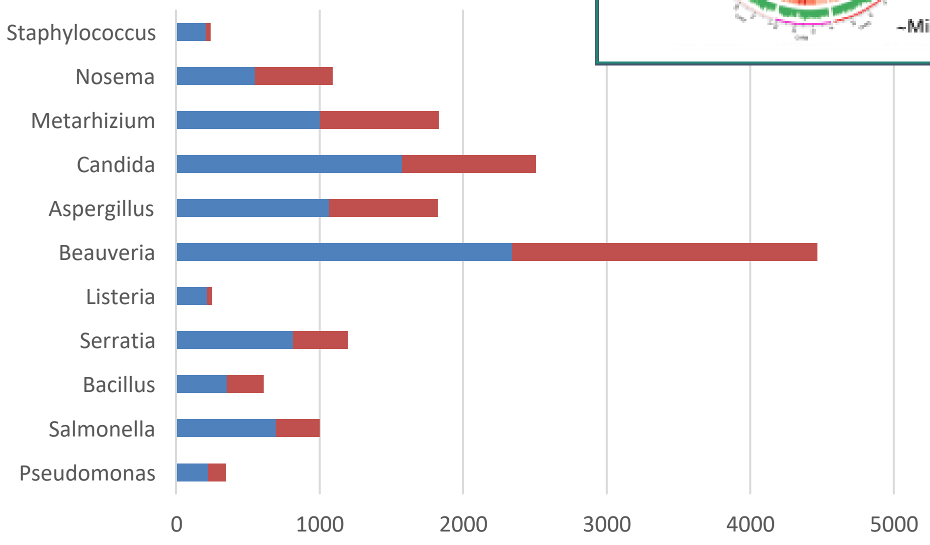
Nosema ceranae

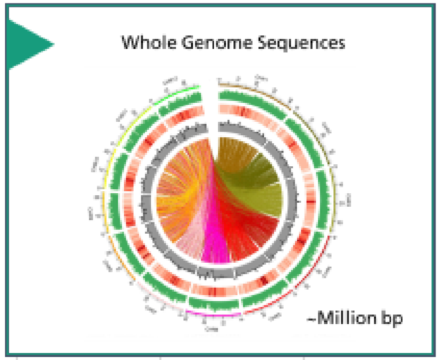
3


A
B
C
Recycling
DNA & RNA archiv
Bioassays
Metagenome/transcriptome
Dedicted databases
Staphylococcus [912]
Beauveria [20]
Nosema [6]
Candida [129]
Bacillus [883]
Aspergillus [479]
Salmonella [1008]
4848
Pseudomonas [940]
Serratia [165]
Metarhizium [19]
Listeria [287]
DNA & RNA sequencing
~5000 datasets of 11 target species for probe desing collected
Host-Fitness monitor
specific probe design

Identification of target regions in genomes of pathogens



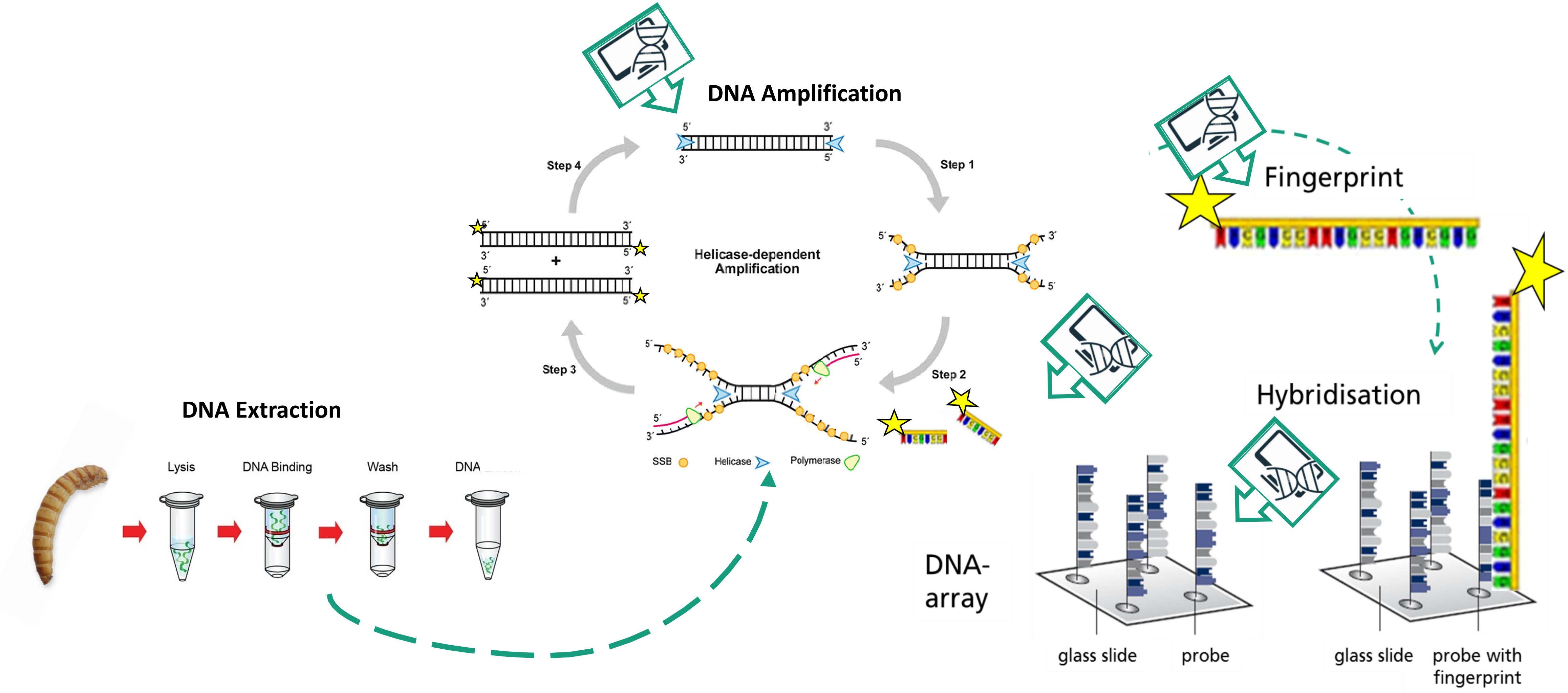




Results

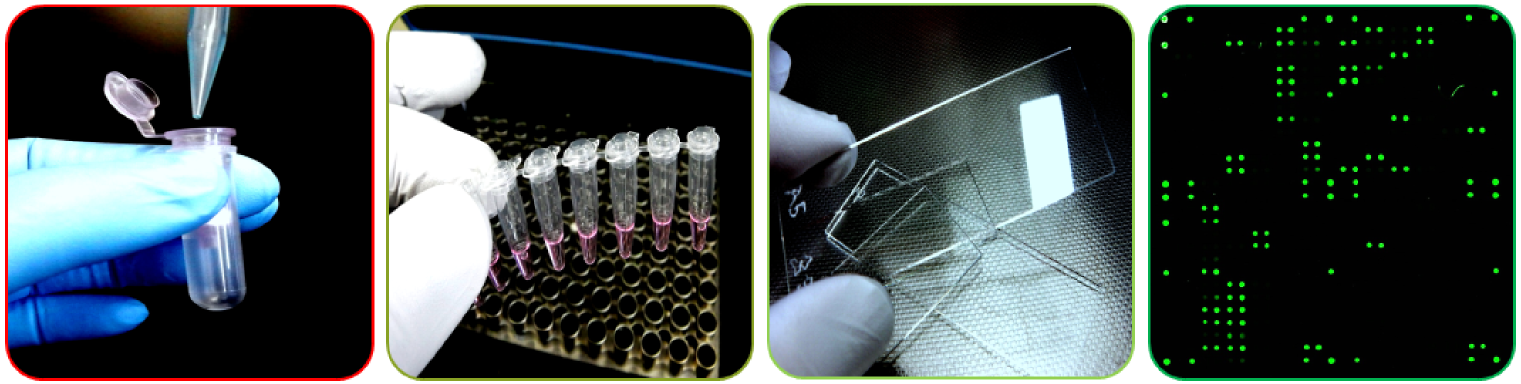
- > 6k specific probes > 300bp overall
- All species sufficient covered for detailed montioring
- Lowest *count on Listera,* less then 350 specific probes

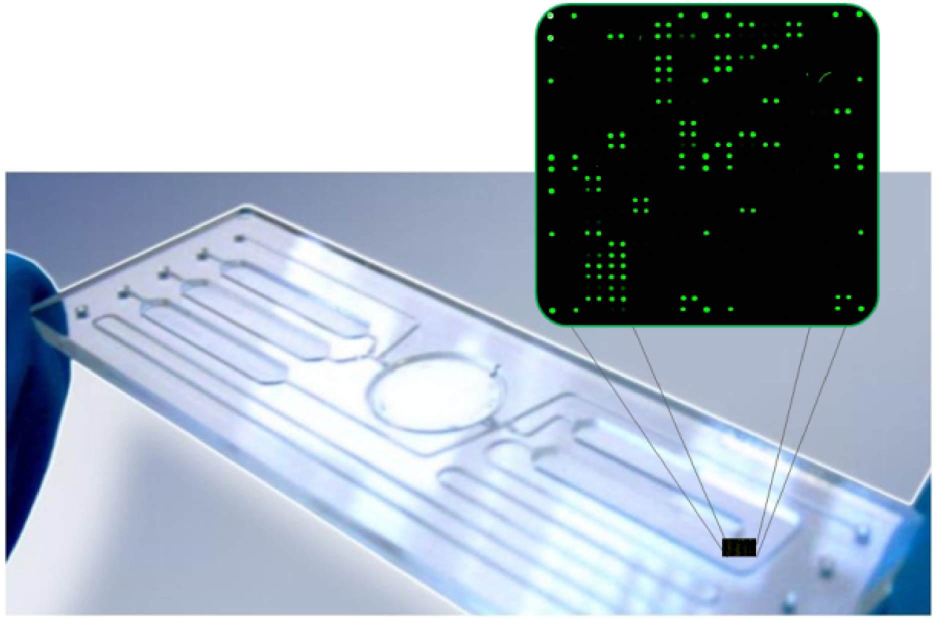
Detection of pathogens in automated insect production systems



Detection of pathogens in automated insect production systems

Proben-aufschluss	Target-Amplifikation	DNA-Array	Readout Ergebnis

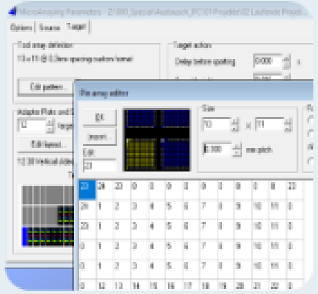


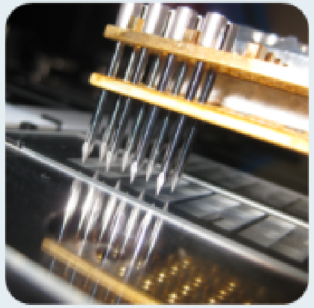


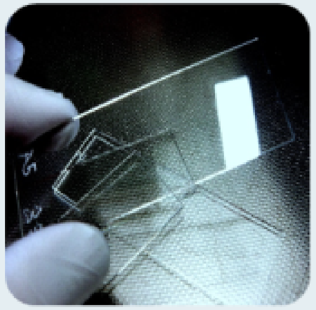
Detection of pathogens in automated insect production systems

Development of DNA µ-Arrays

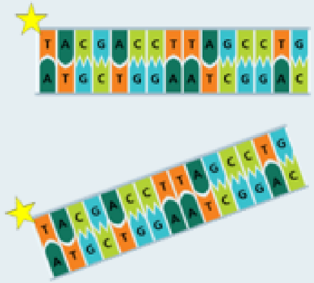
Arraydesign and Spotting

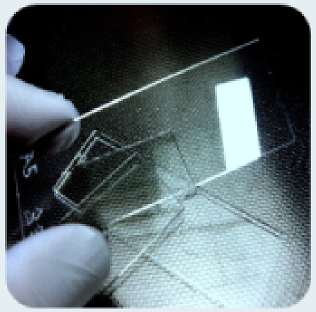


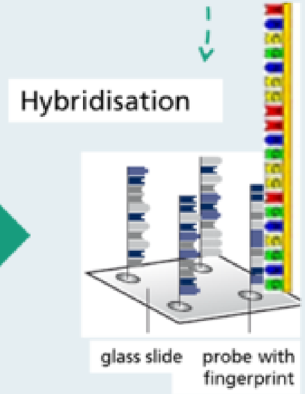




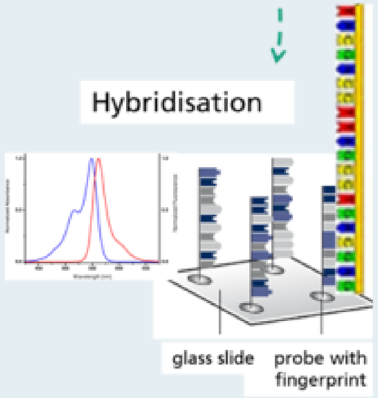
Established Hybridisation

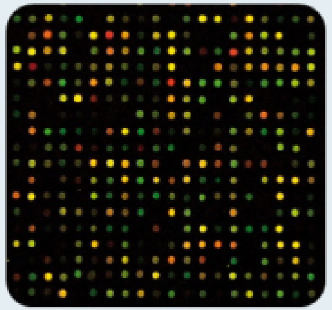




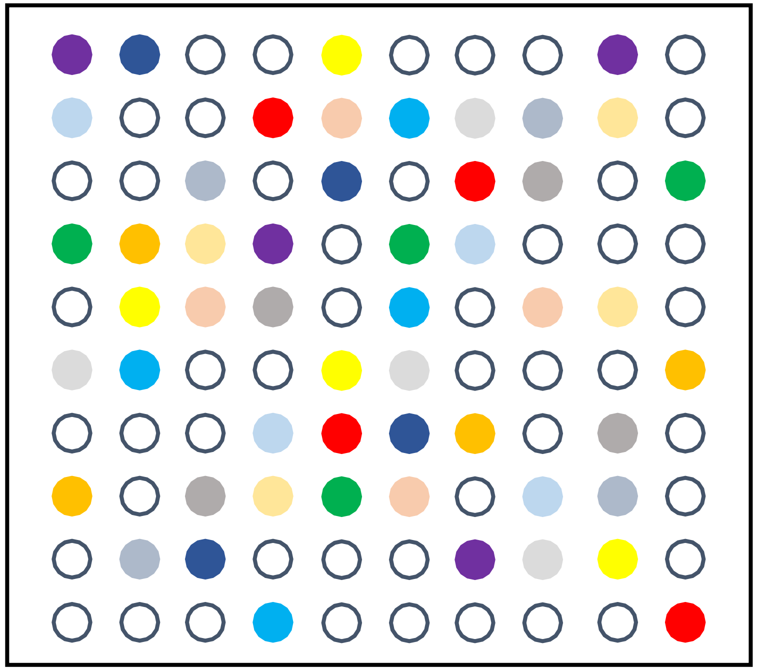


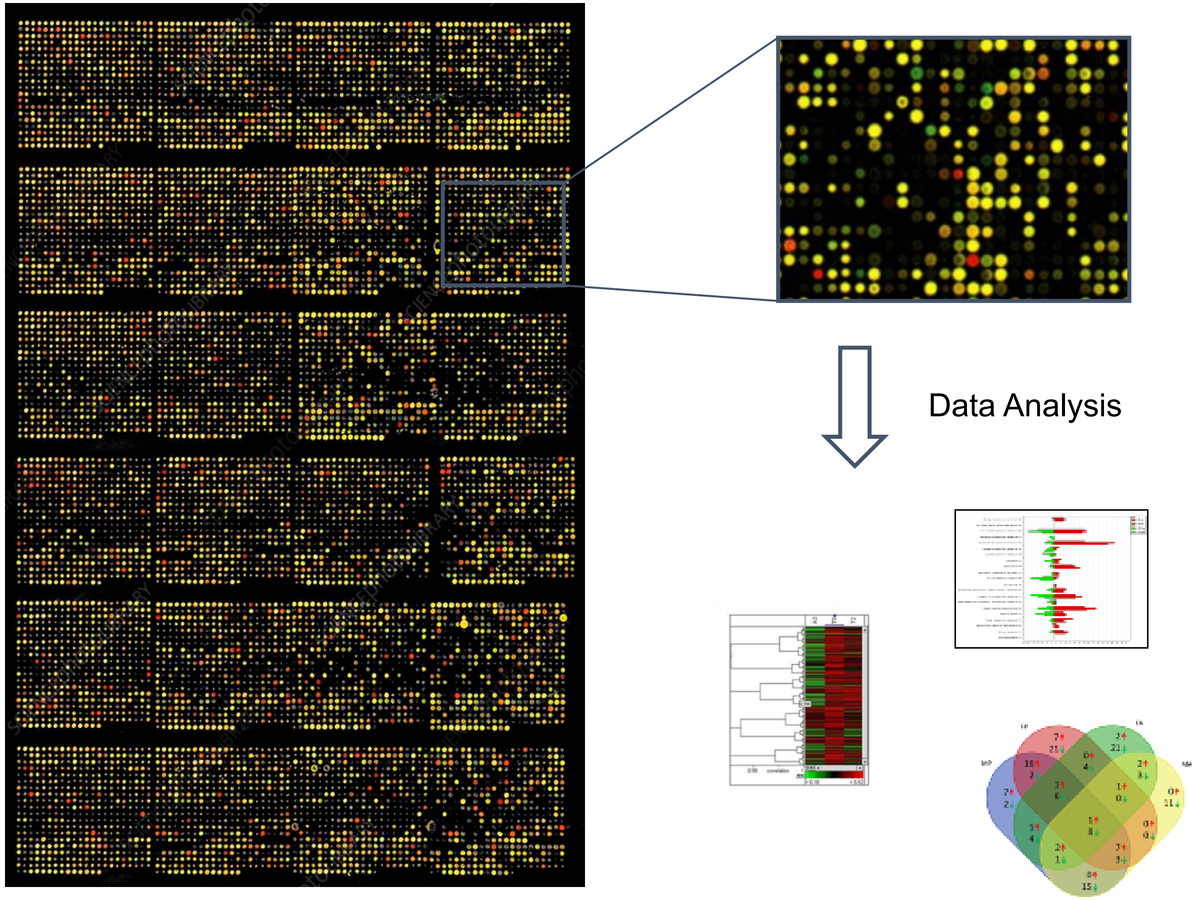
Signal Detection





Pathogen diagnostic for insect farms





- *Salmonella enterica*
- *Bacillus thuringiensis*
- *Listeria monocytogenes*
- *Staphylococcus aureus*
- *Serratia marcescens*
- *Pseudomonas aeruginosa*
- *Nosema ceranae*
- *Beauveria bassiana*
- *Metarhizium brunneum*
- *Candida albicans*
- *Aspergillus flavus*
- *Hybridization Control*
- *Host Control*
- *Internal Control*

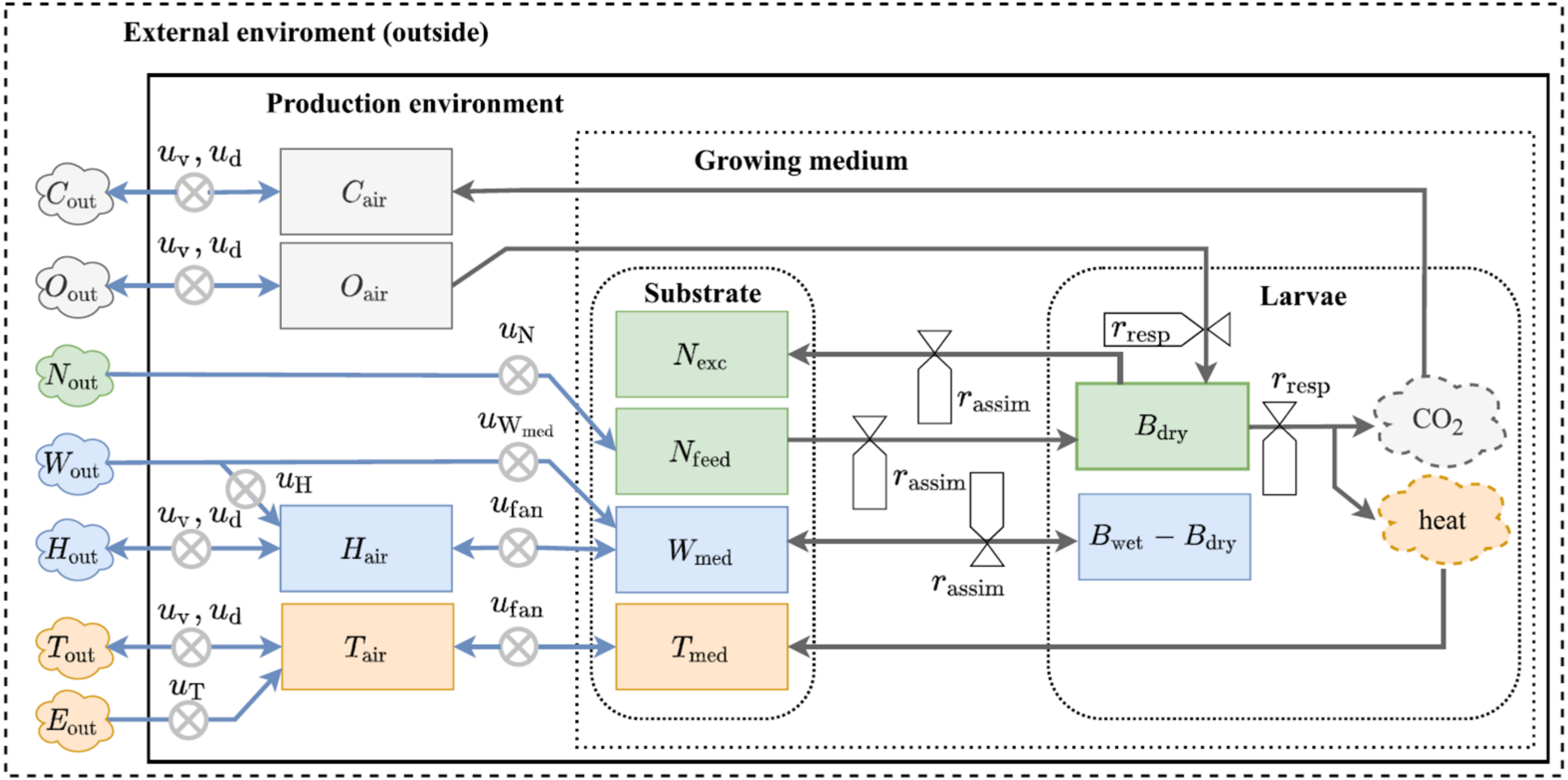


Fig. 1. Overview of the larvae production setup and the internal resource flows. It consists of a growing medium filled with larvae and feed, placed in either a closed or an open production environment. The valves representing the rates labelled as r_{resp} and r_{assim} are internally regulated by the larvae and the substrate states. Circular valves labelled u_{xyz} represent the control signals that control the flow of resources (fluxes).

Modelling and optimization of industrial BSF production

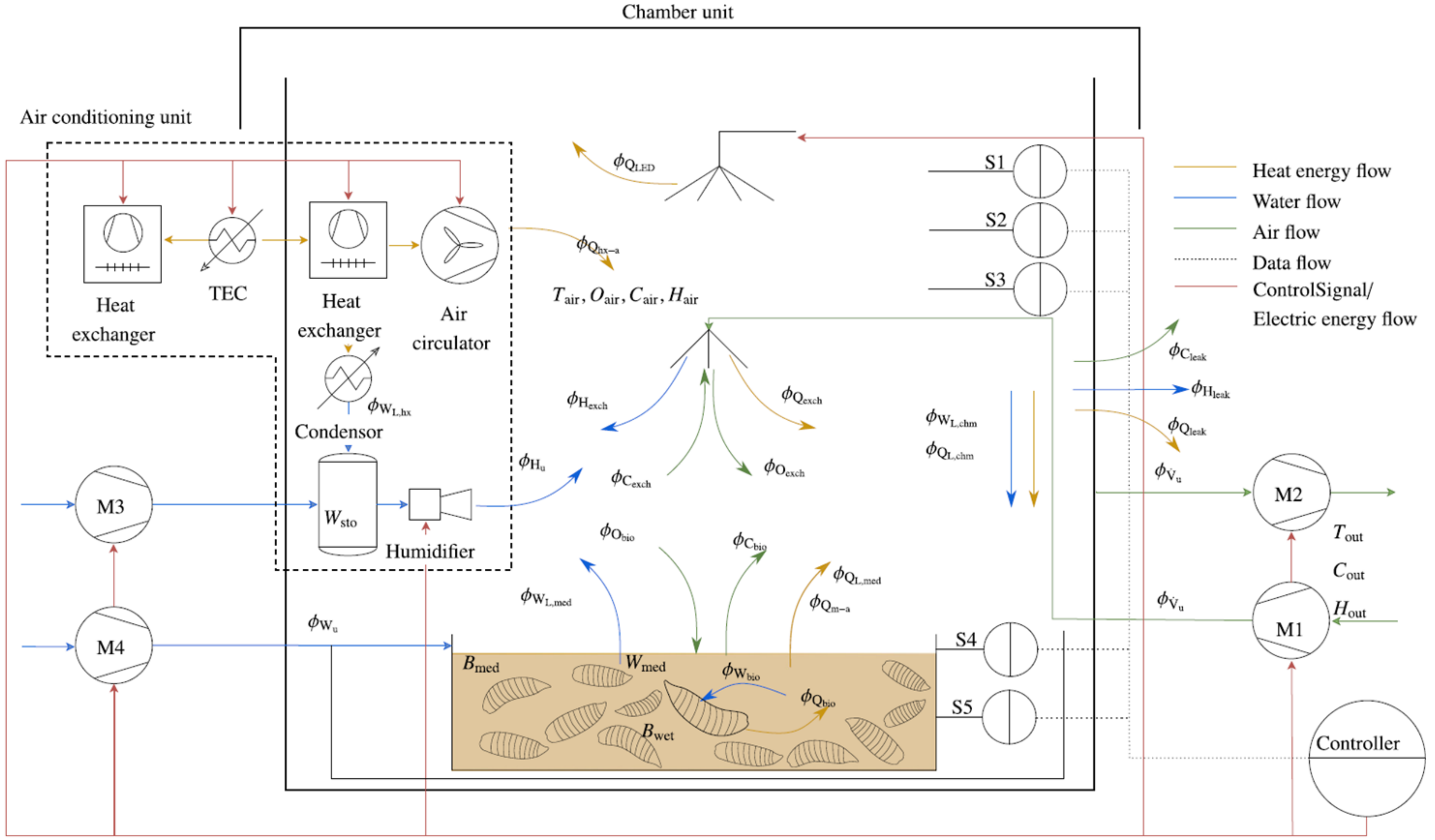


Fig. 2. Production unit components and fluxes in larvae production. Production unit with sensors (S1–S5), air pumps (M1–M2), water pumps (M3–M4), air conditioning unit (based on thermoelectric cooler (TEC) for heating, cooling, and condensation), humidifier, and LED lighting as presented in Padmanabha and Streif (2019).

Modelling and optimization of industrial BSF production

PLOS ONE

RESEARCH ARTICLE

A comprehensive dynamic growth and development model of *Hermetia illucens* larvae

Murali Padmanabha, Alexander Kobelski, Arne-Jens Hempel, Stefan Streif*

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Check for updates

Citation: Padmanabha M, Kobelski A, Hempel A-J, Streif S (2020) A comprehensive dynamic growth and development model of *Hermetia illucens* larvae. PLoS ONE 15(9): e0239084. https://doi.org/10.1371/journal.pone.0239084

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Abstract

Larvae of *Hermetia illucens*, also commonly known as black soldier fly (BSF) have gained significant importance in the feed industry, primarily used as feed for aquaculture and other livestock farming. Mathematical models such as the Von Bertalanffy growth model and dynamic energy budget models are available for modelling the growth of various organisms but have their demerits for their application to the growth and development of BSF. Also, such dynamic models were not yet applied to the growth of the BSF larvae despite models proven to be useful for automation of industrial production process (e.g. feeding, heating/cooling, ventilation, harvesting, etc.). This work primarily focuses on developing a model based on the principles of the afore mentioned models from literature that can provide accurate mathematical description of the dry mass changes throughout the life cycle and the transition of development phases of the larvae. To further improve the accuracy of these models, various factors affecting the growth and development such as temperature, feed quality, feeding rate, moisture content in feed, and airflow rate are developed and integrated into the dynamic growth model. An extensive set of data was aggregated from various literature and used for the model development, parameter estimation and validation. Models describing the environmental factors were individually validated based on the data sets collected. In addition, the dynamic growth model was also validated for dry mass evolution and development stage transition of larvae reared on different substrate feeding rates. The developed models with the estimated parameters performed well, highlighting their potential application in decision-support systems and automation for large scale production.

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Original papers

Modelling and optimal control of growth, energy, and resource dynamics of *Hermetia illucens* in mass production environment

Check for updates

Murali Padmanabha, Alexander Kobelski, Arne-Jens Hempel, Stefan Streif*

Automatic Control and System Dynamics Lab, Technische Universität Chemnitz, Chemnitz, 09107, Germany

A R T I C L E   I N F O

Keywords:
Hermetia illucens mass production
Mass and energy flux modelling
Energy and resource optimization
Process design and control
Bioreactor optimal control

A B S T R A C T

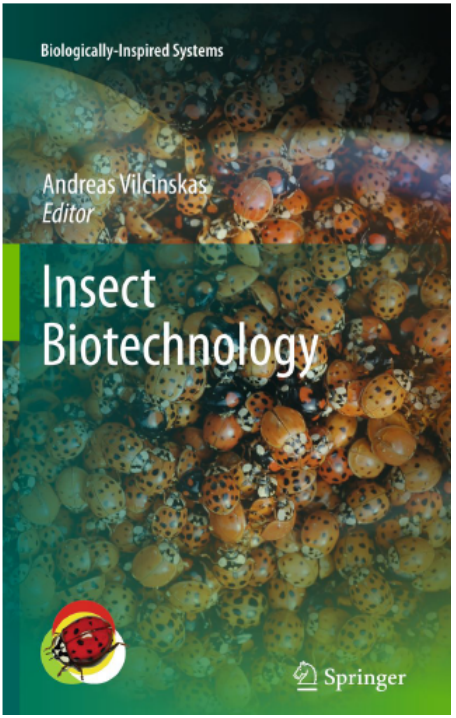
Mass production of *Hermetia illucens* insect larvae is now being adopted in many countries and is taking an industrial production approach. Despite abundant literature on factors that affect larvae growth and the optimal static parameters identified in laboratory setup, for an industrial production process it is necessary to identify the trajectories such that the growth as well as the production process is optimal. To achieve this in this work, some of the important requirements and challenges involved thereof are identified and objectives of the automation process are formulated within a model based optimal control setup. Mechanistic models necessary for the optimization framework are derived as differential equations that describe the dynamic variation of resources (feed, water, O_2 etc.), energy, and larval biomass. In addition, the elevated metabolic activity of larvae corresponding to the final instar development is identified and also modelled based on the observation from experiments. The mass and energy balance approach used in modelling enables the quantification and distinction of the mass and energy flux components in various levels (e.g. larvae body, growing medium, production environment, and external environment) while holding its applicability for both open and closed/reactor based production setups. Finally, the trajectories generated using the synthesized optimal controller are tested under different scenarios showcasing significant reduction in resource consumption compared to a constant set-point operation of the production setup. Results presented in this work not only showcase the potential of the mechanistic models and their application in identifying the relevant process parameters (e.g. reactor properties such as volume, thermal conductivity, actuator capacities), but most importantly in optimizing the process dynamically and tuning the process objectives as desired (e.g. maximize larvae mass, reduce energy).

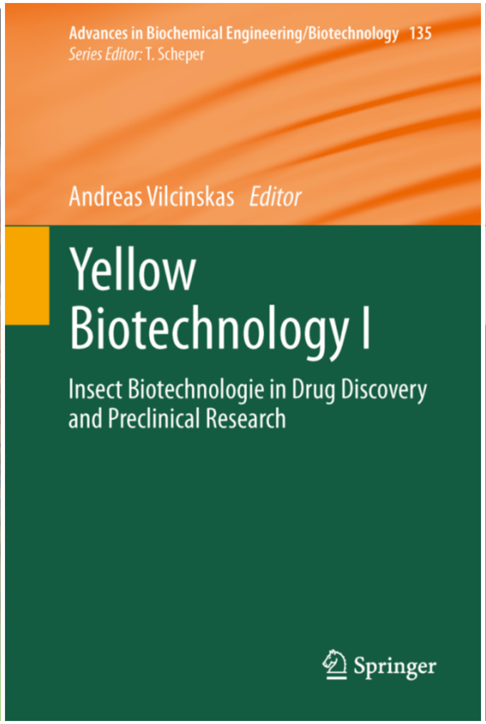
Fraunhofer

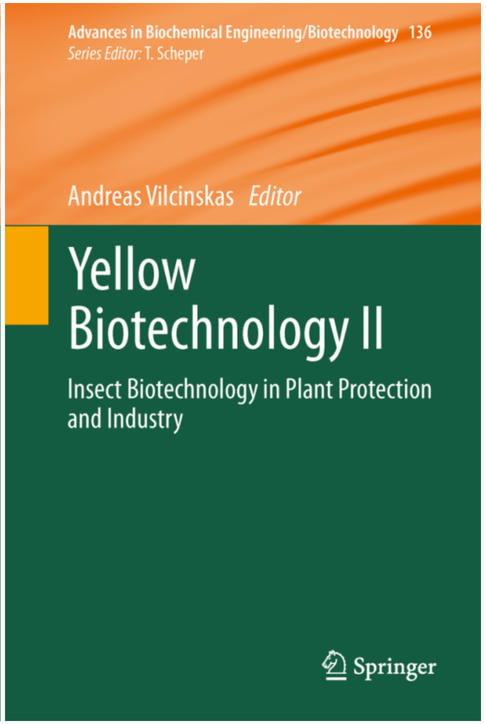
Yellow Biotechnology

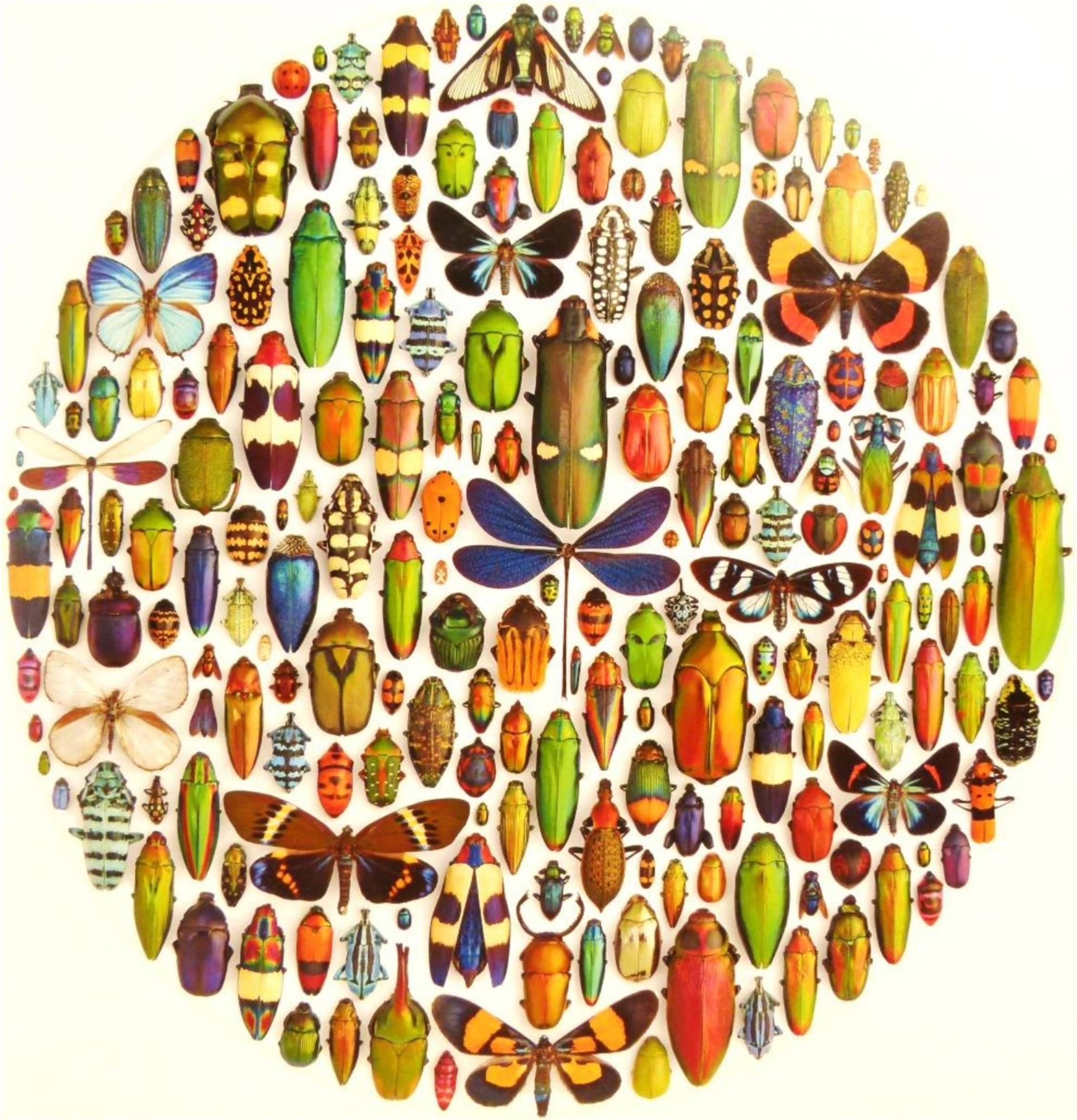
We define Insect Biotechnology or Yellow Biotechnology as:

The development and application of biotechnological methods to translate insects, their molecules, cells, organs or associated microorganism, respectively, into products or services for specific use in medicine, agriculture or industry.



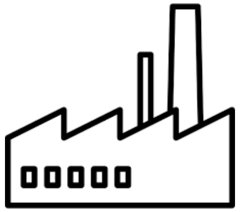






Yellow Biotechnology

- Insects are the most diverse and, therefore, the evolutionarily most successfull group of organisms
- Their biodiversity at species level can be expanded to the molecular level
- Insects represent a incredible compound library
- Insect Biotechnology aims to explore and to develop this compound library for human welfare.
- Consequent translational approach for value creation at industrial scale.



Industry

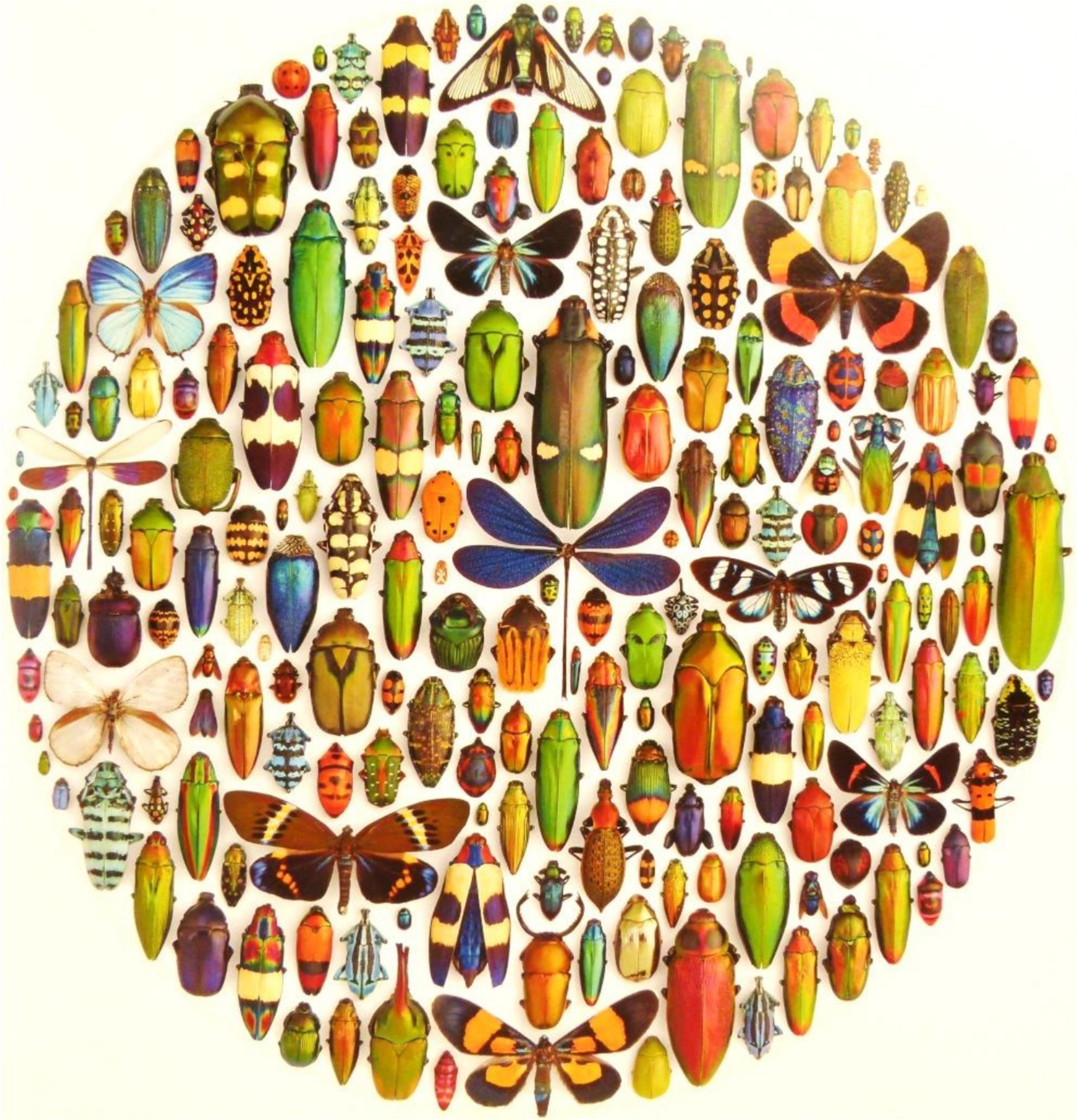
Medicine

Cosmetics

Food

Feed

Agriculture



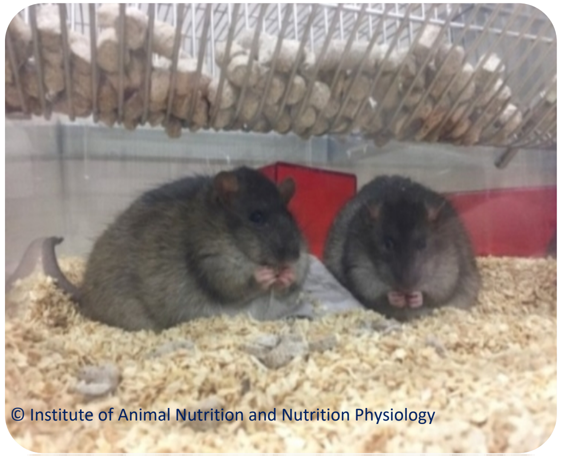
Development of higher added value products from BSF

Health beneficial effects of insect meal

Prof. Klaus Eder

4-week feeding trial

- 36 homozygous obese Zucker rats and 12 heterozygous lean Zucker rats (Crl:ZUC (Orl)-*Lepr*^{fa})
- housed in groups of two animals each under controlled conditions
- randomly divided into three obese groups (OC, OI50 and OI100) of 12 rats each; and lean rats served as lean control group (LC)
- insect meal from *Tenebrio molitor* L.



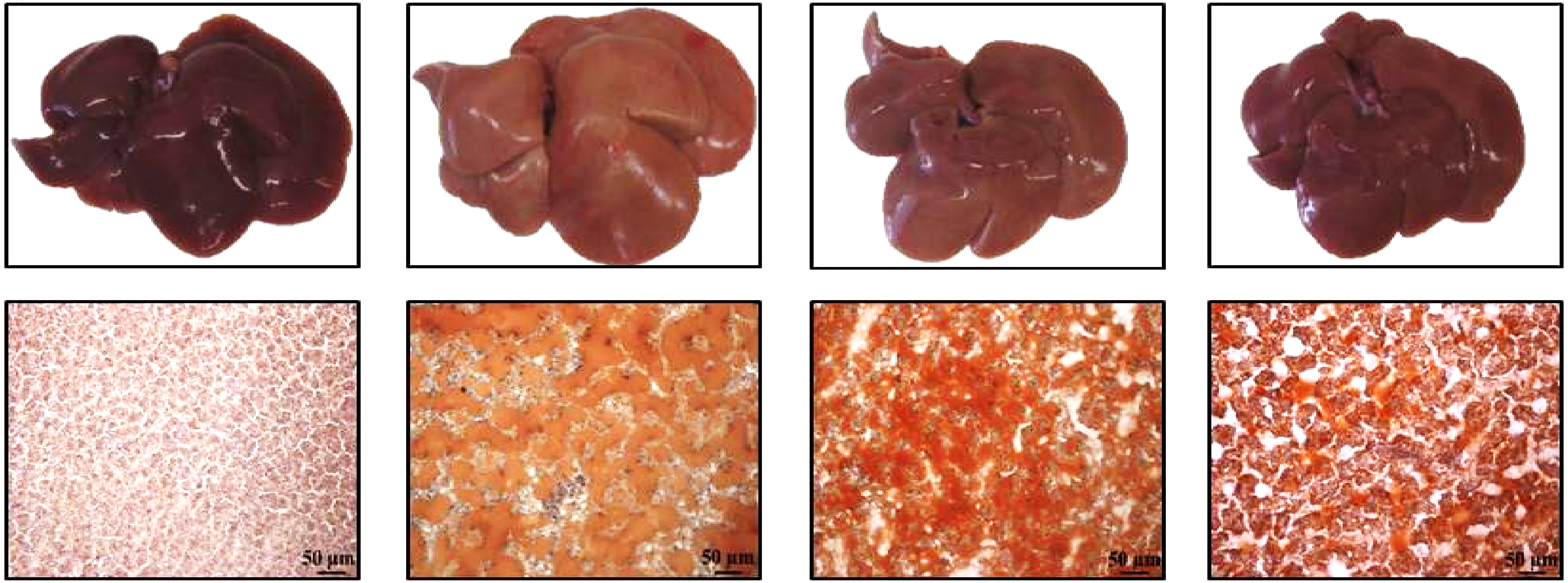
group	n	diet (*ad libitum*)
LC	12	100% casein as protein source
OC	12	100% casein as protein source
OI50	12	50% of casein replaced isonitrogenously by insect meal
OI100	12	100% of casein replaced isonitrogenously by insect meal

insect meal (Ÿnsect)

crude nutrients (% DM)	
crude protein	76.6
crude fat	14.0
crude fibre	13.2
cude ash	4.3
chitin	12.8

effect of insect meal on lipid metabolism

Health beneficial effects of insect meal



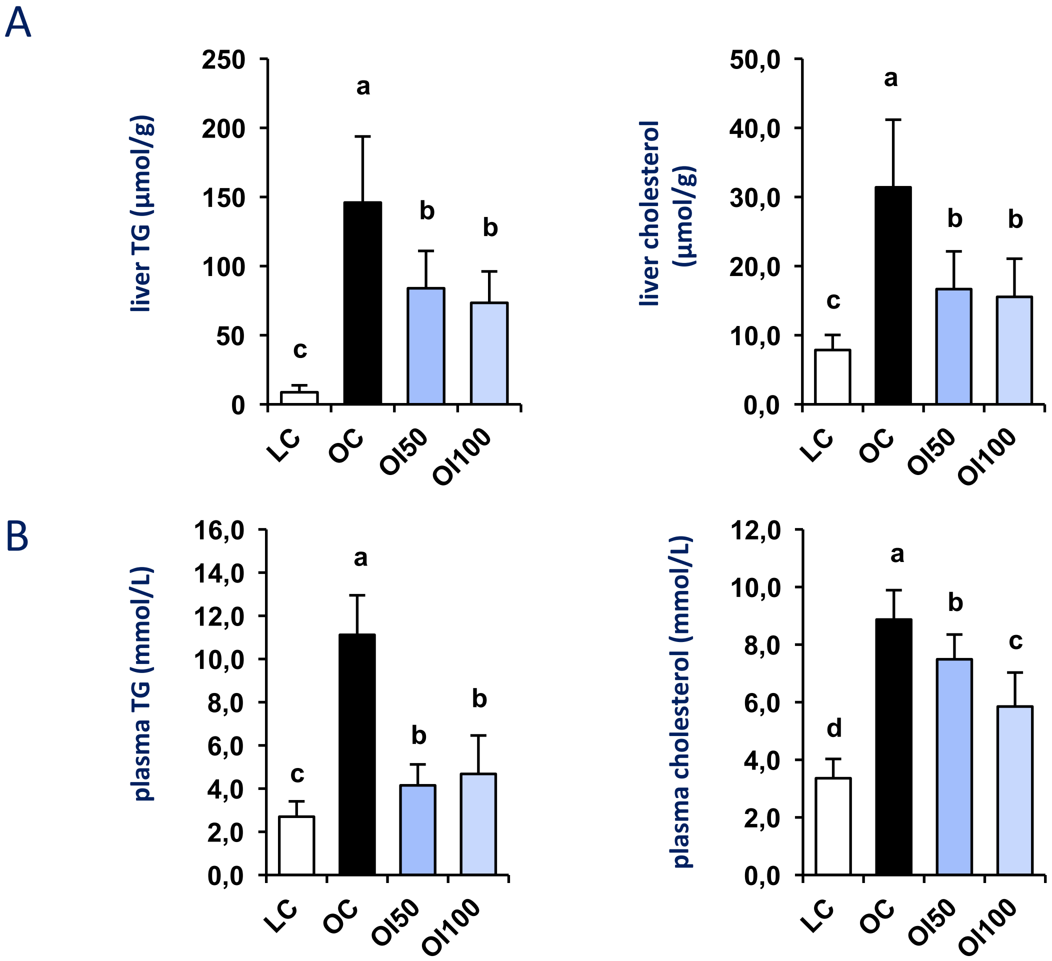
lean casein | obese casein | obese insect meal 50% | obese insect meal 100%

	fold change			lipid synthetic pathway
gene	OC vs. LC	OI50 vs. OC	OI100 vs. OC	
Scd2	14.11*	-6.21*	-9.59*	fatty acid
G6pd	1.24	-1.62	-2.41*	fatty acid
Aacs	2.28*	-1.50*	-2.28*	cholesterol
Fads1	1.27*	-1.32*	-2.01*	fatty acid
Acacb	1.47*	-1.38*	-1.80*	fatty acid
Me1	1.38	-1.37	-1.79*	fatty acid

Gessner *et al.*, J. Nutr. (2019)

total livers and oil red O-stained liver sections of rats

Health beneficial effects of insect meal



liver:

TG ↓

Cholesterol

plasma:

TG ↓

Cholesterol

Gessner et al., J. Nutr. (2019)

means ± SD. *n* = 12; bars without a common letter differ, *P* < 0.05.

concentrations of triacylglycerol (TG) and cholesterol in the liver (A) and plasma (B) of rats fed either casein (OC), casein and insect meal (OI50) or insect meal (OI100)

Health beneficial effects of insect meal

a ab

The Journal of Nutrition
Biochemical, Molecular, and Genetic Mechanisms

Insect Meal as Alternative Protein Source Exerts Pronounced Lipid-Lowering Effects in Hyperlipidemic Obese Zucker Rats

Denise K Gessner,[1] Anne Schwarz,[1] Sandra Meyer,[1] Gaiping Wen,[1] Erika Most,[1] Holger Zorn,[2] Robert Ringseis,[1] and Klaus Eder[1]

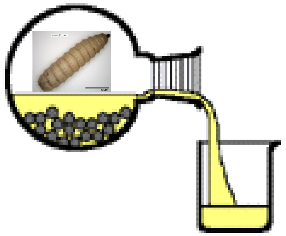
[1]Institute of Animal Nutrition and Nutrition Physiology and [2]Institute of Food Chemistry and Food Biotechnology, Justus-Liebig-University Giessen, Giessen, Germany

Insect-derived AMPs for food and feed preservation

Bundesministerium
für Bildung
und Forschung

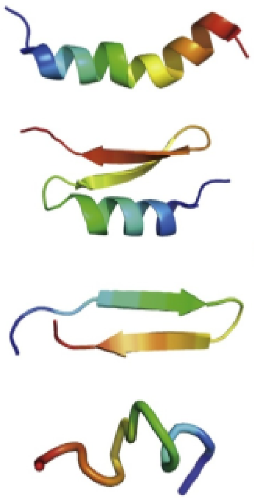
AMP-Food

- Customer demand nature-like or natural, healthy ingredients
- Biologically degradable
- Taylor-made activity profiles



extraction

heterologous expression



- Purification
- Characterization
- application

ISI FOOD PROTECTION
CENTRE OF EXPERTISE FOR
APPLIED FOOD MICROBIOLOGY

VAN HEES
we know how

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Fraunhofer IME

YellowCare

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Fraunhofer IME

AMERICAN SOCIETY FOR MICROBIOLOGY
Microbiology Spectrum
RESEARCH ARTICLE

Check for updates

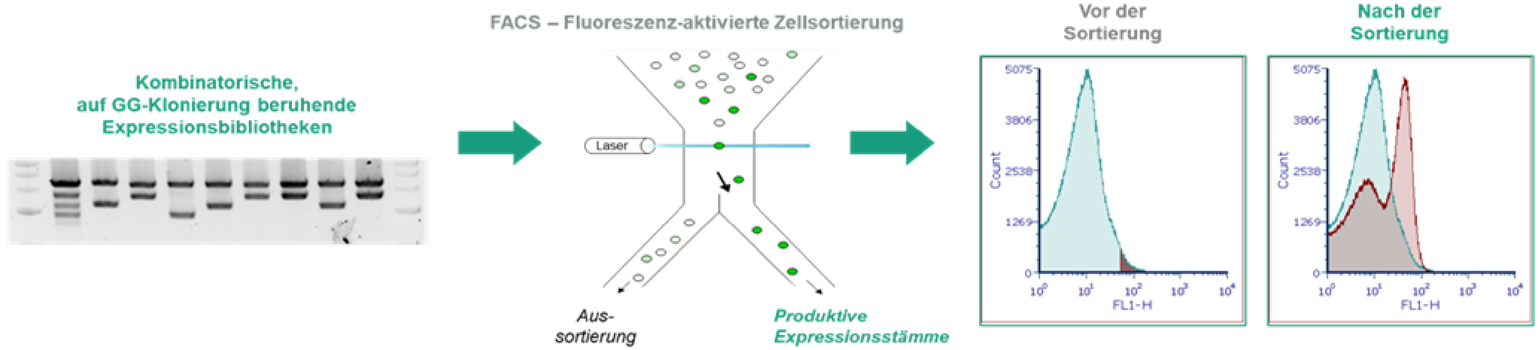
In Vitro Evaluation of Antimicrobial Peptides from the Black Soldier Fly (*Hermetia Illucens*) against a Selection of Human Pathogens

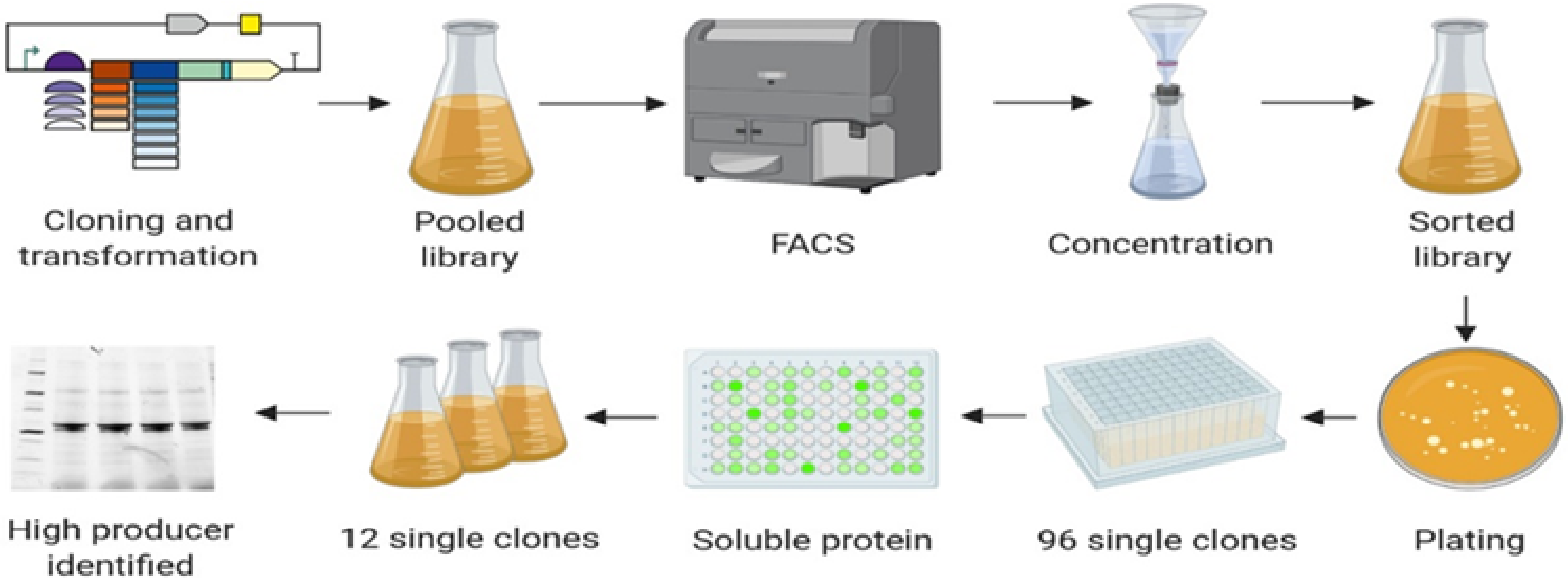
Laurence Van Moll,[a,b,c] Jeroen De Smet,[b,c] Anne Paas,[d,f] Dorothee Tegtmeier,[d] Andreas Vilcinskas,[d,e,f] Paul Cos,[a] Leen Van Campenhout[b,c]

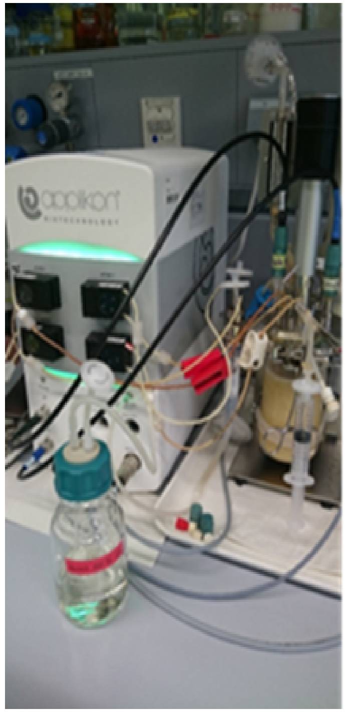
[a]Laboratory for Microbiology, Parasitology and Hygiene (LMPH), Faculty of Pharmaceutical, Biomedical and Veterinary Sciences, University of Antwerp, Antwerp, Belgium
[b]Department of Microbial and Molecular Systems (M^2S), Research Group for Insect Production and Processing, KU Leuven, Geel, Belgium
[c]Leuven Food Science and Nutrition Research Centre (LFoRCe), KU Leuven, Leuven, Belgium
[d]Fraunhofer Institute for Molecular Biology and Applied Ecology, Branch for Bioresources, Gießen, Germany
[e]Institute for Insect Biotechnology, Justus Liebig University of Gießen, Gießen, Germany
[f]LOEWE Centre for Translational Biodiversity Genomics (LOEWE-TBG), Frankfurt am Main, Germany

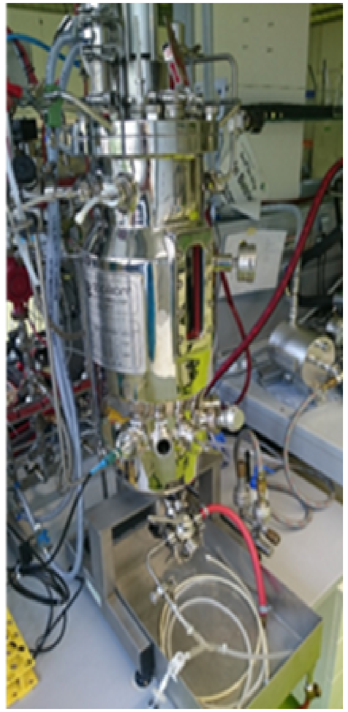
Expression of recombinant insect AMPs

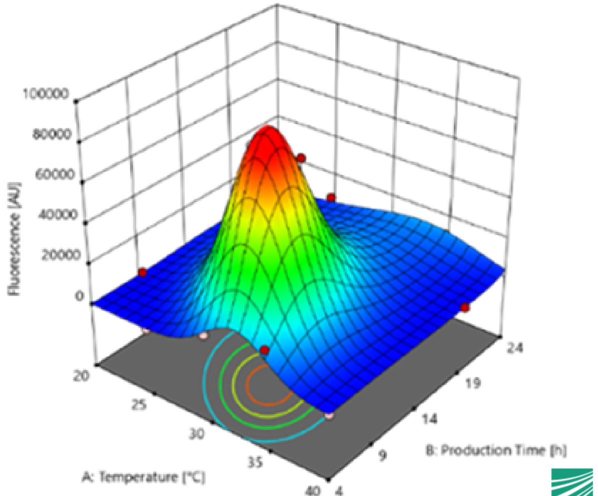
➢ **Develpment of an up-scaling process**











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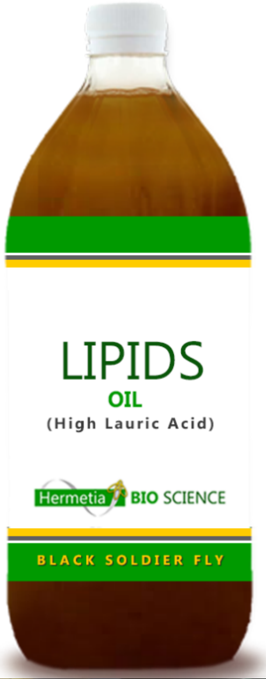
Fraunhofer IME

Insect-AMPs in Veterinary Medicine

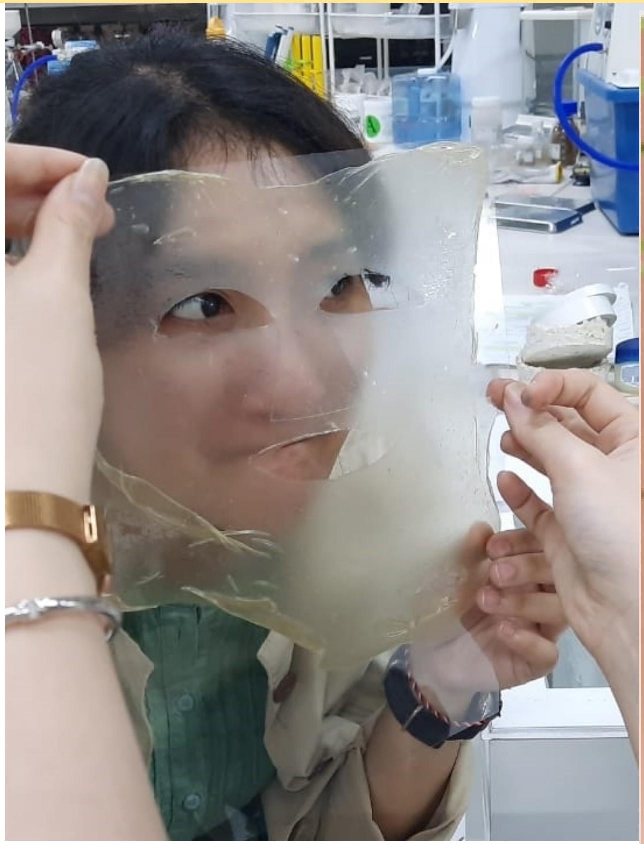
The Black soldier fly as the economically most important species in insect farming

Hermetia BIO SCIENCE

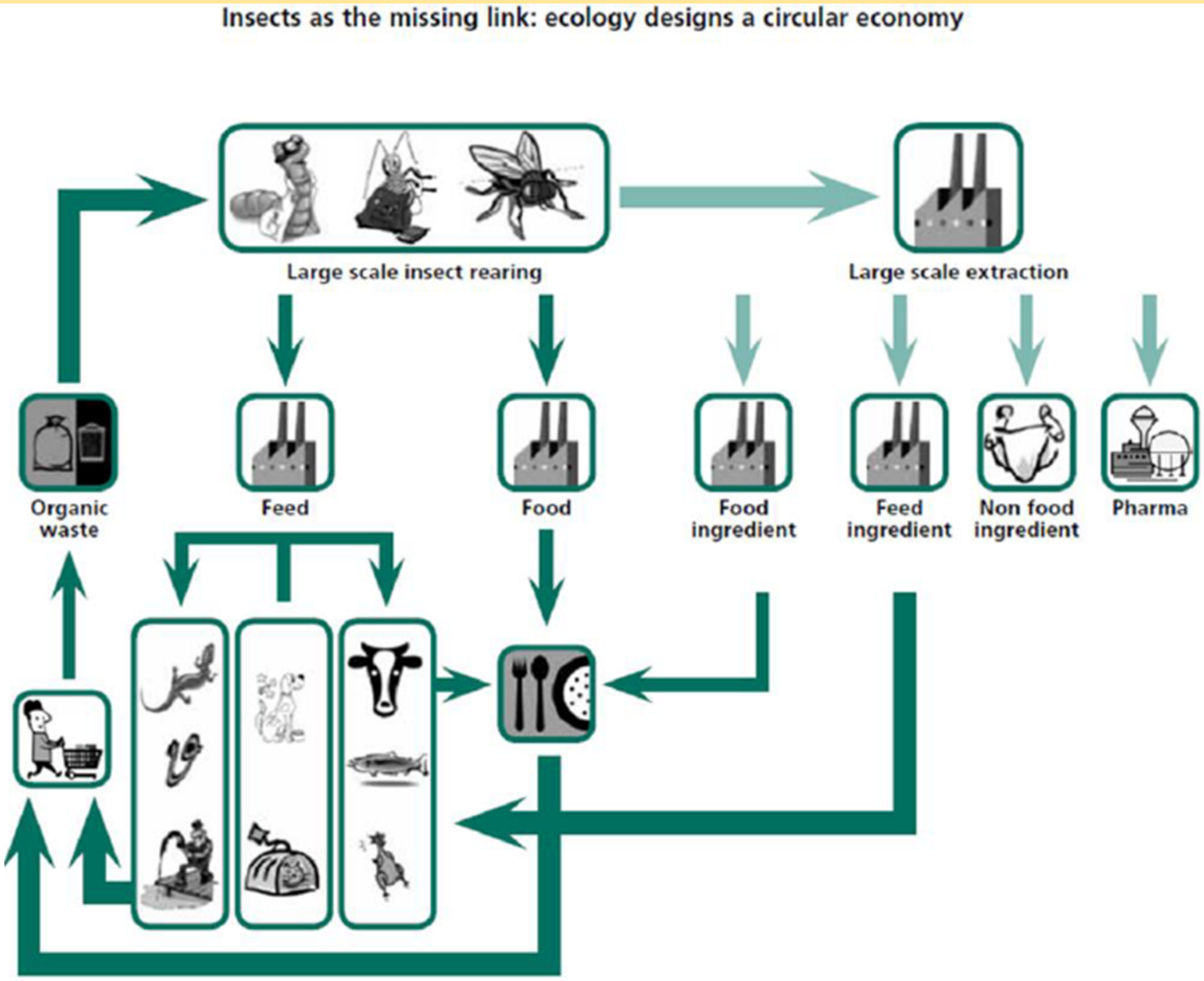
Development of BSF lipids into high quality lubricants



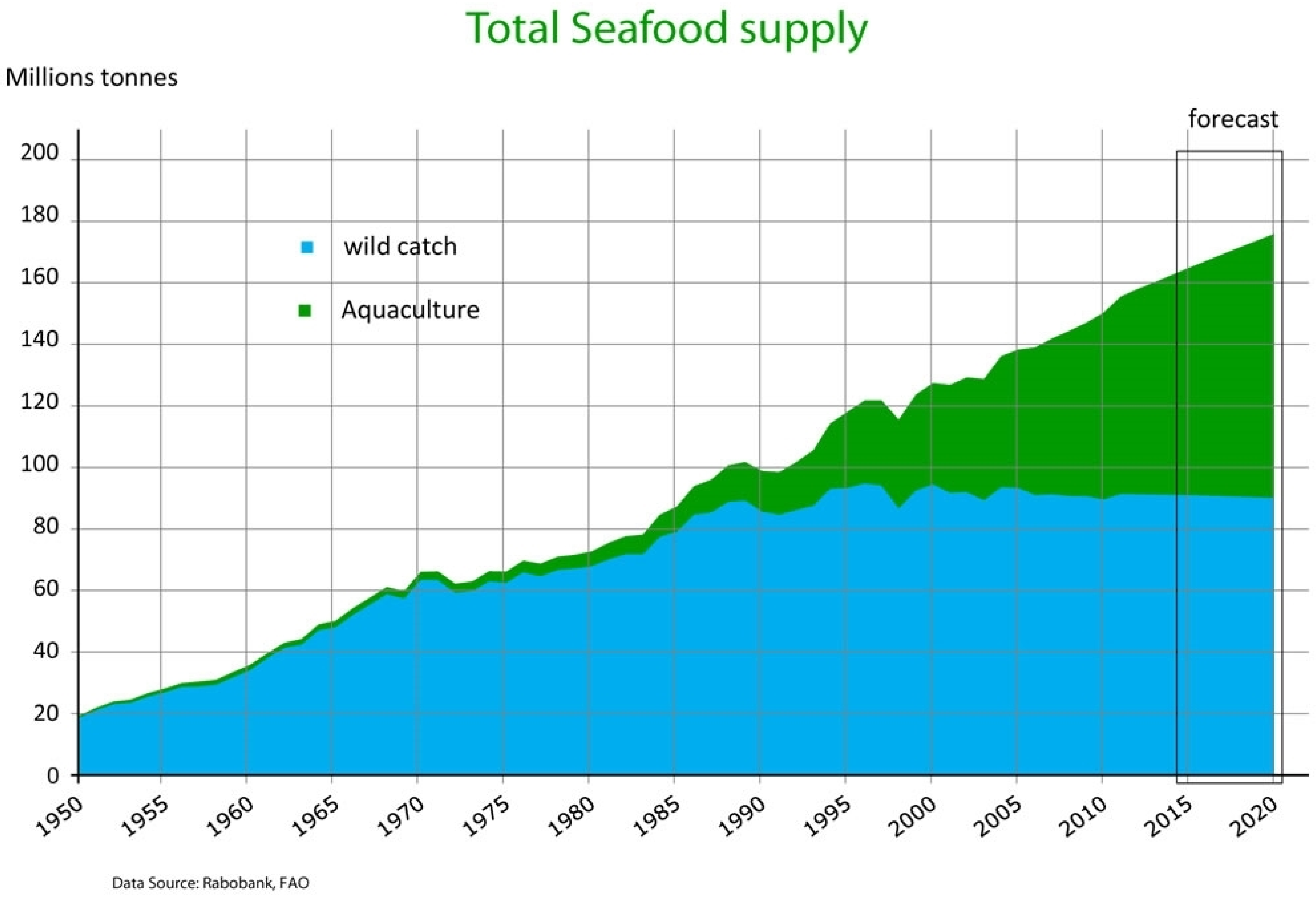
Development of BSF chitin/chitosan into cosmetics and medical care products



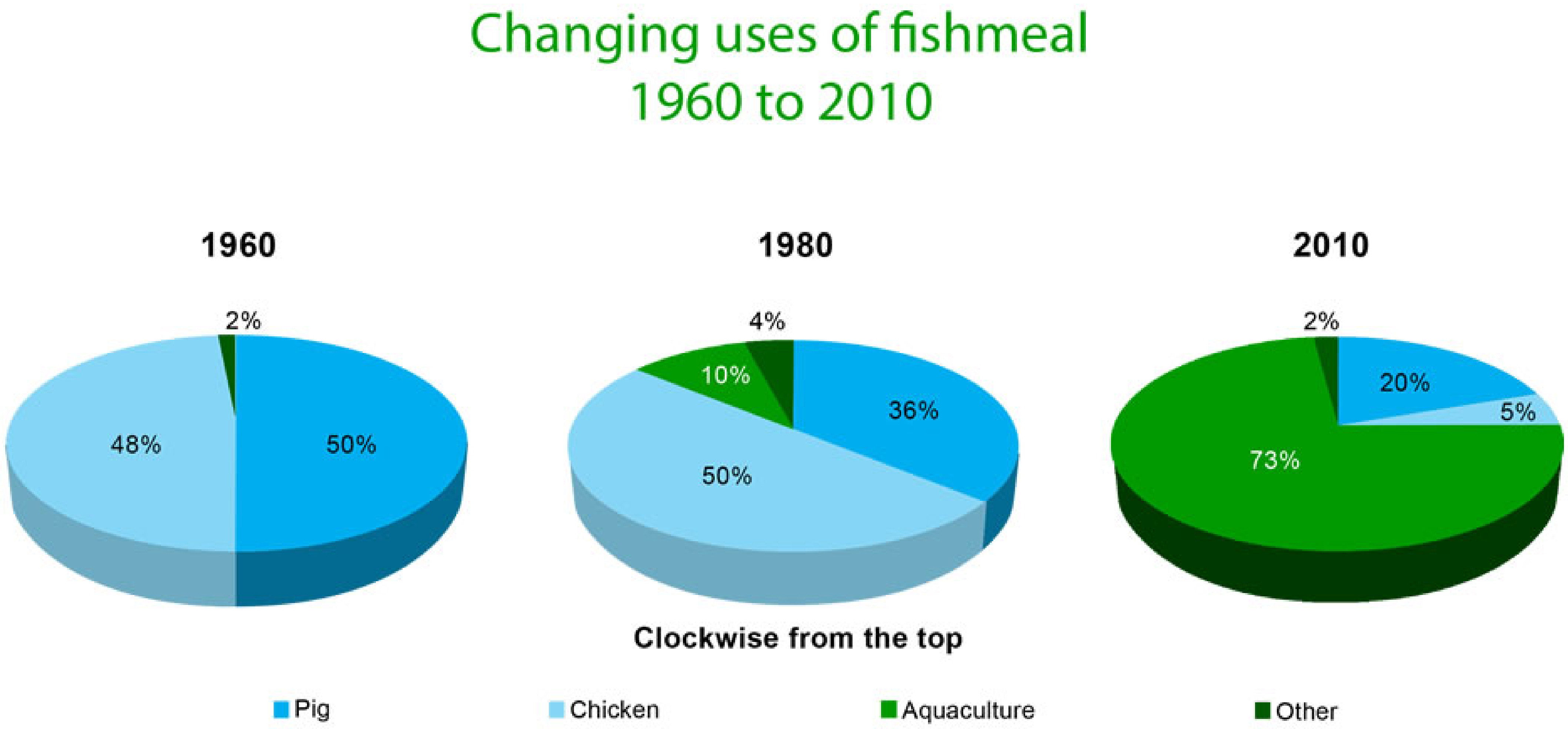
Insects as the missing link in the circular economy



Increasing demand for feed in aquaculture



Pressure to replace fishmeal



Data source: IFFO Estimates

Insect feed in sustainable crustacean aquaculture

- Optimizing the side-stream based died for BSF
- To enhance nutritive quality for shrimps
- Complete replacement of fish meal
- Decoupling of shrimp farming from the ocean

apple pomace

cocoa bean shell

depectinised apple pomace

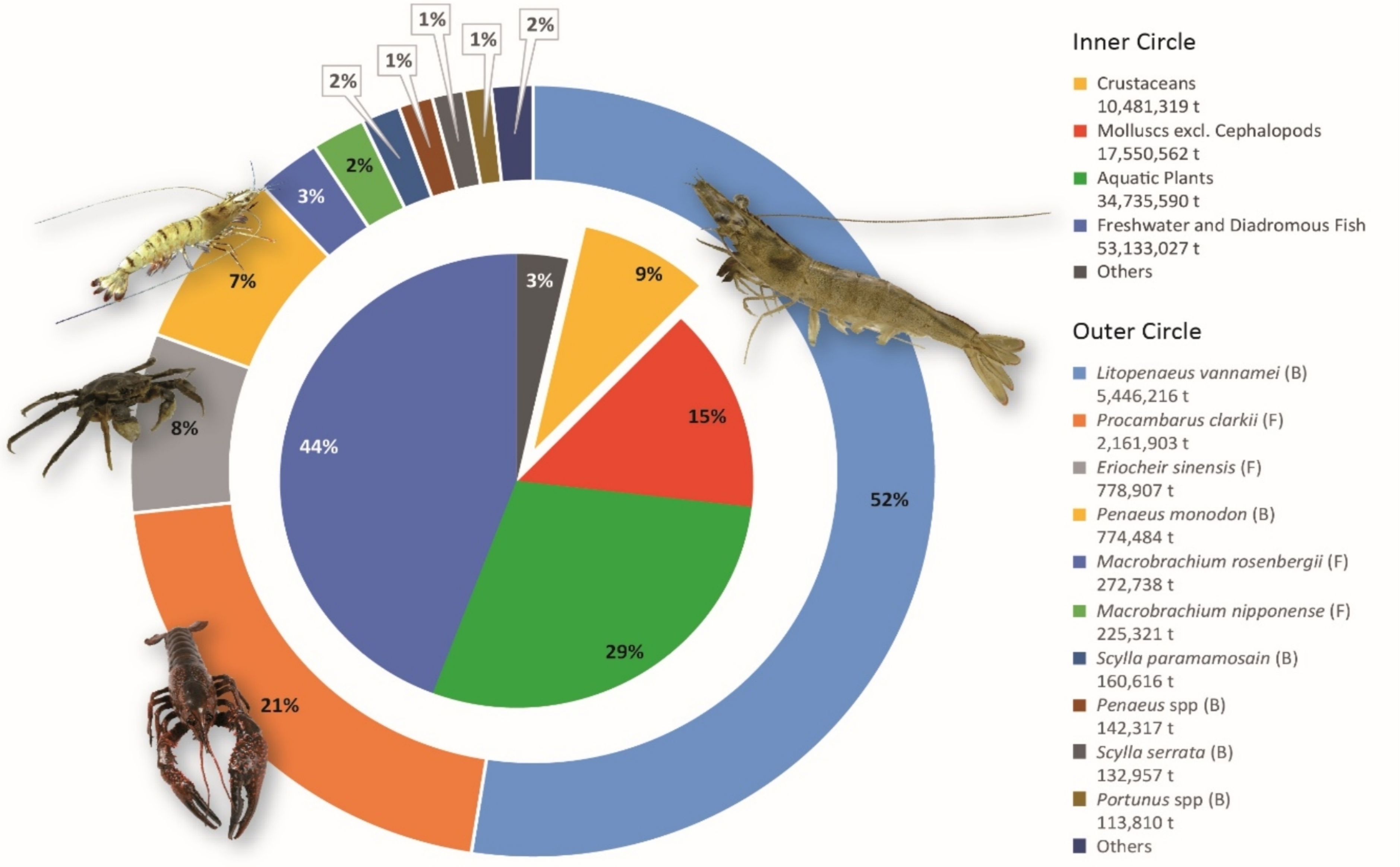
Bundesministerium für Bildung und Forschung

BioBall
Bioökonomie im Ballungsraum

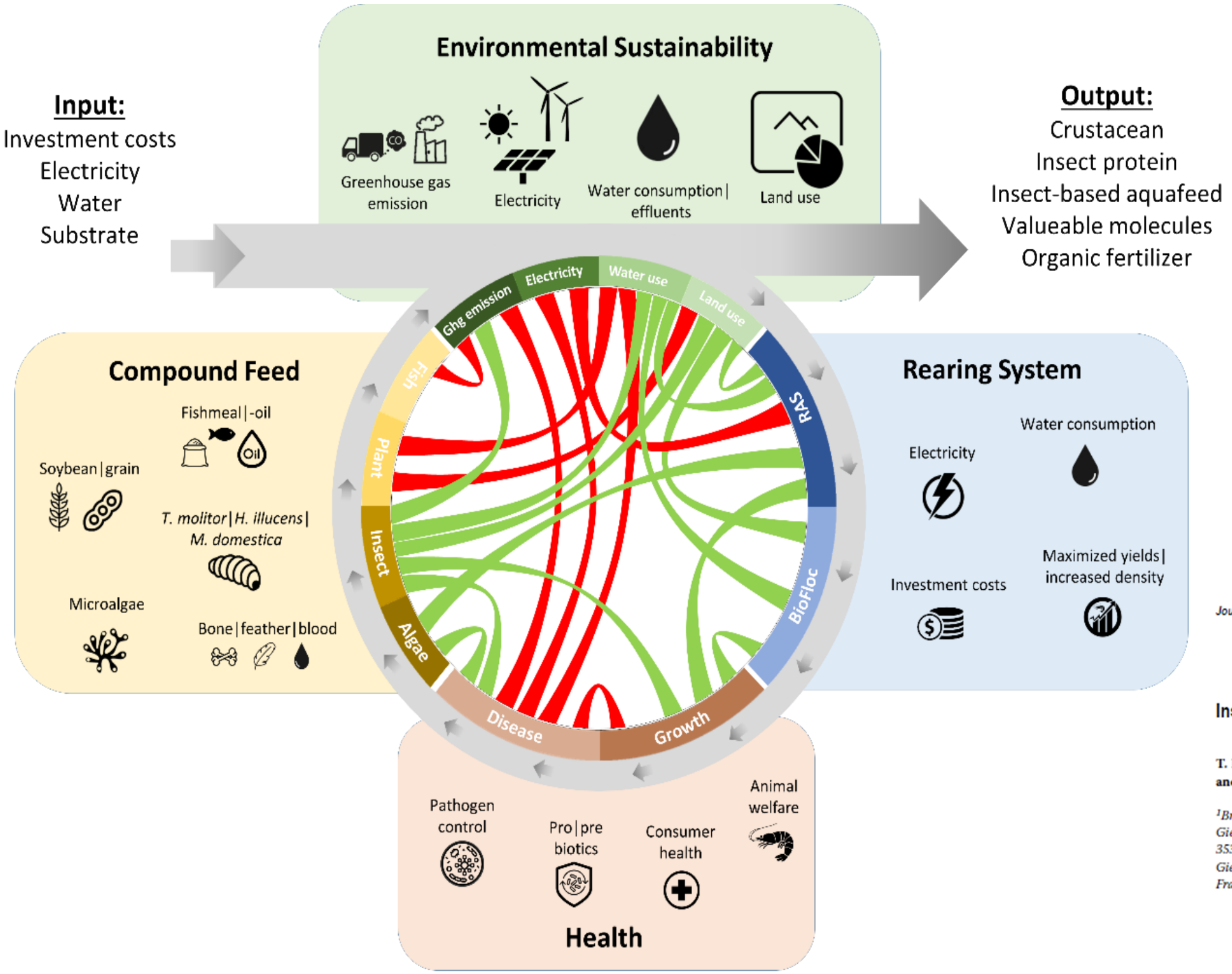
EVONIK
Leading Beyond Chemistry

- Tailor-made shrimp food (InFeed)
- Insect-based sustainable agriculture (InA)

Global aquaculture production and main crustacean species 2019



Conceptual overview on sustainable, insect-based crustacean aquaculture



Journal of Insects as Food and Feed, 2023; 9(9) 1115-1138

Wageningen Academic Publishers

Insect feed in sustainable crustacean aquaculture

T. Röthig[1*], A. Barth[2], M. Tschirner[1,2], P. Schubert[2], M. Wenning[1], A. Billion[1], T. Wilke[1,2] and A. Vilcinskas[1,3,4]

[1]Branch for Bioresources, Fraunhofer Institute for Molecular Biology and Applied Ecology IME, Ohlebergsweg 12, 35392 Giessen, Germany; [2]Institute for Animal Ecology and Systematics, Justus Liebig University Giessen, Heinrich-Buff-Ring 26, 35392 Giessen, Germany; [3]Institute for Insect Biotechnology, Justus Liebig University Giessen, Heinrich-Buff-Ring 26, 35392 Giessen, Germany; [4]LOEWE Centre for Translational Biodiversity Genomics (LOEWE-TBG), Senckenberganlage 25, 60325 Frankfurt, Germany; tillroethig@gmail.com

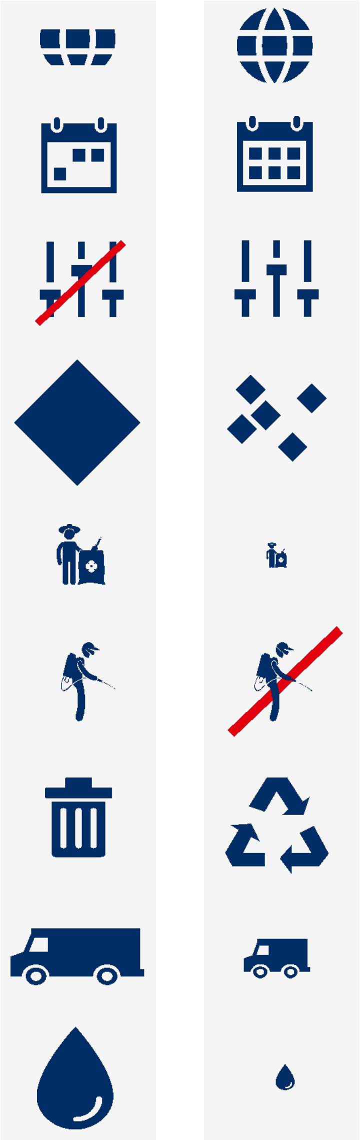
Received: 18 August 2022 / Accepted: 14 February 2023

REVIEW ARTICLE

Controlled Environment Agriculture

Conflict among SDGs

Traditional Agriculture | *Controlled environment* Agriculture



- Harvest-areas
- Harvest-time
- Regulation
- Landuse
- Reduction of fertilizer
- No pesticides
- Waste management
- Low transpotation
- Low water consumption

Controlled Environment Agriculture

- **More food needs to be produced, more sustainable despite climate change**
- **Novel food production systems, including crop, algae, mushroom, fish and insect production in controlled environments-agriculture offer substantially higher productivity**
- **with no pesticides, low water use, towards full circularity, minimal externalities, close to the consumer and independent of climate, weather and region.**
- **Improving efficiencies, particularly in energy use and re-use in controlled-environment agriculture will make these new technologies a component of our future food systems.**

Traditional Agriculture	*Controlled environment* Agriculture	
		Harvest-areas
		Harvest-time
		Regulation
		Landuse
		Reduction of fertilizer
		No pesticides
		Waste management
		Low transpotation
		Low water consumption

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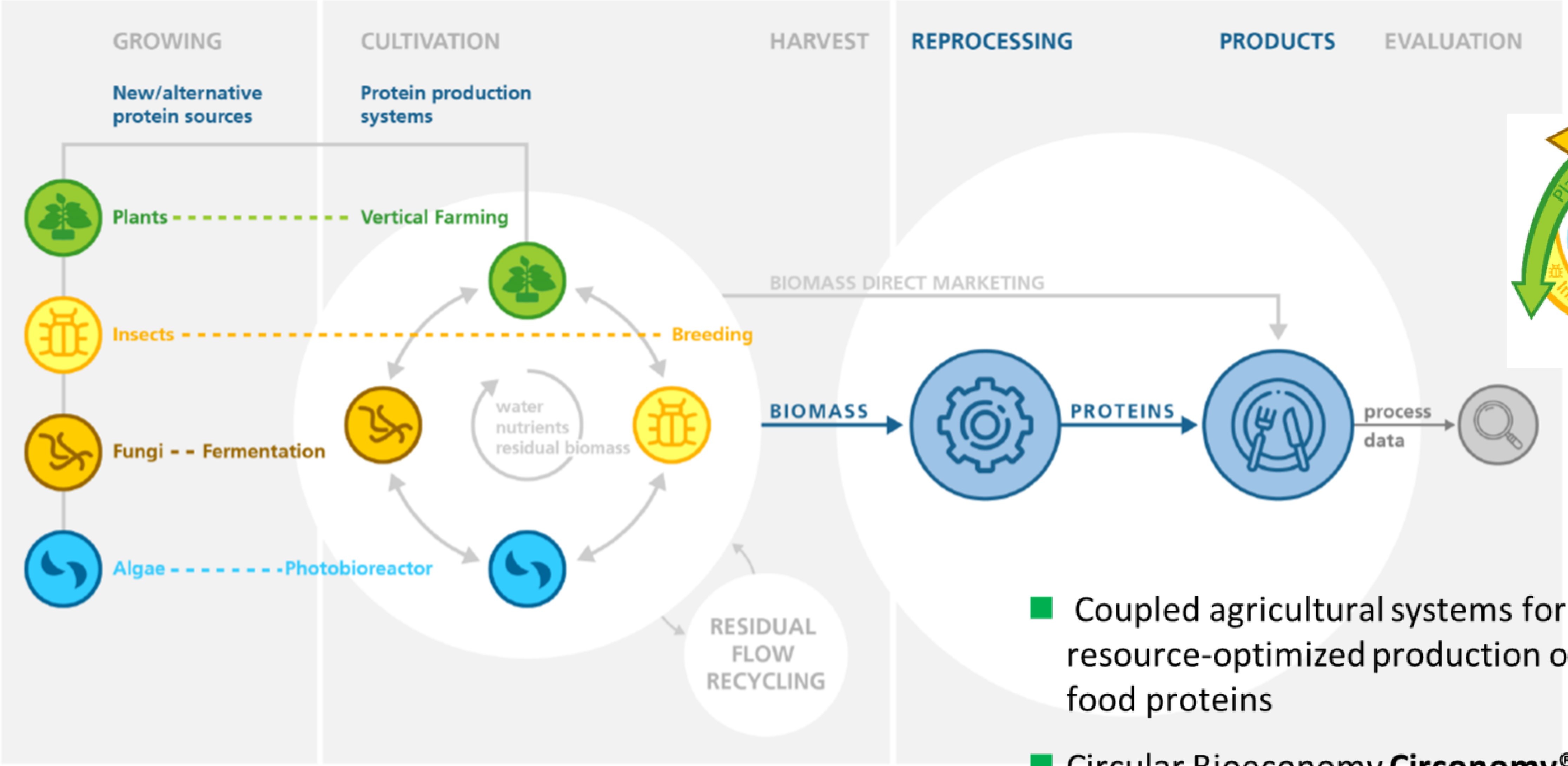
Fraunhofer Lead Project: Future Proteins



- Coupled agricultural systems for resilient and resource-optimized production of high-quality food proteins
- Circular Bioeconomy **Circonomy**®
- Zero Waste

2021-2024, 8 Mio. €

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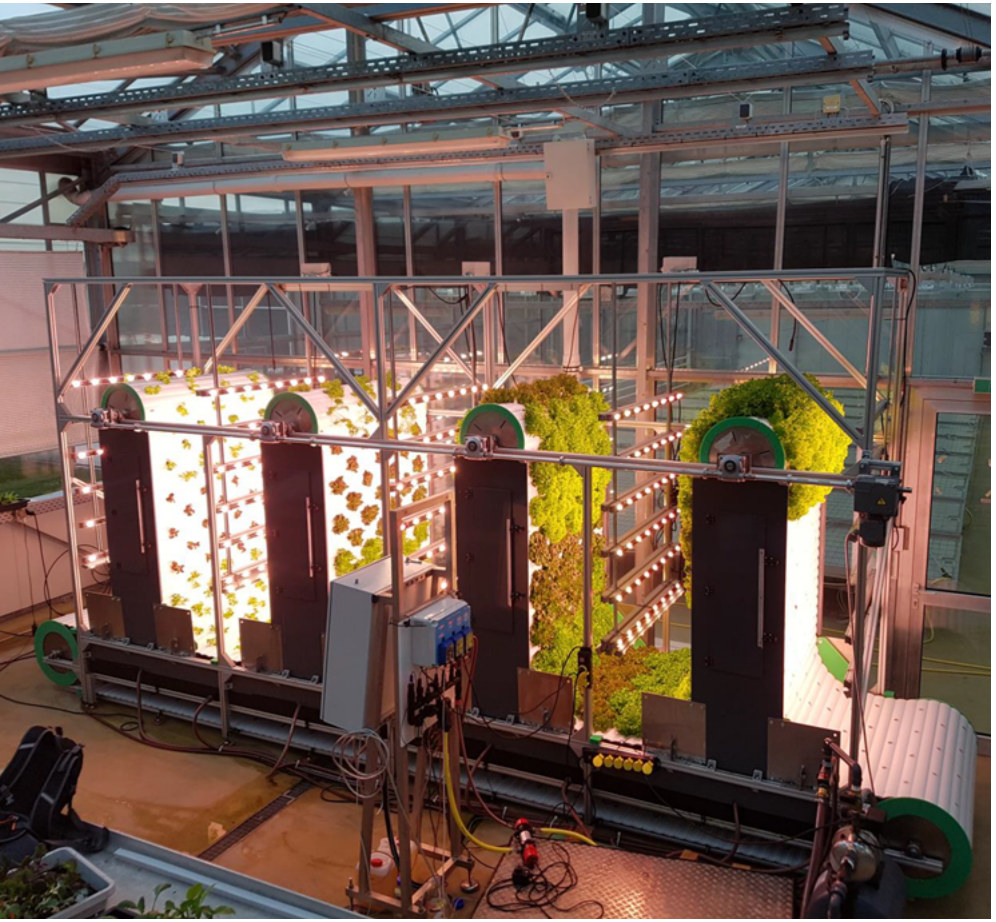
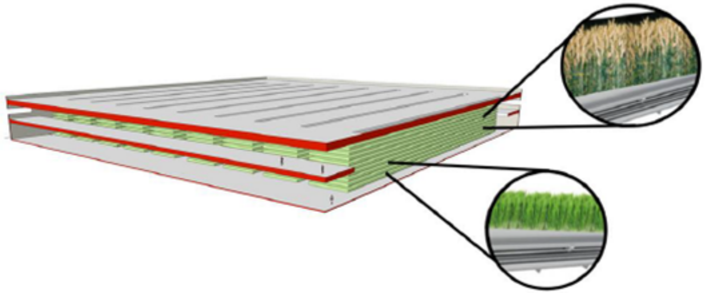
Fraunhofer Lead project: Future Proteins

ORBI PLANT®



- Vertical farming of wheat (Asseng et al. 2020 PNAS)
  - 10 levels
  - 700 ± 20 t/ha
  - 1.940 ± 230 t/ha wheat per year
  - 220-600 more than wheat production in the field



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First food products from *FutureProteins*


Wheatgrass granola


Wheatgrass dessert type panna cotta

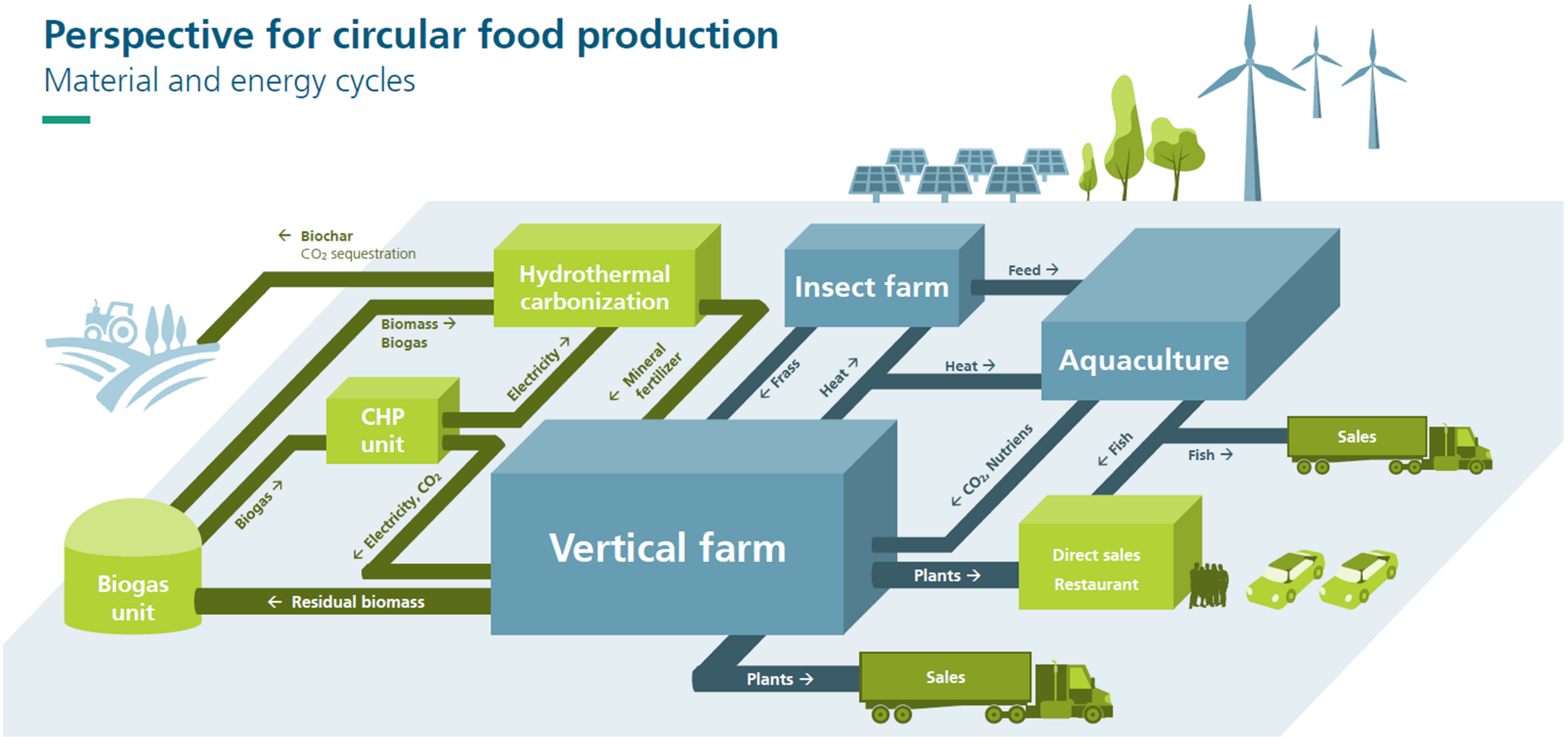

Wheatgrass pesto


Crackers with mealworm flour


Vegan balls:left with pea protein, right with mushroom mycelium


Pasta with algae filling

Fraunhofer Lead project: Future Proteins



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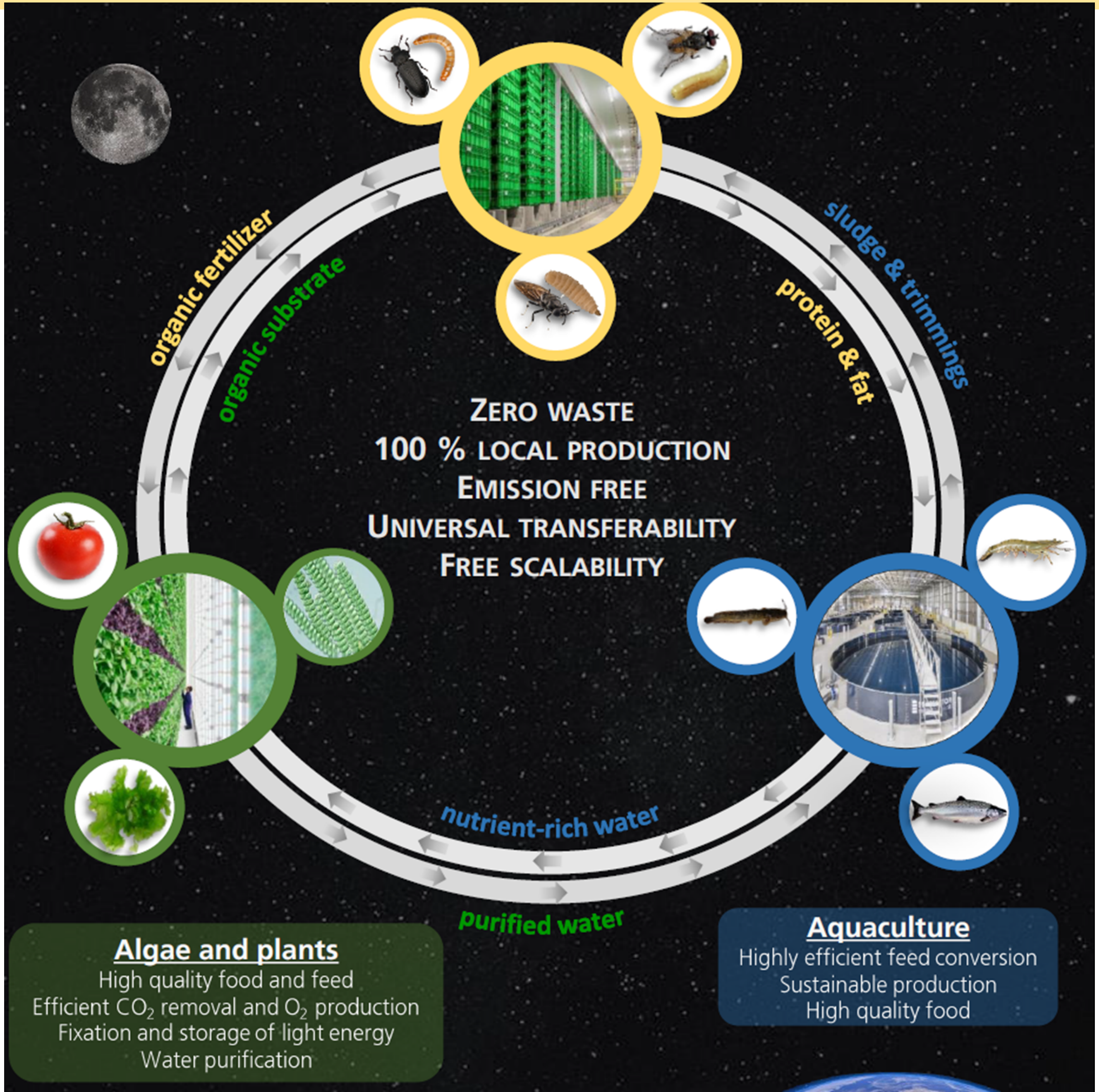
Insect Farming in Controlled Environment Agriculture



JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

First international master program

Core Modules

- Bioprocess Engineering I (6 CP)
- Biostatistics and Experimental Design (6 CP)
- Entomology I (6 CP)
- Entomology II (6 CP)
- Food Technology (6 CP)
- Integrated Pest Management (6 CP)
- Natural Product Discovery Platforms (6 CP)
- Natural Product Chemistry (6 CP)

Profile Modules

- Students tailor their individual profile by selecting 8 modules from the entire profile module catalogue of the faculty. Selection of recommended English modules for this study program:
- Antibiotics: present, past, and future
- Bioinformatics
- Bioprocess Engineering II – Advanced
- Insect Biotechnology
- Insects for food and feed production systems
- Instrumental, biochemical and trace analytical methods in food analysis
- Laboratory Course I
- Laboratory Course II
- Method development in food analysis and food biotechnology
- Milestones of Insect Biotechnology & Bioresources
- Molecular Techniques
- Pharmaceutical Basics
- Selected Chapters of Pharmaceutical & Industrial Biotechnology
- Trends and Advances in Natural Product Research
- Quality Management

https://www.uni-giessen.de/study/courses/master/ibb?set_language=en

LOEWE

Exzellente Forschung für
Hessens Zukunft

ZIB LOEWE Zentrum für
Insektenbiotechnologie
& Bioressourcen

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Thank you for your attention

Fraunhofer