Black soldier fly: prospects and challenges

The 75th EAAP Annual Meeting, 1 September 2024, Florence

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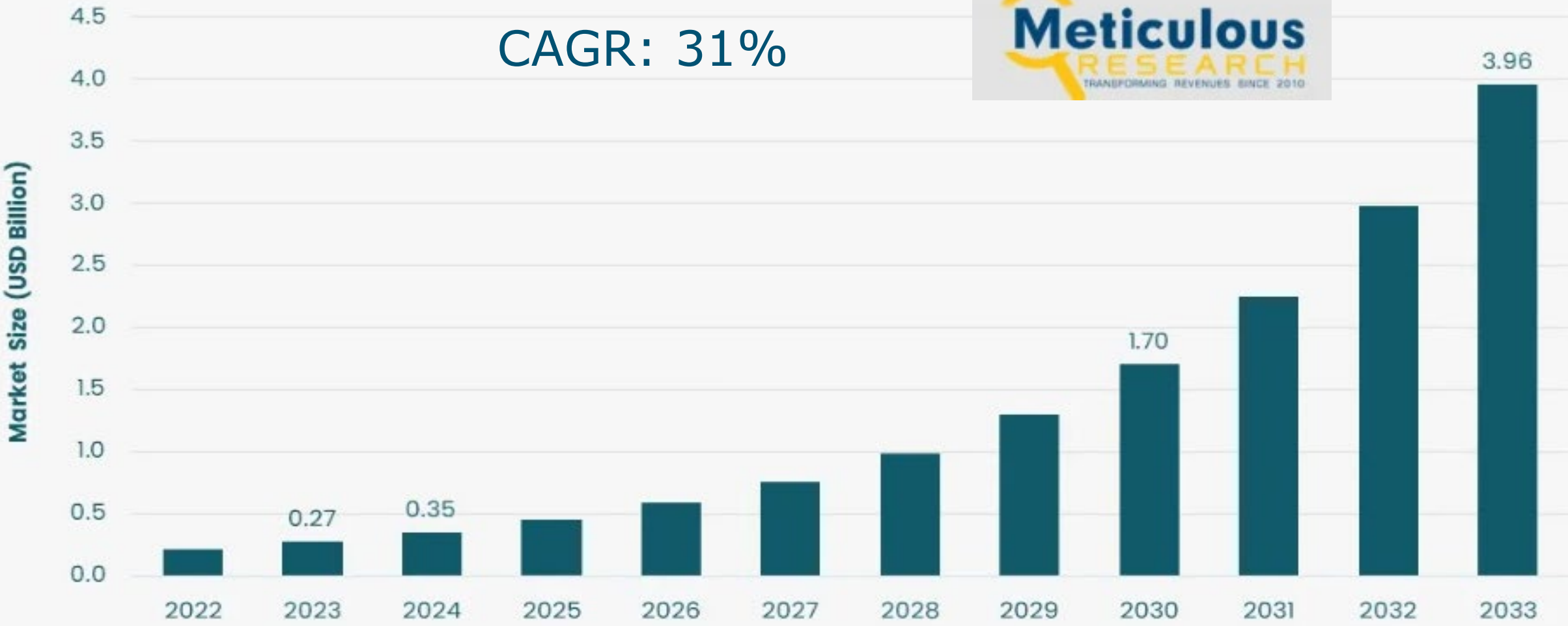
Black soldier fly – History (Tomberlin and van Huis, 2020)

- Neotropical species
- A health risk producing myasis in humans (1940s)
- First publication of potential as feed for livestock: swine (Newton et al., 1977) and poultry (Hale, 1973) from the USA
- 50 years later: most prominent insect for insects as animal feed and for recycling organic waste
- Market value 300 million US$ & 400 tons (2023)
- Compound Annual Growth Rate (2023-2030): 30-45%
- Now cosmopolitan species

BLACK SOLDIER FLY MARKET

Global Opportunity Analysis and Industry Forecast (2024-2033)

CAGR: 31%

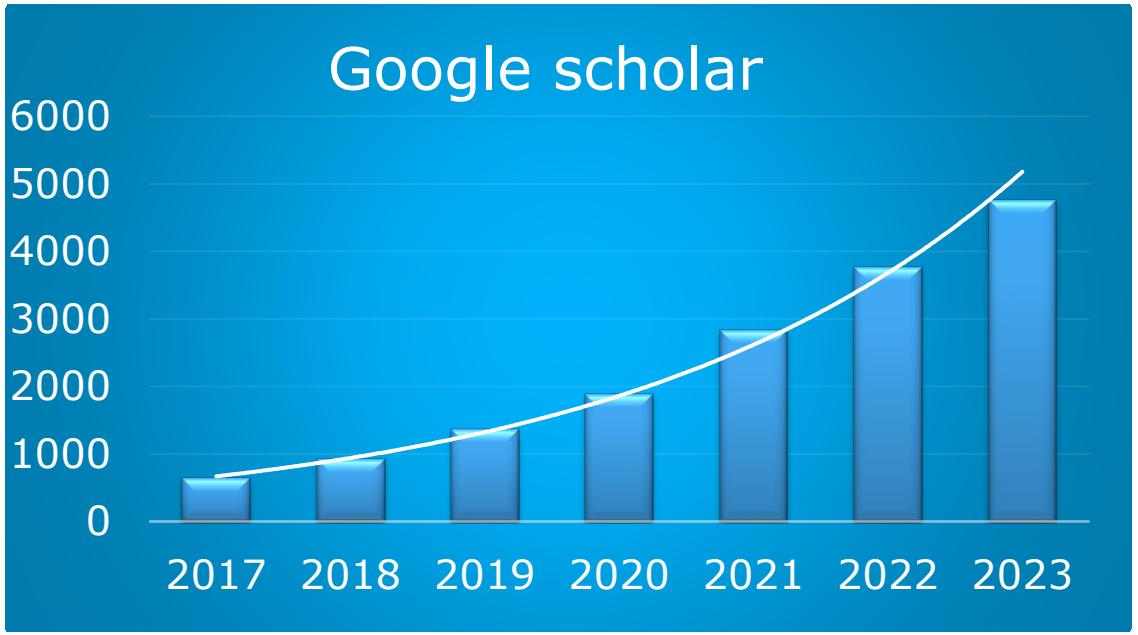


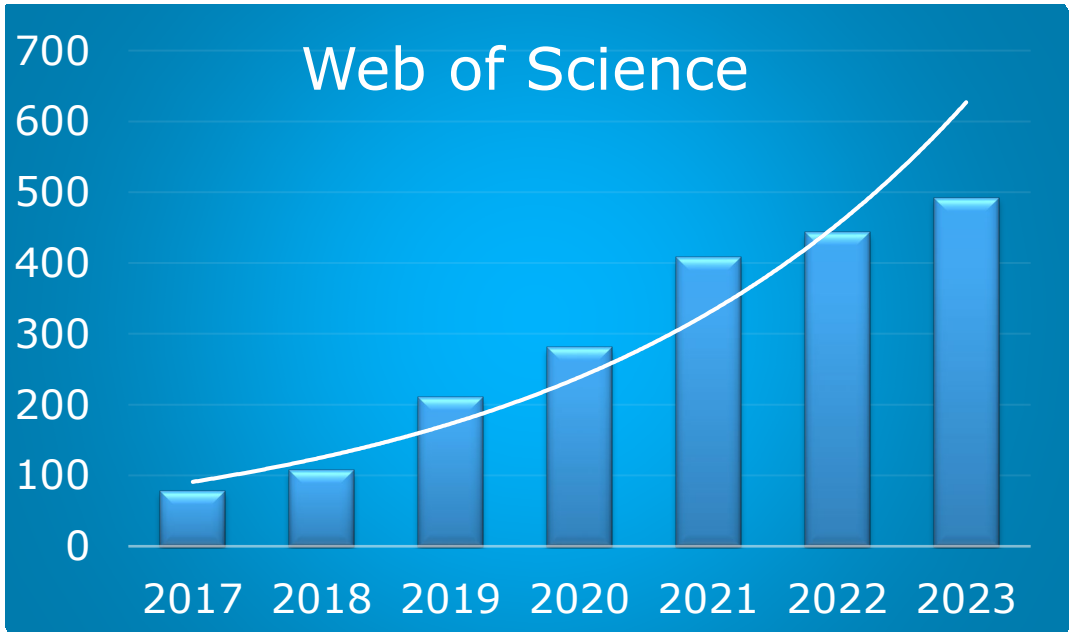
Number of hits using web machines and “Black Soldier Fly”

80% of all publications (2017-2023)

WoS: >40 publications each month)

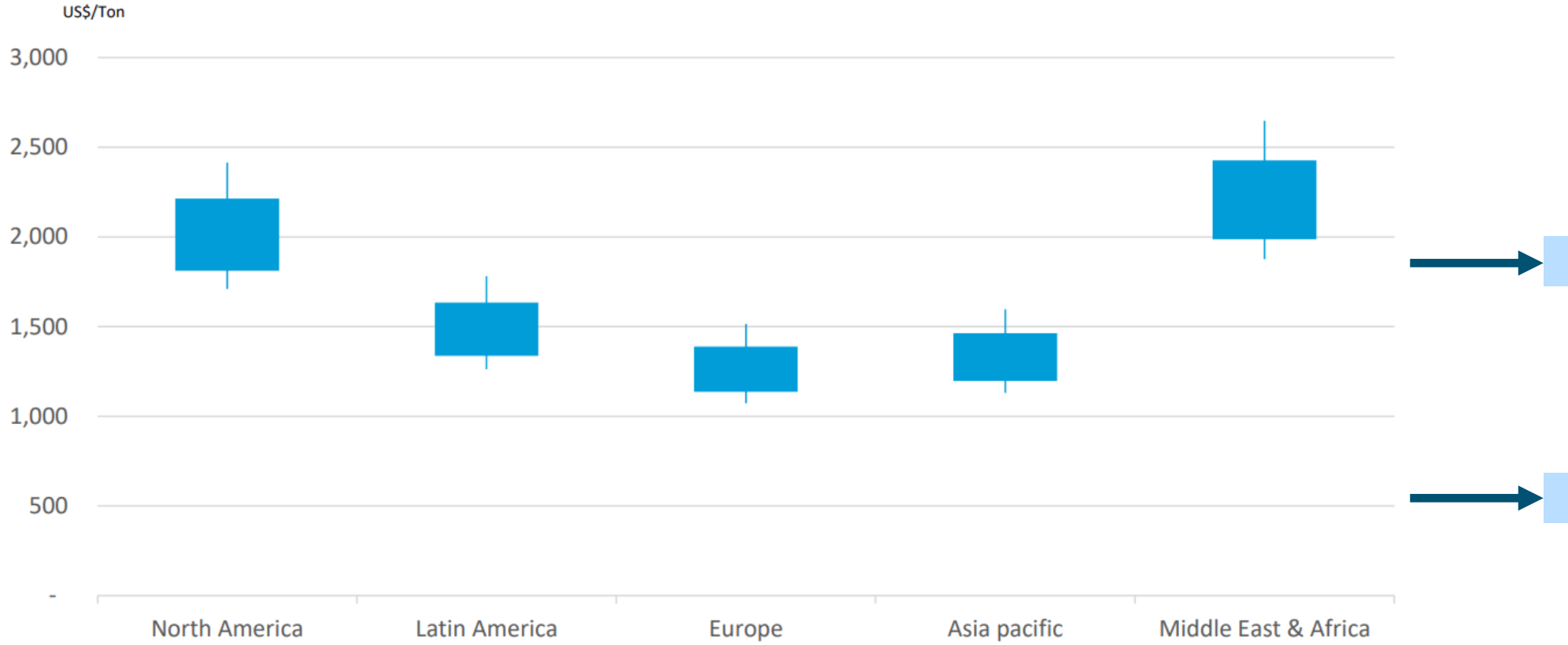
About 55 review articles published up till now





Price Black Soldier Fly (TMR, 2021)

Regional Average Pricing Analysis – Black Soldier Fly



Fishmeal

Soybean meal

**Note: Prices are derived through weighted average method based on quotations from numbers of suppliers, distributors, and manufacturers (pricing varies based on sourcing method, contracts with company, business relationship with company, quantities to be purchased, and payment mode etc.) and also at manufacturer level FoB prices.*

Innovafeed

Nesle industrial site extension

(Hauts-de-France)

> 1 BILLION INVESTMENTS

Top Black Soldier Fly Companies (Oct. 2023)

- Protix B.V. (Netherlands)
- Enterra Feed Corporation (Canada)
- InnovaFeed (France)
- EnviroFlight LLC (U.S.)
- Bioflytech (Spain)
- Entobel Holding PTE. Ltd. (Singapore)
- Entofood (Malaysia)

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VERIFIED MARKET REPORTS

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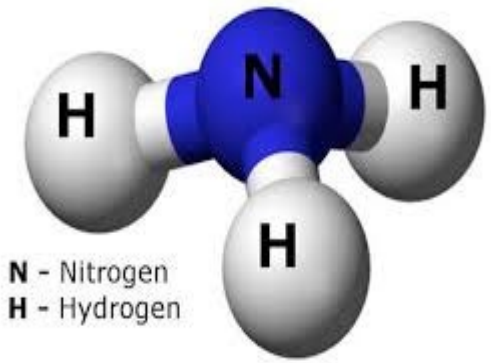
Reducing ammonia emissions by BSF



The livestock sector emits one third of current human-induced N emissions
(Uwizeye et al., 2020)

- 13% of pig manure NH_3-N incorporated into BSFL body mass (Parodi et al., 2022)
- Emissions depend on protein in diet (Coudron et al, 2024)

Mitigation

- Balance C/N ratio; optimize moisture content (Froonincx et al, 2023)
- pH ~ age larvae (Meneguz et al., 2018; Pang et al., 2020), NH_{4+} is volatilized NH_3 (Coudron et al, 2024)
- Add fruit fermentation broth to kitchen waste: inhibits growth of ammonifiers (Li et al, 2023)

microorganisms that reduce nitrate to ammonium
(retention of nitrogen in ecosystems)

BSF and waste

- BSFL can thrive on many types of organic side streams (Surendra et al, 2020); e.g. meat waste (Manyapu et al, 2024)
- Enormous plasticity (Bruno et al, 2024)
    - Substrates low in protein, starch, and lipid exhibited a significant increase in protease, amylase, and lipase activities (gene regulation encoding enzymes)
    - Variations in substrate composition do not affect quality of bioconversion process
- Reduce pollution from leather industry in Indonesia (Rukmana et al, 2024)

Gut microbiota BSF improve performance

1. Protein reduction rate gnotobiotic BSFL 73% greater compared to germ-free counterparts (Yu et al, 2023)
2. Cellulose breakdown (Kariuki et al, 2023)
3. Overall bioconversion efficiency
    1. Substrate (animal/plant-based) impacts make-up microbiota (Auger et al, 2023)
    2. Plasticity microbial community to industrial residual streams (Vandeweyer et al, 2023)
    3. Adding *Bacillus* spp. (*B. cereus* & *B. subtilis*) improves breakdown of organic matter (Shao et al, 2023)

Zhang et al, 2024

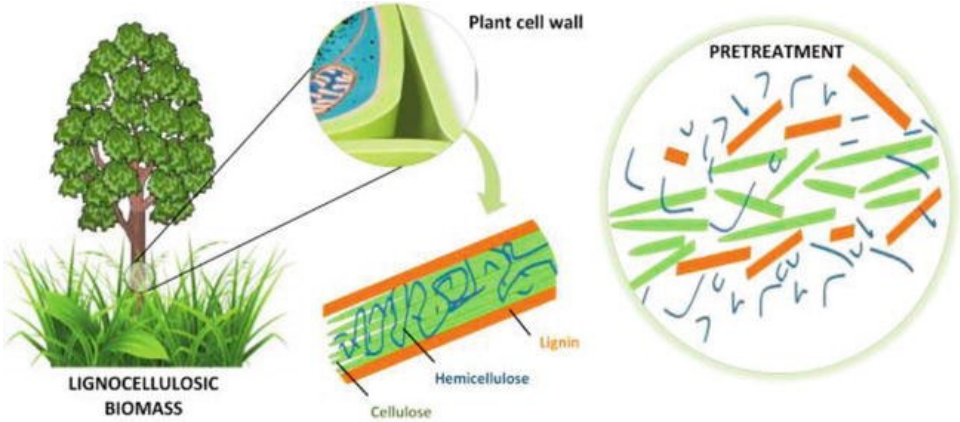
Substrates high in lignocellulose

CAZymes = Carbohydrate-Active enZyme

- BSFL does not have gene-encoding CAZymes (Gold et al, 2018) i.e. cannot secrete lignocellulosic degrading enzymes

But

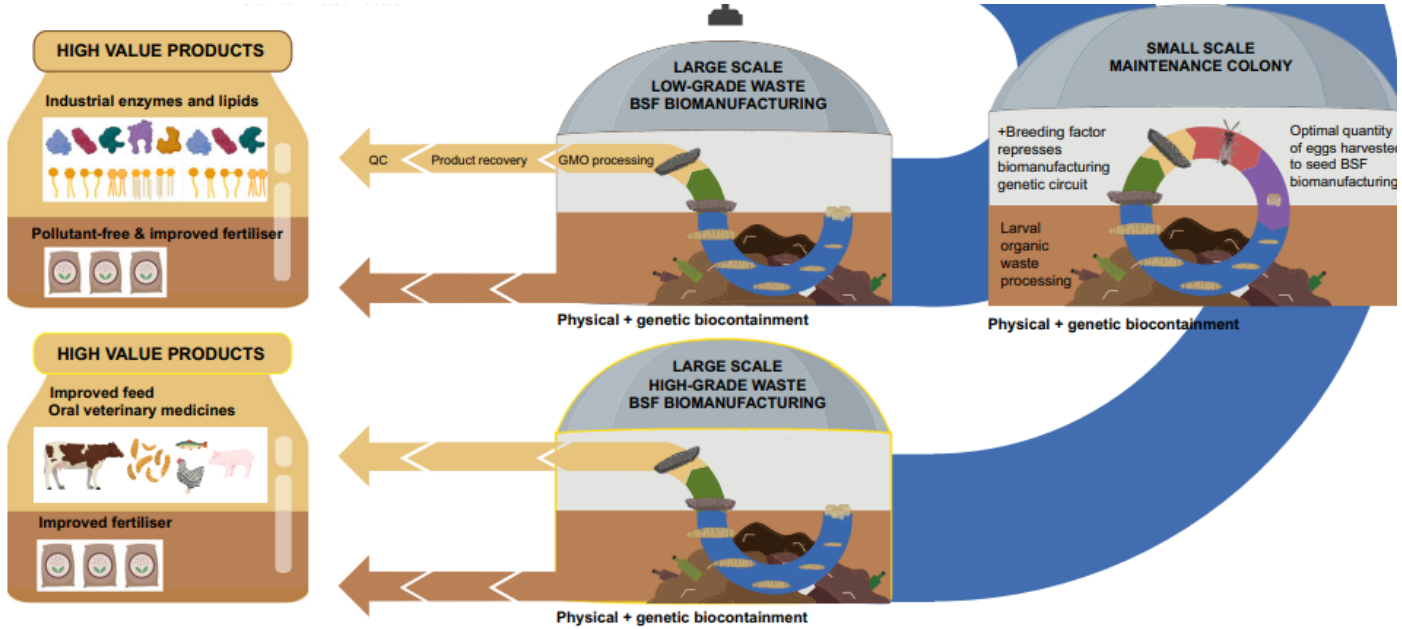
- Degrading bacteria and CAZymes genes in intestines higher than with natural composting (Xiang et al, 2023)
- Metatranscriptomic analysis of gut microbiome of larvae **reared on lignocellulose-rich fiber diets** unveils key lignocellulolytic enzymes (Kariuki et al, 2023)



Engineered BSF (Tepper et al, 2024)

Bio-manufactured BSF to valorize variety of organic waste feedstocks

Enhanced animal feeds and high-value biomolecules (industrial enzymes/lipids & improved fertilizer

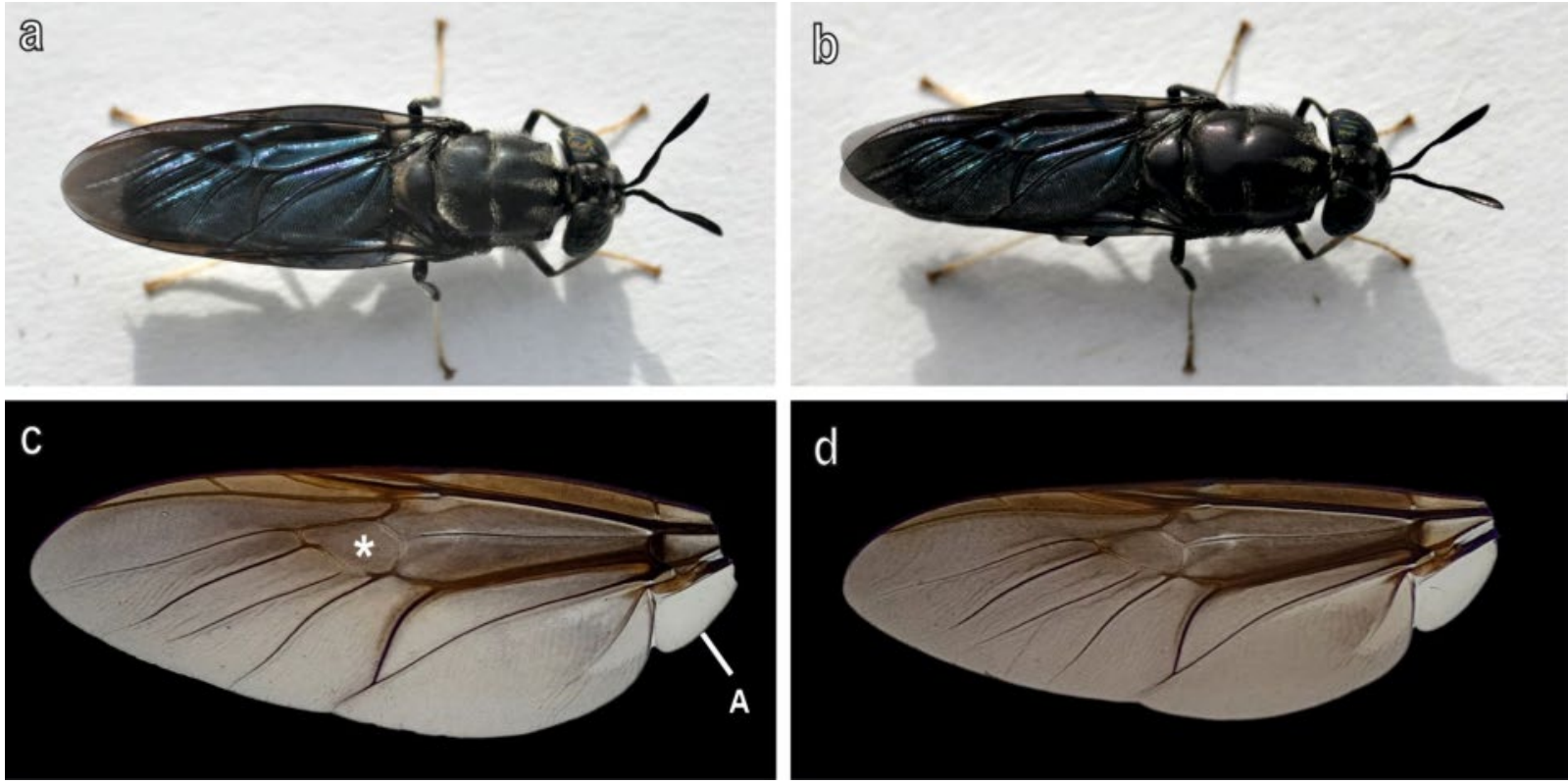


A team of Australian scientists genetically engineering BSF so that it can bioconvert organic waste while producing ingredients for making everything from lubricants and biofuels to high-grade animal feeds (The Guardian, 24 July 2024)

Sexual dimorphism in wings' structural colours (Rebora et al, 2024)

- Wing sexual dimorphism - strong emission of blue light of female wings
- Blue colour induces in males a strong motivation to mate

Improve and optimize breeding techniques BSF



Female Male

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Scientifc Reports (2024) 14:19655

Anti-microbial peptides BSF: Antibacterial, antifungal, antiviral

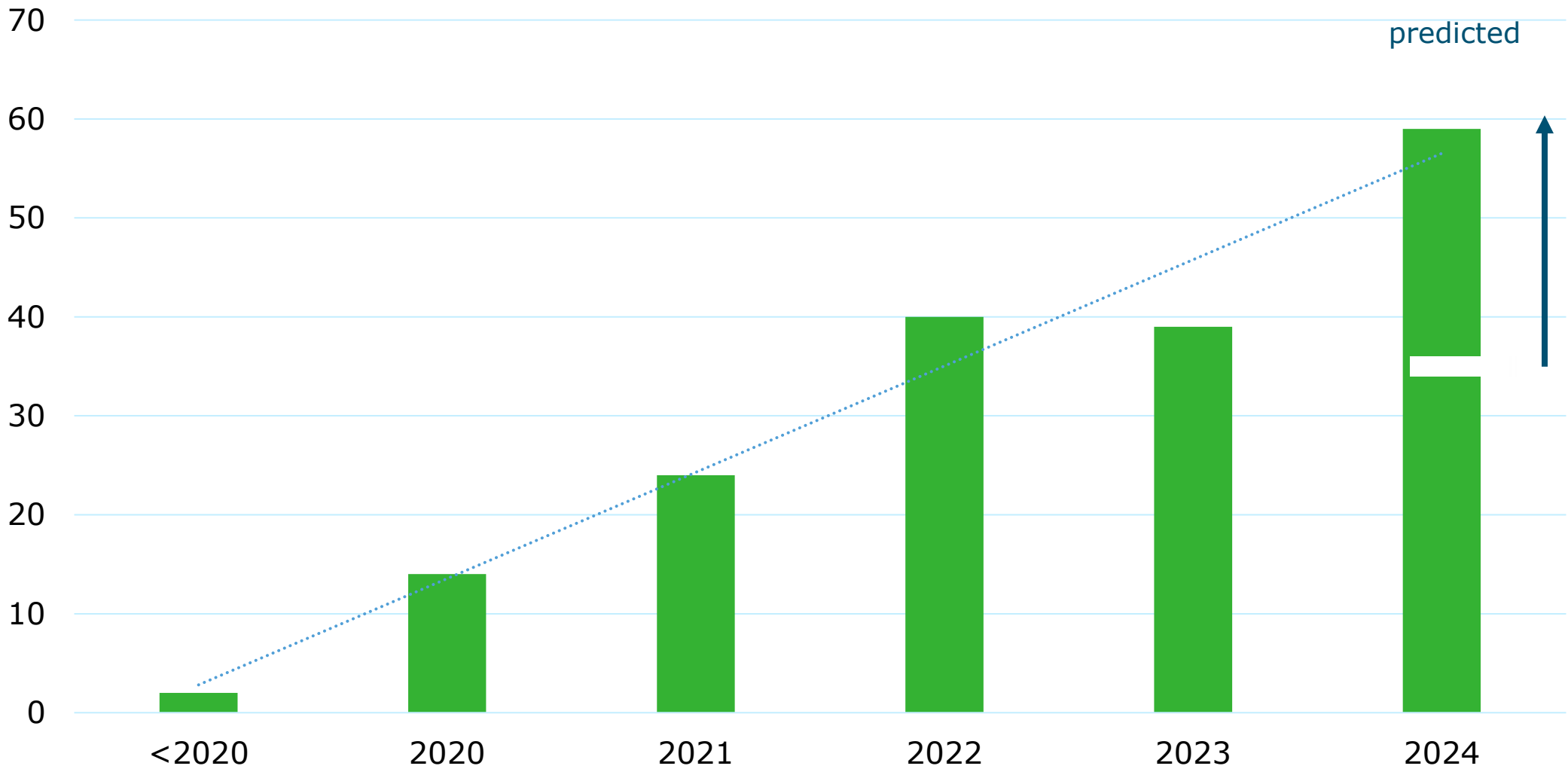
(Hadj Saadoun et al, 2022)

≠57 – highest in insects (Shevchenko et al, 2023)

- **Stimulation** these peptides in larvae: diet (Candian et al, 2023) or thermal (Nakagawa et al, 2023)
- **No drug resistance** among bacteria in livestock (AMPs disrupt microbial membrane) (Wu et al, 2018)
- Therefore, interesting **alternative to antibiotics** in animal diets (Patyra and Kwiatek, 2023; Shevchenko et al, 2023; Xia et al, 2021)
- Cecropin HC1 has potential as **anti- pseudomonal drug** (Wouters et al, 2023)

Number of articles dealing with frass BSF (Web of Science)

Started four years ago



Leftover substrates (frass and exuvia)

(results from last two years)

- Fertilizer – many crops (Abd Manan et al, 2024; Elissen et al, 2023; Hénault-Ethier et al, 2023) such as: tomatoes (Chavez et al, 2023; Ferruzca-Campos et al, 2023); cucumber (Good et al, 2023); kale (González-Lara et al, 2024); lettuce (Chavez et al, 2024); grasses (Rodgers et al, 2024); radish (Nileesha et al, 2024); wheat (Boudabbous et al, 2023)
- Exuviae stimulate beneficial soil microbes (Barragán-Fonseca et al, 2022; Green, 2023; Wantulla et al, 2023) protecting crops (Fusarium tomato) (Arabzadeh et al, 2024)
- Controls cabbage rootfly (Wantulla, 2023)
- Nitrogen-fixation (Chepkorir et al, 2024; Nogalska et al, 2023)
- Reduces drought (frass on basil) (Radzikowska-Kujawsk et al (2023)

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Leftover substrates (frass and exuvia)

Inclusion in diets - immunomodulatory activity and anti-microbial properties

- Channel catfish (Romano et al. 2023; Sankappa et al, 2023; Yıldırım-Aksoy et al, 2023)
- Monogastrics:
  - Pigs (Rubio et al, 2024)
  - Sheep (Fernandez-Mora et al, 2024)

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Environment

Production

Genetics, health, nutrition

Animal feed

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Food safety and legislation

Challenges

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Overview: Conceição da-Silva et al, 2024

BSF as aquafeed

- Replacement (insect/fish species) 10-100% (Alfiko et al, 2023) - Nile Tilapia 75% - Mathai et al, 2024)
- Defatting
  - Rainbow trout (Beleza Oddon et al, 2024; Bartucz et al, 2023, Uslu et al, 2023)
  - Gilthead seabeam (Gai et al, 2023; Karapanagiotidis et al, 2023, Moutinho et al, 2024; Rimoldi et al, 2024)
- Health improvement
  - Chitin controls *Vibrio anguillarum* infection of European seebass - (Rangel et al, 2024) and strengthens immune system of prawns (Reyes-Avalos et al, 2024)
  - Boosts immune system (e.g. Basili et al, 2024; Chu et al, 2024; Linh et al, 2024; Egessa et al, 2024; Moutinho et al, 2024; Nishiguchi et al, 2024; Sayramoğlu et al., 2024; Xiao et al, 2024; Yao et al, 2024; Zhang et al, 2024)

A 'silver bullet' for shrimp disease? Indian startup (Ultra Nutri) claims novel feed breakthrough (saving one billion US$ a year) 12 August 2024

BSF as feed for monogastrics

- High potential of defatting (Geofrey et al, 2024)
- Substituting (up to 10%) FM possible, but limiting AA identified (lysine and methionine) (Geofrey et al, 2024)
- Health
  - Poultry: welfare (Ahmed et al, 2023; Dörper et al, 2024)
  - Pigs: less diarrhea (lauric acid); better immune response; welfare (less tail biting (Veldkamp et al, 2021)
  - Pets: alleviate i.a. diarrhea (Wei et al, 2024)
- Price too high (Gasco et al, 2023)

BSF as feed for ruminants

- Limited interest (BSE); legislation more restrictive for proteins than oils (Renna et al, 2023)
- Improve digestion (defatted) (Carrasco and Drewery, 2024)
- Encapsulation to enhance stability and functionality of bioactive substances (Muslykhah et al, 2024)
- Chitosan/chitin - positive impact on production performance, feed digestibility, rumen fermentation, and bacterial population in ruminants (Shah et al, 2023)

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Fermentation (desirable change in organic compounds)

(Van Campenhout, 2021)

- Fermenting substrate prior to feeding
  - Prevent spoilage -microorganism impeded at low pH
  - Improve digestibility (Wong et al, 2021, Lindberg et al, 2022, Niero et al, 2022)
  - Increase protein/lipid content (Gao et al, 2019; Wong et al, 2020)
- Pre-treatments: potassium sorbate, biochar, and lactic acid fermentation (Heussler et al, 2022; Taghikhani et al., 2023); enzymes (Meng et al, 2023)
- Thermal pre-treated sewage sludge > lipid > biodiesel (Liew et al, 2023)

catering waste: crushing, heating and fermentation (Ornela et al, 2024)

Industrial applications (van Huis, 2022; Tettamanti and Bruno, 2024)

- Biodiesel/fuel from lipids (Jung et al, 2022; Mohan et al , 2022; Park et al, 2022)
- Cosmetics: skincare products from purified fat to improve skin conditions such as smoothing, revitalizing, moisturizing, antiaging, and tightening (Franco et al, 2022; Khyade et al, 2023)
- AMP: products for skin health
- Surfactants from fat (Verheyen et al, 2020)
- Bioplastics from protein (Barbi et al, 2019; Qoirinisa et al, 2022)
- Others:
  - Biomedical (chitosan-based hydrogel - Binti Padli, 2014)
  - Melanin for organic electrodes (Al-Shamery et al, 2024)
  - Packaging: Nanochitin (Falgayrac et al, 2024)

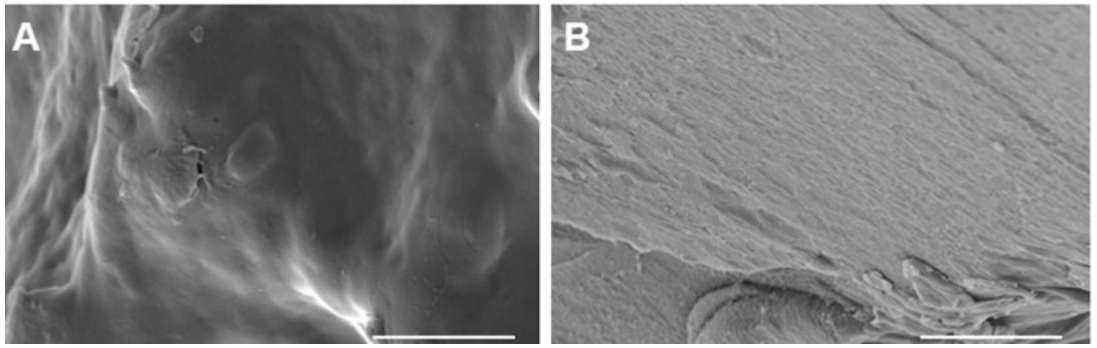
Insect oil skincare Oricga™ Entovegan

Plastics shape BSF gut microbiome (De Filippis et al, 2023)

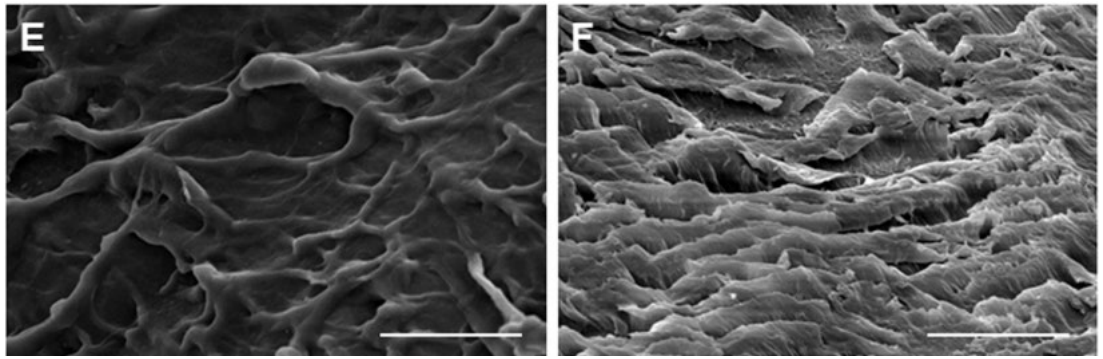
- Plastics shaped bacterial composition at species and strain level
- Functions that trigger degradation of polymer chains (DyP-type peroxidases, multicopper oxidases, and alkane monooxygenases)

Isolate microbial strains and enzymes for the development of innovative plastic biodegradation strategies

Polyethylene Polystyrene



Before rearing



After rearing

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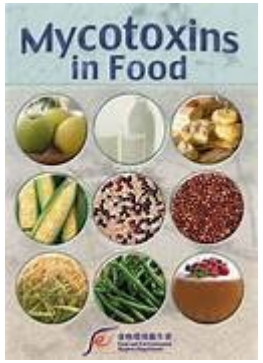
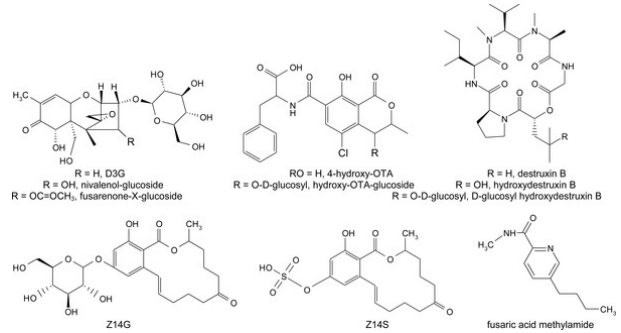
Chemical contaminants





- Heavy metals: Cd (but also Cu, As, Pb) (Siddiqui et al,2023)
- Mycotoxins and PAHs (Polycyclic Aromatic Hydrocarbons) not accumulated; mycotoxins degraded (Alagappan et al, 2022; Niermans, 2024)
- Pesticides: legal concentrations caused reductions in yield (deltamethrin most toxic) (Meijer et al, 2023)
- Pharmaceuticals: Degraded tetracycline (Pei et al, 2023); cipro-floxacin (Yang et al, 2023); lincomycin (Luo et al, 2022); oxytetra-cycline (Liu et al, 2022), and others but not completely (Van Dongen et al, 2024); larval growth affected (Zhang et al, 2022)

Symbiotic microbes help in detoxification
(Shi et al, 2022; Zhao et al, 2022)

Biological contaminants BSF

- Core gut microbiota: *Actinomyces* sp., *Dysgonomonas* sp., *Enterococcus* sp. and *Morganella* sp. aid in degradation of organic substances (Vandeweyer et al, 2021)
- Gut microbiota inhibit proliferation of potentially pathogenic microorganisms (Achuoth et al, 2024; Azmiera et al, 2023; Shi et al, 2024; Van Moll et al, 2022)
- Food pathogen *Salmonella aureus* seems to pose limited risks, but should be further explored (De Smet, 2023); fungus *Trichosporon* reduced *S. aureus* in gut (Gorrens, 2023)

Spalangia cameroni Perkins

Spalangia obscura Bouček

Parasitoid species BSF

(Rojo, 2024)

Nanoplastics can move up food chain from plants to insects and from insects to fish (Monikh et al, 2022)

- Nanoplastics in soil: atmospheric deposition, irrigation with wastewater, application of sewage sludge for agricultural purposes, and use of mulching film
- Experiment: 1) Lettuce exposed to nanoplastics (14 days) via contaminated soil; 2) Lettuce fed to BSFL; 3) BSFL fed to insectivorous fish (roach)
- In fish, particles were detected in gills, liver and intestine tissues of fish (not in brain)

University of Eastern Finland: lettuce take up nanoplastics from soil and transfer them into the food chain

77% of humans have microplastics in body

https://www.uef.fi (12 sept. 2022)

EU legislation insects in feed (IPIFF, 2022)

Feed stocks	Regulatory approval
Vegetal substrates	☑
Former food stuff: vegetal, dairy[1] & eggs[1]	☑
Former food stuff: meat & fish	☒
Catering waste & slaughterhouse products	☒
Animal manure	☒

According to IPIFF members the most commonly used insect species in animal feed are the black soldier fly, the yellow mealworm and the common housefly larvae

Target species	Protein	Fat	Live larvae	Whole insects (dried or frozen, not milled)
Pets	☑	☑	☑	☑
Fish	☑	☑	☑	☒
Poultry	☑	☑	☑	☒
Swine	☑	☑	☑	☒

2017

2021

Contents

Conclusion and challenges

Conclusions

- Offer sustainable solutions to protein production and waste management

Challenges

- Transform waste into all kinds of valuable resources (not only **feed)**
- BSF as food?
- Improve regulatory frameworks and scalability
- Invest in strategic innovations (degradation; health)
- Collaboration promotes innovation, attracts talent (human capital) and devise solutions for challenges of tomorrow

BSF: a bright future !!!

THANK YOU
FOR YOUR
ATTENTION

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