Best practice: Radio frequency drying of mealworms and BSF larvae

Overview	
Short summary	Radio frequency (RF) drying is a dielectrical drying technology to stabilise products for further applications and preservation. The application of RF drying on mealworms and black soldier fly (BSF) larvae results in high quality and stable dried insect products. RF drying also has a slight decontaminating effect on microorganisms present in/on the insects. Compared to conventional drying technologies such as oven and freeze drying, RF drying has a similar impact on nutritional and physicochemical quality, while requiring shorter drying times and consuming lower amounts of energy. Furthermore, it has the advantage of being able to process large volumes of insects.
Related key barrier(s)	Specific insect processing technologies are required to produce a wide variety of intermediate and end products. Since many processing technologies have specific outcomes related to product quality and potential for further application, additional processing technologies specifically applied on insects are required in the insect sector. There is a need to investigate the effect of novel technologies such as RF drying for insect matrices.
Relevant for insect species	Black Soldier Fly (*Hermetia illucens*) Yellow mealworm (*Tenebrio molitor*)
Relevant for which supply chain stage	Insect storage & processing Use of insects in feed Use of insects in food
Level of best practice	Company Insect sector as a whole (in a country) Insect sector as a whole (EU)
Other information	

Detailed description	
Detailed description of best practice	The aim of a drying technology is to reduce the water activity of a product to a value that reduces or impedes deterioration of the product quality by microbiological, chemical or enzymatic processes. As such, when drying insects using RF drying, a stable water activity of 0.60 (corresponding with complete microbiological stability) was aimed for. To obtain this water activity value, processing parameters during drying have to be optimised depending on the insect species, volume to dry and RF installation. In order to reach the most optimal processing conditions for RF drying, a large scale continuous RF dryer (with a conveyor belt) is advised. Using a large-scale RF dryer comparable to the RF insect dryer used for the experiments in the framework of the SUSINCHAIN project (DI30, Dymotec, Belgium, see Annex 1) following process parameters can be employed to obtain good quality dried mealworms and BSF larvae. Here, a mass of ± 11 kg blanched BSF larvae and ± 25 kg blanched mealworms was used as starting material. • RF power should be adapted to the mass of insects to be dried. By operating an automatic RF installation, the power can be adjusted to the required value for optimal drying. Here, automatic power was provided between 6 and 9 kW to dry BSF larvae and between 2.2 and 9 kW to dry mealworms. • A higher layer thickness was observed to provide more uniform and homogeneously dried insects. A layer thickness of 45 mm for BSF larvae and of 85 mm for mealworms was applied.

- No maximum temperature was set in this RF drying system. As such, temperatures could rise up to 130 °C during drying (as measured by fiber optic sensors), although very shortly. A long exposure to high temperatures may cause the insects to be overprocessed or even burnt. On the other hand, a very short but high temperature may assist in decontamination of the insects and can especially impact bacterial endospores (see below).
- Apply a drying time of 90 minutes for BSF larvae and 123 minutes for mealworms. Drying time may vary depending on the initial moisture content of the insects. An end moisture content of max. 8% should be aimed for to correspond with a stable water activity.
- Assist the RF drying with a hot air module and fans to allow for an increased drying speed (removal of moist air) and a more efficient drying process. By using a perforated conveyor belt, moisture can be removed via two sides, also improving the drying process.

Further, it is advised to include a decontamination step as pretreatment, e.g. blanching, in order to improve the initial microbiological quality of the insects. As demonstrated in the best practise sheet "Low electron energy beam of dried mealworms and black soldier fly larvae", a decontamination step after drying is possible as well.

The application of RF drying was compared to oven and freeze drying as benchmark technologies. It can be stated that, for a not yet completely optimised RF process (i.e. in a research context), that the RF drying did not result in losses in terms of nutritional quality (protein, fat, ash and chitin content and amino acid, fatty acid and mineral profile) compared to the other drying technologies. The only difference in nutritional quality was observed for vitamin B_{12} content in dried BSF larvae, which was lower for RF-dried insects compared to oven- and freeze-dried insects (see Annex 2). This is most probably related to the higher processing temperature (up to 130 °C) for RF drying, compared to oven drying (60 °C) and freeze drying (- 55 °C). On the other hand, RF drying had an additional decontaminating effect on mealworms in terms of microbiological quality compared to the benchmark drying methods (see Annex 3). Reductions in total viable counts and bacterial endospore counts were observed. In combination with a decontaminating pre-treatment, this may, in some cases, improve the microbiological safety of the product.

After drying, RF-dried BSF larvae and mealworms were subjected to shelf life tests in order to monitor chemical (lipid oxidation) and microbiological stability. Since the water activity remained stable, no microbiological changes were observed, but lipid oxidation could continue (see Annex 4). Especially primary oxidation (peroxide value) was observed for the dried BSF larvae and according to international threshold limits (Ismail et al., 2016), RF-dried BSF larvae can be given a shelf life of approximately 3 months. For RF-dried mealworms, following the limited shelf life period that was tested, a shelf life of 3 months can be guaranteed as well.

Finally, three major advantages of the RF technology are the short drying times (minutes to a few hours) and the low relative energy consumption required to dry insects and the large capacity to dry products (high layer thickness). Depending on the desired end quality or application, RF drying may therefore be a valuable technology for insect stabilisation.

Targets for (intermediate) products and/or process outcomes

A target water activity of 0.60 should be aimed for. This corresponds, in general, with a moisture content below 8%.

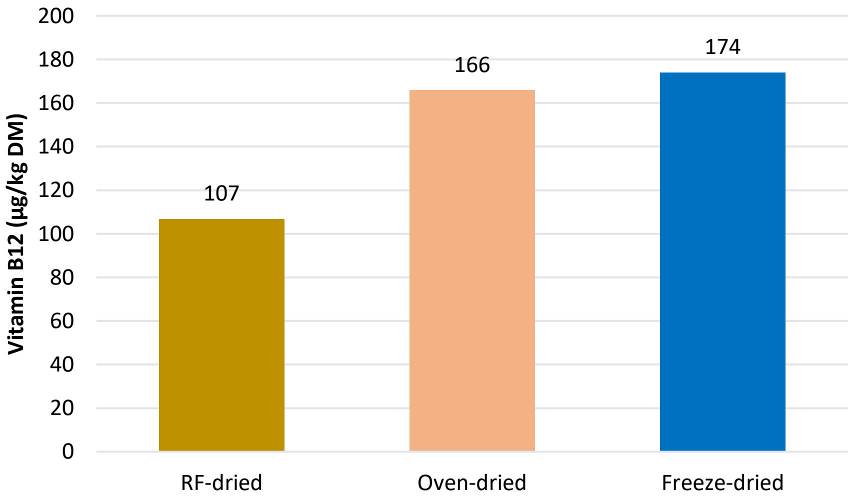
When integrating a drying process in an insect production chain, it is advised to incorporate an efficient flow. For example, after rearing, insects should be killed, decontaminated, processed and stored or transported as quickly as possible. By

	aligning the different processing steps to avoid unnecessary storage and waiting times, process efficiency can be improved. For example, by applying a drying step immediately after blanching (as killing and decontamination step), no thermal energy is wasted.
Risks involved	Improper drying may result in a water activity that is too high after processing. This may allow microbiological spoilage or increased lipid oxidation during further storage of the product. During preservation of the dried insects, attention should be paid to the storage conditions (packaging, temperature, humidity), in order to retain the stable conditions and to prevent the products to take up water again, thus increasing the water activity.
Legislation involved (if any)	As in all cases, end products should comply with national and EU legislation regarding food safety. Additionally, animal welfare should be taken into account, e.g. by not subjecting living larvae to RF drying.
To be avoided / worst practices	It should be avoided to dry living insects. Not only does this provoke ethical questions, the movement of insects may cause arcing (electrical discharge) which may damage the equipment or create hotspots of burnt material.

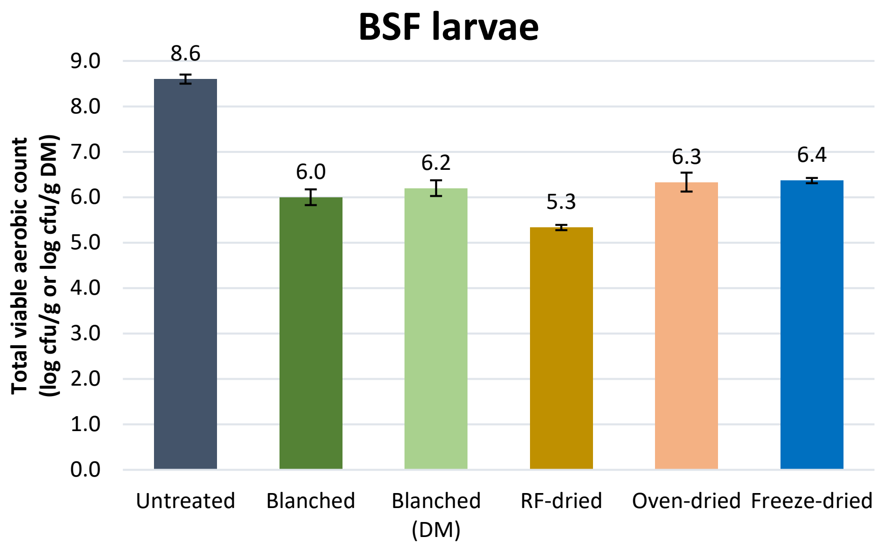
Further reading and sources	
Further reading	Deliverable 3.4, Deliverable 6.3, Milestone 3.1
[Future research needs (if any)]	Further research on the impact of RF drying on the quality and stability of insects (including other species) is advised. Of particular interest is the monitoring of a relevant large-scale industrial protocol implemented in a real insect processing facility. Furthermore, longer shelf life experiments, including additional preservation technologies should be investigated.
Prepared by (name and WP)	Dries Vandeweyer, KU Leuven (WP 3). Conceptualisation of best practice sheets, coordination and editing process: Civic Consulting (WP1), Frank Alleweldt
Sources	Ismail, A., Bannenberg, G., Rice, H. B., Schutt, E., MacKay, D. (2016). Oxidation in EPA- and DHA-rich oils: an overview. *Lipid Technology*, 28(3-4), 55-59. https://doi.org/10.1002/lite.201600013

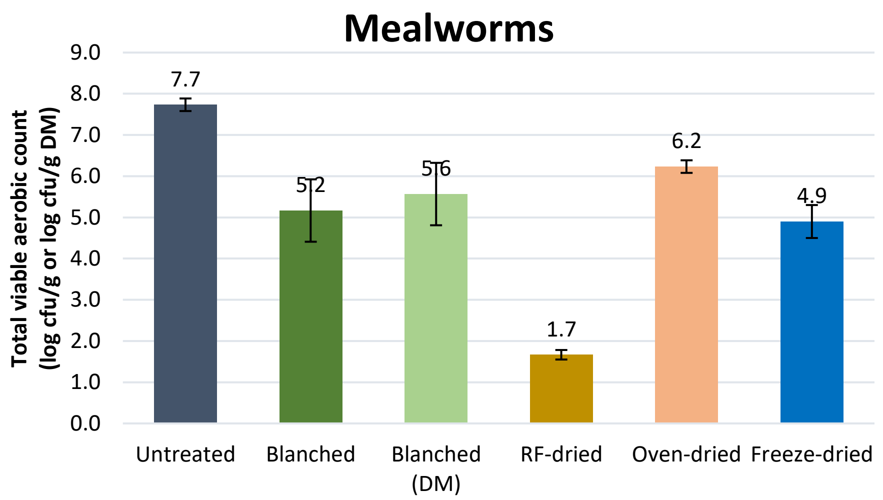
Technical annex	
Annex 1	DI30 RF Insect dryer (Dymotec, Belgium)

Annex 2 Vitamin B_{12} content of dried BSF larvae. Results were obtained from one replicate (n=1).

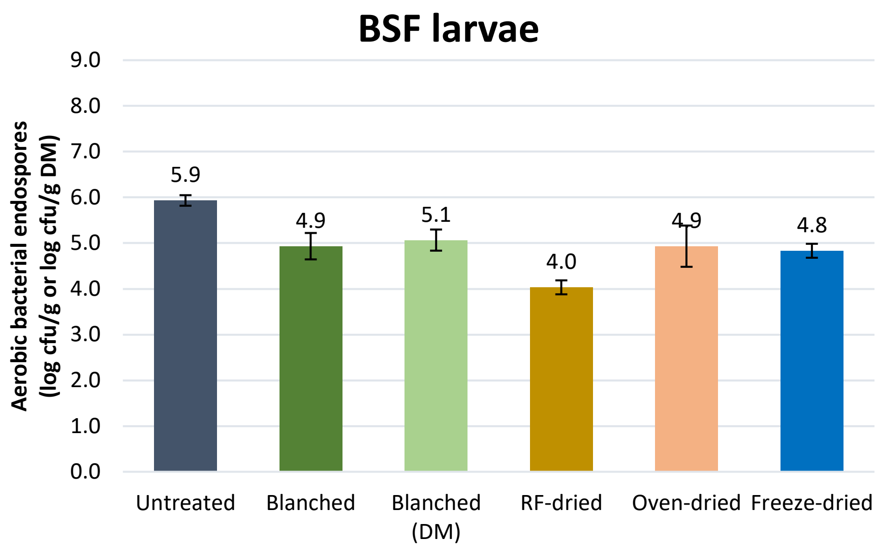


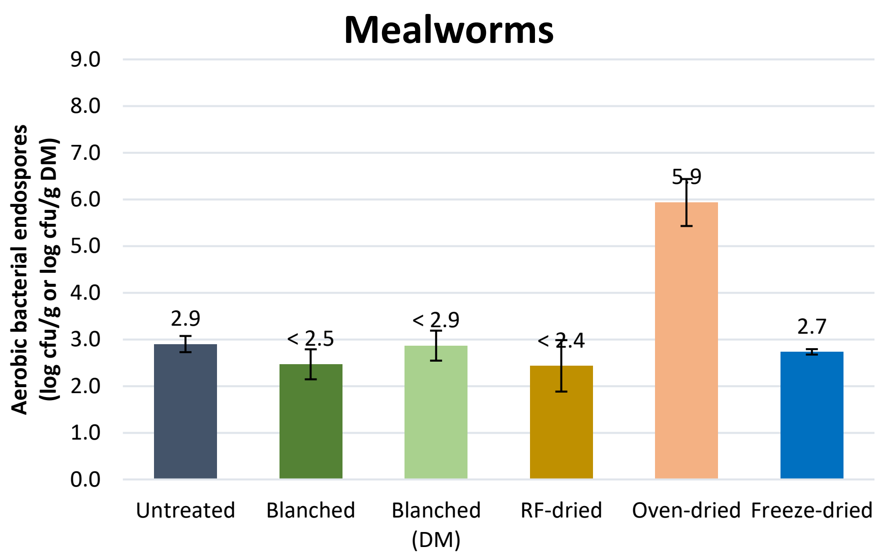
Annex 3 (1) Total viable aerobic counts (TVC) of BSF larvae and mealworms before and after drying with different drying technologies. Results are mean values (n=3) ± standard deviations and expressed as log cfu/g for untreated and blanched BSF larvae and as log cfu/g dry matter (DM) for dried larvae. Blanched (DM) represents a TVC of blanched BSF larvae expressed as log cfu/g DM for proper comparison with dried larvae.



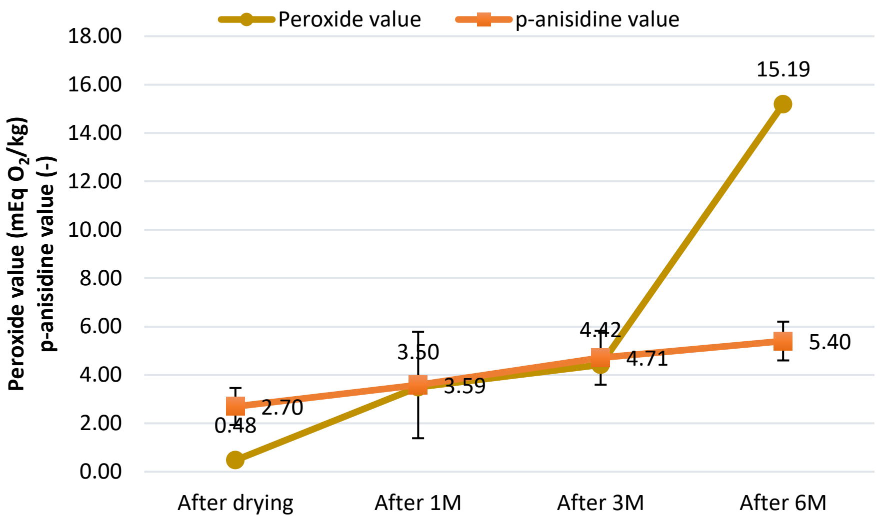


(2) Aerobic bacterial endospore counts (AES) of mealworms before and after drying with different drying technologies. Results are mean values (n=3) ± standard deviations and expressed as log cfu/g for untreated and blanched BSF larvae and as log cfu/g dry matter (DM) for dried larvae. Blanched (DM) represents a TVC of blanched BSF larvae expressed as log cfu/g DM for proper comparison with dried larvae.





Annex 4	Lipid oxidation of RF-dried BSF larvae during 6 months of storage. Primary oxidation is shown as peroxide value (gold graph), secondary oxidation as *p*-anisidine value (orange graph). Results are mean values (n=3) ± standard deviations.



Peroxide value
p-anisidine value
Peroxide value (mEq O_2/kg)
p-anisidine value (-)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
15.19
4.42
3.50
3.59
4.71
5.40
2.70
0.48
After drying
After 1M
After 3M
After 6M