Norwegian Centre for Organic Agriculture

Fish waste as fertiliser

Effect of drying methods on fish waste and supplementing fish waste with other residual raw materials to form an organic fertiliser

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TITLE

Fish waste as fertiliser - effect of drying methods on fish waste and supplementing fish waste with other residual raw materials to form an organic fertiliser

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SUMMARY:

In organic farming systems, soil-plant systems fertility is sustained by recycling of nutrients through the addition of organic inputs and nitrogen fixation by clover and other legumes. Several of the nutrients in fertilisers are limited resources. Thus, it is crucial to recycle nutrients from various value chains so that in the future also one can produce fertilisers that ensure good plant crops in both conventional and organic agricultural production.

The fishing industry produces large amounts of fish waste. In 2018 in Norway, about 40% of fish waste was not utilised, which is a substantial amount. Fish waste such as fish backbones and bones-rich heads constitute an important source of phosphorus and calcium. We applied fish waste (fish sediments, conserved with formic acid) that originates from the white fish industry in our field experiments with ryegrass, oats, and leek. Fish sediments showed a quick and good effect on the growth of plants. However, to apply as a fertiliser, the fish sediments need to be dried to remove moisture, reduce odour and deterioration rate. The drying method/drying temperature can affect the pH, total nitrogen, and ammonium nitrogen concentrations.

In this project, we investigated how the fish waste (fish sediments and minced fish backs) are affected by the drying in a cabinet, adjusted to temperatures 25°C, 40°C, and 80°C with and without air-circulation, and by drying in a freeze dryer and a microwave oven. We studied how different drying temperatures affect the sample weight over time and which method was most effective. Additionally, we also investigated how different methods of drying can affect the pH and the concentrations of total nitrogen and ammonium nitrogen in fish sediments and minced fish backs.

Altogether, cabinet drying with air-circulation was found to be more effective as compared to drying without air-circulation for both fish sediments and minced fish backs, particularly in terms of reduction of moisture/weight reduction over time and also the appearance of the material. The dried samples of fish sediments showed slightly higher pH values (4.8 – 5.3) compared to wet fish sediments (pH 4.5). Contrary, the dried samples of minced fish backs showed equal or slightly lower pH values (6.7 – 7.1) compared to wet minced fish backs (pH 7.1 or pH 7.5). The drying temperature and the drying with- and without air-circulation also affected the concentrations of total nitrogen and ammonium nitrogen. The samples of fish sediments dried at 25°C with air-circulation showed the lowest concentrations of total nitrogen and ammonium nitrogen. The samples of minced fish backs dried at different temperatures with- or without air-circulation showed minor differences for the concentrations of total nitrogen. Though, for ammonium nitrogen, some variations were observed among samples, where microwave oven-dried samples showed the greatest concentration.

Algae fibre, bottom ash, and crab shells are residual raw materials (RRMs) that are/can become available in Møre og Romsdal/Trøndelag. These materials possess suitable concentrations of some of the macronutrients, such as potassium, sulphur, calcium, and magnesium, and can be utilised as additives to fish waste or other fertilisers. However, these materials also contain toxic elements, such as cadmium, chromium, zinc, arsenic and lead. Regulations about fertilisers of organic origin have specific limits for heavy metals contents as a basis for classifying fertilisers. In crab shells, the concentration of arsenic was a bit over the proposed limit of quality class I soil amendment products. Algae fibre had a concentration of arsenic at the border level of the proposed limit of quality class III and cadmium in class II. Bottom ash showed contents of heavy metals zinc, nickel, cadmium, and copper higher than for quality class 0.

Neither fish waste nor other RRMs have sufficient amounts of nitrogen, phosphorus, and potassium to give a fertilisation combination that can fulfil grass-clover ley, oats, and leek requirements. Fish sediments and minced fish backs can be applicable in certain conditions such as lack of phosphorous in the soil. The bottom ash can be applied as an additional fertiliser when there is a lack of potassium and phosphorus in the soil.

By performing calculations, we found that RRMs: fish sediments, minced fish backs, algae fibre, bottom ash, and crab shells in combination with cattle manure or commercially available fertiliser Eco 16-1-0 can accomplish the nutritional requirements of an organically cultivated oat, leek and grass-clover ley with two harvests with middle levels of clover.

Fish sediments / minced fish backs or algae fibre, bottom ash, and crab shells can give a good fertiliser effect but must be mixed with other fertilisers to balance the primary nutrients. The contents of some of the heavy metals are too high in these materials and cannot be applied without any processing.

Sammendrag

I økologisk landbruk er resirkulering av næringsstoffer og nitrogenfiksering viktig for å opprettholde jordfruktbarheten. Flere av næringsstoffene i gjødsel er begrensede ressurser som det er viktig å resirkulere fra ulike verdikjeder, slik at en også i framtida kan produsere gode planteavlinger både i konvensjonell og økologisk jordbruksproduksjon.

Fiskeindustrien produserer store mengder fiskeavfall. I 2018, ble ca. 40% av fiskeavfall ikke utnyttet, noe som er en betydelig mengde. Fiskeavfall som beinrike fiskehoder og fiskerygger utgjør en viktig kilde til fosfor og kalsium. Vi brukte fiskeavfall (grakse, konservert med maursyre) som kommer fra klippfiskindustrien i våre feltforsøk med raigras, havre og purre. Graksen viste rask og god effekt på plantevekst. Men graksen må tørkes før bruk for å fjerne fuktighet, redusere lukt og for å unngå at den blir skjemt. Tørkeprosessen og temperatur kan påvirke pH og innhold av totalnitrogen og ammoniumnitrogen.

I dette prosjektet, undersøkte vi hvordan fiskeavfallet (grakse og oppkvernede fiskerygger) påvirkes av tørking i tørkeskap ved 25°C, 40°C and 80°C med og uten luftsirkulasjon; i frysetørke og mikrobølgeovn. Vi undersøkte hvordan ulike tørketemperaturer påvirker prøvevekten over tid og hvilken metode som var mest effektiv. Vi studerte også hvordan de forskjellige tørkemetodene påvirket pH og konsentrasjonene av total- og ammoniumnitrogen i grakse og oppkvernede fiskerygger.

Tørking i tørkingsskap med luftsirkulasjon var mer effektivt enn tørking uten luftsirkulasjon. Dette gjaldt både for grakse og oppkvernede fiskerygger. Også utseendet til materialet viste forskjeller ved tørking med luft- og uten luftsirkulasjon. De tørkede prøvene av grakse viste litt høyere pH-verdier (4,8 - 5,3) sammenlignet med en våt prøve av grakse (pH 4,5). I motsetning til dette, viste de tørkede prøvene av oppkvernede fiskerygger like eller litt lavere pH-verdier (6,7 - 7,1) sammenlignet med den våte prøver av oppkvernede fiskerygger (pH 7,1 og 7,5). Tørketemperaturen og tørking- med og uten luftsirkulasjon påvirket også konsentrasjonene av total- og ammoniumnitrogen. Prøvene av grakse, som var tørket på 25°C med luftsirkulasjon viste de laveste konsentrasjonene av total- og ammoniumnitrogen. Prøvene av oppkvernede fiskerygger, tørket ved forskjellige temperaturer med eller uten luftsirkulasjon viste lite variasjon i konsentrasjon av totalnitrogen. For ammoniumnitrogen ble det imidlertid observert noen variasjoner mellom prøvene, hvor mikrobølgeovnstørkede prøver viste den høyeste konsentrasjonen.

Algefiber, bunnaske og krabbeskall er restråstoff som er/kan bli tilgjengelige i Møre og Romsdal/Trøndelag. Disse materialene inneholder blant annet makronæringsstoffer som fosfor, kalium, svovel, kalsium og magnesium, og er derfor aktuelle som gjødselmidler. Imidlertid inneholder disse restråstoffene også giftige elementer som kadmium, krom, sink, arsen og bly. Forskrift om

gjødselvarer av organisk opphav inneholder grenseverdiene for tungmetallinnhold som grunnlag for klassifisering av gjødselmidlene.

Gjennom kjemiske analyser fant vi at krabbeskall har innholder arsen i en konsentrasjon som gjør at krabbeskall kommer i kvalitetsklasse II. Algefiber hadde konsentrasjon av arsen på grensenivået for kvalitetsklasse III og kadmium i klasse II. Grakse inneholdt sink og oppkvernede fiskerygger arsen i mengder som klassifiserte for kvalitetsklasse I.

Verken fiskeavfall eller noen av de andre restråstoffene inneholder tilstrekkelige mengder nitrogen, fosfor og kalium for å gi en gjødslingskombinasjon som kan oppfylle gjødslingsbehov for gras-kløver eng, havre og purre. Grakse og oppkvernede fiskerygger kan være anvendbare under visse forhold, for eksempel, når det er mangel på fosfor i jorda. Bunnaske kan påføres som en ekstra gjødsel når det er mangle på kalium og fosfor i jorda.

Beregninger viste at fiskeavfall (grakse og oppkvernede fiskerygger), algefiber, bunnaske og krabbeskall i kombinasjon med storfegjødsel eller pelletert kyllinggjødsel (Eco 16-1-0) kan tilfredsstille næringskravene til økologisk dyrket havre, purre og gras-kløver eng med to slåtter. Grakse, oppkvernede fiskerygger, algefiber, krabbeskall og bunnaske kan gi god gjødselvirkning, men må blandes med andre gjødselmidler for å få en god balanse mellom hovednæringsstoffene. Innholdet av tungmetaller er for høyt til at disse restråstoffene kan tas i bruk uten videre foredling.

COUNTRY:	Norway
COUNTY:	Møre og Romsdal
MUNICIPALITY:	Tingvoll

APPROVED	**PROJECT LEADER**
Turid Strøm	Ishita Ahuja
NAME	**NAME**

Preface

"Fish bones as fertiliser" was a qualification support project from the Regional Research Fund (RFF) from Møre og Romsdal. Additionally, the project was supported with funding from NORSØK and from the project partners: Møreforsking, Sigurd Folland AS, O SKARSBØ AS, and Fjordlaks AS. This project was a side project of the research that was carried out in the projects RESTOR (Marine rest raw materials for fertilisers to organic agriculture), funded by the County of Møre og Romsdal, and Horizon 2020 Organic-PLUS (Pathways to phase-out contentious inputs from organic agriculture in Europe), where Anne-Kristin Løes is a work package leader. We thank and appreciate her for sharing knowledge and some of the chemical composition data about fish sediments, algae fibre, and fish backs, which was obtained through analyses conducted as a part of the RESTOR project.

In this project, we studied how different drying methods affect weights and the concentrations of nitrogen in fish waste (fish sediments and minced fish backs) that can be available from the white fish industry and which other RRMs can supplement fish waste to produce an organic fertiliser that can fulfil the plants' nutritional requirements.

The research experiments were carried out in Møreforsking lab., Ålesund, and in the NORSØK lab. Tingvoll. The chemical analyses of the materials were done at the SINTEF Norlab AS, Namdal. Fish sediments were provided by Fjordlaks AS, fish backs by Sigurd Folland AS, algae fibre by Algea AS, bottom ash by Tingvoll Flis og Varme, and crab shells by Hitramat AS (available through the Møreforsking project consortium).

The project partners: Emil Eliassen Folland (Sigurd Folland AS); Kevin Salbuvik, (Fjordlaks AS); Odd Skarsbø (O SKARSBØ AS); and members of the reference group: Arnar Lyche (Møre og Romsdal Bondelag); Maud Grøtta (Landbruk Nordvest-Norsk Landbruksrådgiving); Lorena Jornet, (Fiskeri og Havbruksnæringens ForskningsFinansiering (FHF); Hege Gjerde and Maren Christina Heyn, Algea AS; Ragnar Dæhli, Felleskjøpet; and Petter Aune, Drågen Smokehouse AS are kindly acknowledged.

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Tingvoll, 16.04.21

Ishita Ahuja

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1 Introduction

Organic agriculture emphasises the recycling of nutrients through organic inputs to sustain the soil-plant fertility systems and balance food production, and preserve the environment (Ahuja et al., 2020b; Illera-Vives et al., 2013).

The fishery industry is economically valuable in several countries, including China, the US, Canada, and Norway. In 2018, Norway, after China, was the second major exporter of fish and fish products. Catches by the Norwegian fleet comprise vast amounts of cod, herring, mackerel and other whitefish and small pelagic species (FAO, 2020; Ahuja et al., 2020b). Through the interview surveys, it has been found that an average fishing vessel in the open sea and near the coast can generate up to 3000 tonnes of fish waste (Løes et al., 2020).

Globally, the fishing industry produces large amounts of fish waste. The "fish waste" may include different materials such as whole fish (dead or damaged fish), fish trimmings, and specific tissues, such as heads, intestines, tails and fins, skins, scales, and bones etc." (Ahuja et al., 2020b). The fish waste in Norway is usually mentioned as "raw materials" or "residual raw materials".

In Norway, the pelagic sector utilises 100% of fish waste for fish meal, and fish oil production and secondary waste streams that can be applied for fertiliser purposes are not present (Richardsen et al., 2019). For white fish, an increase of 40 – 60% utilisation of fish waste has been observed from 2012 to 2018. In 2018, the remaining unutilised 40% waste from white fish amounted to approximately 120.000 tonnes (Ahuja et al. 2020b).

Bone-rich heads and backbones make up more than half of this fish waste and represent a valuable source of unutilised nitrogen, phosphorus, and calcium. So far, a considerable amount of fish waste from the processing of white fish has been used as feed for fur animals. Farmers who have had fur animals before January 2018 can keep them until Feb. 2025; after this date, fur farming will be banned in Norway (Ahuja et al., 2020b).

The shellfish ("skalldyr" in Norwegian) sector is small in Norway, and the utilisation of residual raw materials has been less in this sector compared to white fish (Ahuja et al. 2020b). In 2018, the utilisation rate from this sector was 36% (Richardsen et al., 2019). Shells from shrimps are available in larger volumes (Ween and Sunde, 2019). If Norway manages to negotiate new quotas for snow-crab in the Barents Sea, this could substantially increase the available volumes of crab shells (Hjelset et al., 2020).

As a part of the projects, RESTOR (Marine rest raw materials for fertilisers to organic agriculture), and Horizon 2020 Organic-PLUS (Pathways to phase-out contentious inputs from organic agriculture in Europe), we have tested fish backs and fish sediments (available from Fjordlaks AS, Ålesund), and fish backs (available from Folland AS, Averøy), as fertilisers in the pot and field experiments with ryegrass, oats and leek (Ahuja et al., 2020a; Ahuja and Løes, 2019; Løes and Ahuja, 2020). Besides testing fish waste, we have also tried another residual raw material called "algae fibre" ("algekake" in Norwegian), described later in this section. Fish waste (fish- bones, sediments, and backs) and algae fibre possess valuable macro- and micronutrients. Still, these materials are not balanced compared to the agricultural crop plants' requirements; when applied individually as a fertiliser and hence need to be combined/supplemented with other materials. As part of RESTOR and Organic-PLUS projects, we compared their effect individually and in combination as fertilisers to ryegrass, oats, and leek. We studied their effect on plant growth, yield, plant nutrient uptake and soil characteristics. The fish sediments (in the form of "porridge") are conserved with formic acid, possess a strong odour, and are not convenient to apply as fertiliser as such (described later in section 1.1.1), and thus need to be dried before the application. We applied floor dried fish sediments as fertilisers individually or in combination with wet algae fibre (Ahuja et al., 2020a; Løes and Ahuja, 2019). The drying process can reduce the odour, remove moisture (reducing the rate of deterioration from the biological and chemical activities) (Ghaly and Alhattab, 2013), can increase the dry matter content (Brod et al., 2017), and make its application as a fertiliser easier. On the other hand, the method of drying/drying temperature can affect the concentration of nitrogen. The concentrations of total nitrogen in air-dried fish sediments were higher than those dried at 40°C with active aeration (Ahuja and Løes, 2019).

Below, we have described fish waste (fish sediments and fish backs), algae fibre, and the two new residual raw materials (bottom ash and crab shells) that are/can become available in the Counties of Møre and Romsdal and Trøndelag, and have potential as additives to fish waste, cattle manure and the commercial fertiliser Eco 16-1-0.

1.1 Fish waste

1.1.1 Fish sediments (FSs)

FSs (in Norwegian called "Grakse") are the residues of bones, skin, and offal after the production of clip fish (Picture 1). FSs also contain eyeballs and ear stones etc., which are not soluble in water. Formic acid is added to FSs to bring the pH < 4 and thus preserved as silage in large tanks.

Picture 1: Fish sediments (FSs) in a container showing the top surface **(A)** and a closed view of FSs when kept in a bucket **(B)**. Photos: Anne-Kristin Løes.

During storage, the hydrolysis process occurs, the fat settles on the top of the storage tank. Below the oil layer, there is a dissolved protein, and at the bottom, a layer of sediments. Oil and soluble protein are drained and used to feed farmed fish. While the utilisation of FSs depends on a customer's availability (if anyone is interested in purchasing them). The FSs possess a moderate amount of nitrogen but also significant amounts of calcium and phosphorus. Mattilsynet (The Norwegian Food Safety Authority) has defined FSs from the hydrolysed fish as fish meal (EuropeanCommission, 2016; Løes and Adler, 2019; Mattilsynet, 2019). Fish meal has been approved as a fertiliser in organic farming since the EU published its first public regulations in 1991 (IFOAM Organics Europe, 2020). In 2020, until September, 330 tonnes of FSs were available from Fjordlaks (pers. communication Kevin Salbuvik). FSs possess high concentrations of phosphorus (110 g/kg dry matter DM), calcium (Ca) (175 g/kg DM), and moderate concentrations of nitrogen (45 g/kg DM) (Ahuja et al., 2020a). FSs, which are high in phosphorus, are currently not utilised in organic agriculture. Utilising FSs has considerable relevance as they can bring phosphorus from the sea to terrestrial environments.

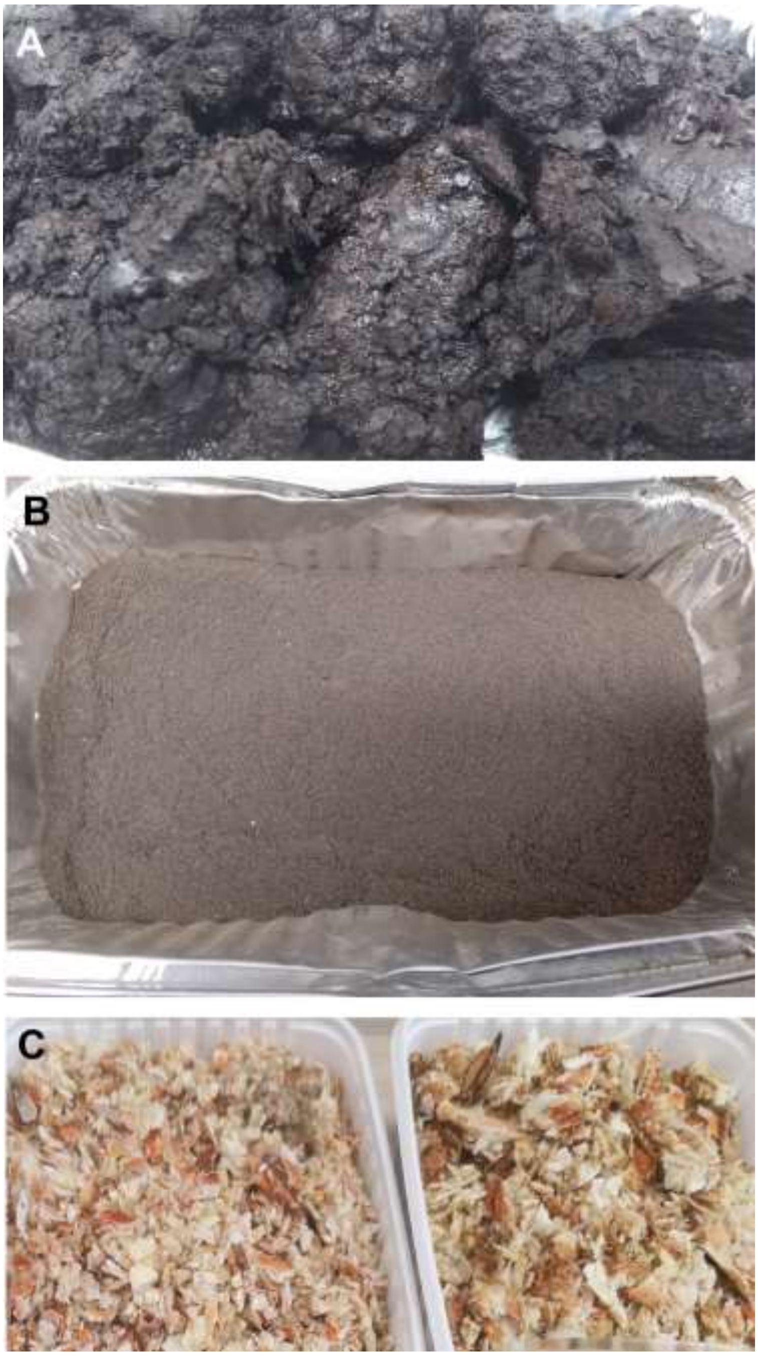
1.1.2 Fish backs (FBs)

Fish backs in the marine sector are also referred to as "fish backbones". Fish backs of cod (*Gadus morhua*); in Norwegian called "Torsk", cusk, cod-like fish (*Brosme brosme*); in Norwegian called "Brosme", and common ling (*Molva molva*); in Norwegian called "Lange" is another kind of fish waste (marine by-product) that can be available from Folland AS, Averøy (Langøya), Møre og Romsdal (Picture 2).

Picture 2: Sigurd Folland with four crates of fish backs (FBs) of cod, common ling **(A)**, a crate with FBs of cusk and common ling **(B)**, and a crate with FBs of cod **(C)**. Photos: Anne-Kristin Løes.

1.2 Other residual raw materials

The other residual raw materials (RRMs) that are/can be available in the Counties of Møre and Romsdal/Trøndelag are algae fibre, crab shells and bottom ash from burning of wood chips (Picture 3). These materials are rich in plant nutrients and can supplement fish waste (FSs or MFBs) to produce a complete organic fertiliser.



Picture 3: Other residual raw materials that are/can be made available in Møre and Romsdal.
(A) Algae fibre from Algea AS, **(B)** Bottom ash from Tingvoll Flis og Varme AS, **(C)** Crab shells from HITRAMAT AS). Photo shown in **C**: Anne de Boer.

1.2.1 Algae fibre

Fresh algae fibre (Picture 3A) comprises left-over residues from the production of commercial bio-stimulants from the seaweed knotted wrack (*Ascophyllum nodosum*), called "Grisetang" in Norwegian. In Norway, bio-stimulants are produced by Algea AS, Kristiansund, which is part of an international company Valagro AS (Ahuja and Løes, 2019). Every week tonnes of algae fibre is delivered to a company in Vestnes to use as a substrate for composting with sewage sludge (not allowed in organic agriculture) to produce a product called Park-Mix (Grønn Vekst), which is not suitable for growing edible plants. The algae fibre has approximately 30% of dry matter and high contents of potassium and sulphur (Ahuja et al., 2020a).

1.2.2 Ash (Bottom ash)

The combustion of residual forest biomass forms ash (an inorganic incombustible part of the fuel), depending upon the availability of biomass, the operating conditions, and the type of the system adapted (Hakkila, 1989; Sørheim et al., 2015). In Norway, grate-fired incinerators are the most common type of combustion plants for solid biofuels (Horn et al., 2016). Typically, two types of ash are produced, the bottom ash (Picture 3B) and the fly ash (James et al., 2012; Sørheim et al., 2015). The ash contains most of the nutritional elements, and the heavy metals present in the wood before combustion (Horn et al., 2016).

Tingvoll Flis og Varme AS operates a wood-chip plant at Tingvoll Farm. A bio-boiler of 850 kW burns wood chips (Picture 4) and heats hot water to 80 – 85°C, sent through the district heating network. The wood chips that are used in the combustion plant originate mainly from pulpwood and energy wood of pine and spruce. The moisture content in the wood chips is < 40% (Sørheim et al., 2015).

Picture 4: Forest chips that are used in the Tingvoll Flis og Varme AS combustion plant, Tingvoll Farm. Photo: Ingvar Kvande.

The results from the "Askeverdi" project have shown that the bottom ash from the grate-fired combustion plants can be used as a supplement to soil or to fertilisers (Horn et al., 2016). Field experiments and literature studies conducted in this project provide a basis to assess the forest types, the types of ash and the amount that can be suitable under the Norwegian conditions. The ash from the combustion plants with the clean wood can be used for soil improvement in soil- and forestry or for the recirculation as a fertiliser mixture (Horn et al., 2016).

1.2.3 Crab shells

Crab shells (Picture 3C) is a residual raw material representing the shellfish production in Norway. The main facility for processing brown crab in Norway is in Trøndelag (Hitramat AS, Hitra), and about 1250 tonnes of crab shells are produced as residual raw material annually.

Crab shells consist of an organic matrix composed of minerals, chitin, protein and carotenoid pigments and trace elements (Pires et al., 2017). Brown crab (*Cancer pagurus*), which is the major commercial species in Norway, have shells with a very high content of minerals (> 70 %). Typically, the mineral content in descending order is: Calcium > phosphorus > Sulphur > Strontium > Chloride > potassium. Calcium constitutes about 45 - 55% of the minerals, whereas the phosphorus content can be as high as 35%. Around 12 - 14% of the shells are composed of the carbohydrate polymer chitin. The protein content depends on the processing of shells and storage after removal of the edible parts. Both chitin and protein in the shells represent a natural source of nitrogen. The contents of contaminants are considered low and thus make the shells almost an ideal source to be utilised as fertilisers or feed ingredients (Pires et al., 2017). A study with soybean (*Glycine max* Merr.) showed that the application of crab shells as a soil amendment produced similar yields as those produced by the N-P-K (5-18-20) (Ah et al., 1998).

1.3 Aim of the project

Main aim

To study how different drying methods/drying temperatures affect the nitrogen content in fish waste (fish sediments and fish backs) originating from the white fish industry, and which other residual raw materials can supplement fish waste to produce a complete organic fertiliser that can fulfil the plants' nutritional requirements.

Sub-objectives

- Assess how different methods of drying/drying temperatures affect the weights of fish-sediments (FSs) and fish backs (FBs) during the process of drying; and what is the outcome of FSs and FBs at the final point of drying?
- Assess if the circulation of air enhances the drying process of FSs and FBs?
- Assess the effect of different drying methods/different temperatures (25°C, 40°C and 80°C) with- and without air-circulation on the concentrations of total nitrogen and ammonium nitrogen in fish sediments and minced fish backs.
- To assess if algae fibre, bottom ash and crab shells can supplement fish sediments/fish backs to become a complete organic fertiliser that can fit the need of plants such as oats, leek, and grass-clover ley?

2 Materials and methods

2.1 Materials

FSs and FBs were used to study the effect of methods of drying. Algae fibre, bottom ash, and crab shells were analysed to assess their use as additives to the nutrients present in the FSs and FBs. The crab shells were obtained from Hitramat AS after processing by cooking, removing edible meat, and grinding (Picture 3C).

The fish backs (FBs) (Picture 2) were brought to Tingvoll from the Folland AS, Averøy (Langøya), and were stored in a freezer. In order to use FBs in drying experiments, it was necessary to mince them. Therefore, the frozen FBs after thawing were cut and processed in a meat grinder to a minced form (Picture 5). During mincing, the FBs of cod, cusk and common ling got mixed, and minced fish backs (MFBs) are mixtures of these fish species. The MFBs were kept in the buckets and stored in a freezer.

Picture 5: Cutting and processing of fish backs in a meat grinder. **(A and B)** Anne de Boer cutting and putting fish backs (FBs) in a meat grinder, **(C)** minced fish backs (MFBs) in a tray**, (D)** the closer view of MFBs.

2.2 Methods used to dry FSs and MFBs

The wet FSs were dried on a plastic sheet which was spread on the floor. FSs and MFBs were dried at different temperatures in the drying cabinets, in a freeze drier and a microwave oven, as presented in Table 1.

Table 1. An overview of the methods used to dry FSs and MFBs.

	Methods used to dry FSs and MFBs
1	Drying on a plastic sheet by spreading it on the floor in a ventilated big room (only FSs).
2	Drying in a cabinet adjusted to 25°C with and without air-circulation.
3	Drying in a cabinet adjusted to 40°C with and without air-circulation.
4	Drying in a cabinet adjusted to 80°C with and without air-circulation.
5	Vacuum freeze-drying, - 86°C, 0.04 mbar (millibar).
6	Drying in a microwave oven.

2.2.1 Drying of FSs on a plastic sheet in a ventilated room

The FSs were dried (from 19.3.2020 until 04.05.2020) by spreading it as a thin layer on a thick plastic sheet, which was placed in a big room with good ventilation (Picture 6A and B). During the drying period, the mass was loosened four or five times by mixing lightly with a rake. FSs were sieved through a 1.2 x 2.5 cm mesh to take out the big-sized bones and stones and thus obtain a material with a smaller size of bones that can be applied as fertiliser and (Picture 6C and D). The floor dried FSs were used as fertiliser in the field experiments that were conducted with rye grass in 2020 (Løes and Ahuja, 2020).

Picture 6: Drying and sieving of FSs. **(A)** Drying of FSs on a plastic sheet in a room, **(B)** A closer view of FSs during the period of drying, **(C)** Sieving of dried FSs**, (D)** FSs with small size bones and other material (left side) and FS with big size bones and other material (right side). Photos shown in **C** and **D** are taken by Anne de Boer.

2.2.2 Cabinet drying of FSs and MFBs (with and without air-circulation)

The bucket of MSBs (about 5 kg), which was not covered, was taken out from the freezer and kept in a cold room for approximately two days for thawing. FSs were stored in plastic boxes with closed lids that were kept in a cold room. FSs and MSBs were taken out from the cold room just before the weighing of samples. Approximately 500 g /1000 g samples of FSs and MSBs were accurately weighted in plastic (used for FSs) or aluminium trays (used for MSBs). The trays with samples were placed on the same shelf in the drying cabinets. The temperatures of the drying cabinets were adjusted digitally to 25°C, 40°C and 80°C (with and without air-circulation). The drying experiments were conducted in the Møreforskning lab, Ålesund and lab. in Tingvoll. The air-circulation was stopped by closing the valve of the intake air flow. The samples were monitored during the drying progress. The weights of the samples were recorded, and pictures were taken at different time points during the drying process. The samples were mixed with hands during the drying process. Since FSs are treated with formic acid, we had gloves while mixing them.

2.2.3 Vacuum freeze-drying of FSs and MFBs

Vacuum freeze-drying is a gentle method that preserves most properties in biological material. Six samples of about 40 -70 g of FSs (total of 330 g) were accurately weighed into the plastic containers. The samples were frozen at –20°C overnight and re-weighed to compensate for the loss of humidity during the freezing. The frozen samples were then placed in the freeze dryer vacuum chamber. Samples were frozen at -86°C with vacuum settings at 0.04 mbar. Samples were dried until constant weight.

2.2.4 Microwave oven drying of FSs and MFBs

A sample of the FSs (400 g) was kept in a microwave oven in a microwave-safe plastic tray and dried at 800 watts. After about 30-40 minutes, the sample was completely charred, produced smoke, and melted the plastic tray. This attempt using a microwave oven for drying of FSs was not successful, and therefore it was abandoned. The plastic tray could be melted due to the presence of formic acid in FSs.

A sample of MFBs (500 g) was dried successfully in a microwave oven at about 500 watts by dividing it into two portions and keeping them on the microwave-safe plates. During the process of drying, MFBs were taken out from the microwave oven every 10 - 15 min to mix them to have an even drying. The time inside the microwave oven was approximately 105 minutes. About 5% of the material was lost during this process. This process of drying of MFBs was repeated once by taking the same amount of material.

2.3 Chemical analysis of FSs, MFBs, algae fibre, bottom ash and crab shells

Representative samples of wet FSs and MFBs that were dried using different methods (Table 1) were sent to the Møreforsking lab, Ålesund for measuring pH, and to the SINTEF Norlab, Namdal for measuring the pH, the dry matter content, and concentrations of total nitrogen and ammonium nitrogen. Algae fibre, bottom ash and crab shells were analysed for the nutritional composition.

2.3.1 pH measurement

The pH of the samples was measured using the standard method [NS-EN ISO 15933:2012] of determining pH. Some samples were measured at the Møreforsking lab and some samples at the SINTEF Norlab depending upon the sample and the utilisation of available resources at Møreforsking lab. At Møreforsking lab, the samples of FSs and MFBs were homogenised with a hand mixer. A representative sample of five grams was weighed and mixed with 50 ml of tap water, put on a shaker (150 rpm) for 2 hours, and the pH was measured in the liquid phase of the suspension with a calibrated pH meter. However, at SINTEF Norlab, the pH was measured in an aqueous solution where the sample included about 1/5-unit volume, and the ion-exchange water included 4/5-unit volume. The sample was kept on a shaker for an hour, filtered, and the pH was measured in a filtrate with a pH meter.

2.3.2 Dry matter content

The dry matter contents in the samples were measured using the standard method of gravimetric determination of drying of solids in soil, sludge, and sediments [NS 4764:1980]. The main principle in this standard method is to weigh the samples before and after drying at 105°C for 4 - 24 hours, depending upon the sample, and calculating the result in a percentage of the sample weight. The dry matter content of the samples is measured usually by taking the sample (3 - 10 g) in a bowl and then placing the bowl in a drying cabinet (set at 105°C ±3°C) for about 16 hours.

2.3.3 Determination of total nitrogen

The total nitrogen was determined at SINTEF Norlab by the modified Kjeldahl method. The Kjeldahl-N is a well-known method to determine total nitrogen in organic materials; organic materials are heated with H_2SO_4 to release nitrogen as $(NH_4)_2SO_4$ and measure the amount of nitrogen indirectly by titrating the amount of NH_4 in 0.1 M hydrochloric acid (Ahuja and Løes, 2019; EN13654-1, 2001; Øien and Krogstad, 1989). A known amount of sample (0.5 – 2 g) (without drying) was digested with concentrated sulfuric acid at 420°C for 40 min with copper (I) oxide as a catalyst. (Potassium chloride was used to increase the boiling point of sulfuric acid). This results in the formation of ammonium sulphate in the digestion tube. After digestion, the sample is placed in a steam distiller, and an excess of sodium hydroxide is added to bring NH_4 to NH_3 (gas). NH_3 is distilled over to a flask with a known amount of hydrochloric acid (0.1 M, 25 ml). The nitrogen determination is further carried out by back-titration with 0.1 M sodium hydroxide to neutralise excess hydrochloric acid after the steam distillation.

2.3.4 Determination of ammonium nitrogen

The ammonium nitrogen (NH_4-N) was determined following the standard EN ISO 11732 (Brod et al., 2017; EN ISO11732, 1997), as described earlier, with minor modifications. For extraction of samples, the SINTEF Norlab, Namdal internal method's was followed. The dried and grinded samples were extracted with ion-exchanged water for one hour, then filtered through a 1.2 µ filter, and acidified with the sulphuric acid. After shaking and filtration, the concentrations of ions were detected by a photometrical method where the complex building chemicals were added to the filtrate to produce coloured components to be detected in a carrier flow analysis (CFA, thymol method). The flow injection analysis was done according to the NS-EN ISO 11732: 2005, where the main principle is that a continuous stream of sample enters an air-segmented carrier stream; and forms a blue coloured complex with the content of ammonium ion.

2.3.5 Determination of phosphorus, potassium, calcium, magnesium, and heavy metals

The concentrations of "total" phosphorus, potassium, calcium, magnesium, micronutrients, and heavy metals were determined at SINTEF Norlab using ICP-MS [Internal method based on NS-EN ISO 17294-2: 2016]. The multi-element determination of selected elements, including uranium isotopes, by inductively coupled plasma mass spectrometry, included the following steps:

- Chemical digestion of sediments / AL-extracts to bring ions into aquatic solution (nitric acid/hydrogen peroxide solution, autoclaving at 120 °C for 30 min, pressure: 1 atm);
- Introduction of a measuring solution into a radiofrequency plasma by pneumatic nebulisation where energy transfer processes from the plasma cause desolvation, decomposition, atomisation, and ionisation of elements;
- As an additional option, collision and reaction cell technology are used to overcome several interferences;
- Extraction of the ions from plasma through differentially pumped vacuum interface with integrated ion optics and separation based on their mass-to-charge ratio by a mass spectrometer (i.e. a quadrupole MS);
- Transmission of the ions through the mass separation unit (a quadrupole) and detection by a dynode electron multiplier assembly, and ion information processing by a data handling system;
- Quantitative determination after calibration with calibration solutions;
- The relationship between signal intensity and mass concentration is linear up to at least 10 log.

2.4 Model calculations

The chemical analysis and an Excel-based spreadsheet were used to investigate whether FSs, algae fibre, bottom ash and crab shells could be suitable as fertilisers together with other types of fertilisers that are allowed in organic farming. The plants that were tested in the spreadsheet were grass-clover ley, oats, and leek. These materials were used in different combinations with cattle manure and pelleted organic chicken manure (Eco 16-1-0) that is available from Grønn Gjødsel AS (Grønn Gjødsel, 2021).

Assumptions for the calculations:

- Silty sandy soil with optimal content of phosphorus (5 - 7 mg/100 g) and potassium (7 - 15 mg/100 g) (Eurofins, 2021).
- In Mid-Norway, organic ley farming can be achievable to about 650 kg dry matter/ decare (dekar in Norwegian) (da) under good conditions when the ley is cut twice and has medium content of clover. This data and the information about nutritional requirements were obtained from the Norwegian Agricultural Advisory Service (pers. communication Maud Grøtta).
- The yield of the organic oats was set to an expectation of 400 kg/da (80 % of conventional yield).

- The yield of organic leek was set to an expectation of 2000 kg/da (Solberg, 2021).

We have not done any corrections for the nitrogen requirements due to the content of mould in the soil or fixation of nitrogen from clover in the ley. The nutrients requirements for oats and leek and the necessary corrections at low and high contents of phosphorus and potassium in the soil are published by NIBIO, 2021. Farmers who have organic farming usually have crop rotation, which among other factors, is important for the fertilising practice. While setting up the requirements for nutrients, we have not calculated the effect of the previous crop.

3 Results and Discussion

3.1 Effect of drying methods (with and without air-circulation) on FSs and MFBs

The effect of drying methods (Table 1) on FSs and MFBs was studied by taking the weights of wet samples of FSs and MFBs, which was regarded as a zero-time point, and then by measuring the weights of the samples at different time points until a constant weight was achieved. The effect of drying methods was also observed on the change in the appearance of FSs and MFBs during the process of drying, done by taking the photos of samples of FSs and MFBs at certain time points.

3.1.1 Effect of drying methods on the weights of FSs

3.1.1.1 Drying of FSs at 25°C in a drying cabinet

Picture 7 shows the appearance of the samples of FSs at the final time point of the drying process at 25°C. The drying of samples of FSs at 25°C with air-circulation showed 37% weight reduction at 262 hours, which remained constant until 450 hours (Figure 1A). In contrast, the samples that were dried at 25°C without air-circulation showed only 5% weight reduction after 450 hours (Figure 1B).

Picture 7: Appearance of samples of fish sediments (FSs) at the final point of drying (450 hours) at 25°C with and without air-circulation. **A.** Wet FSs, **B.** FSs dried with air-circulation; **C.** FSs dried without air-circulation. Photos presented in **B** and **C**: Ola Ween.

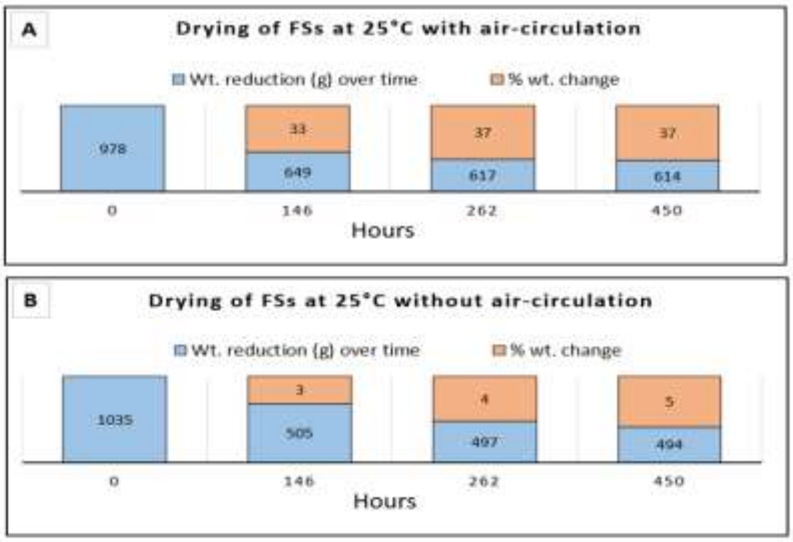


Figure 1. Average weight (g) and the percentage weight change in samples of fish sediments (FSs) at different time points (hours) during the drying process in a drying cabinet at 25°C with and without air-circulation. **A.** With air-circulation (n = 4), **B.** Without air-circulation (n = 4).

3.1.1.2 **Drying of FSs at 40°C in a drying cabinet**

Picture 8 shows the appearance of samples of FSs at different time points during the drying process in a drying cabinet at 40°C with and without air-circulation. The cabinet drying of FSs samples at 40°C with and without air-circulation didn't show any variations in the percentage weight change at respective hours (Figure 2).

Picture 8: Appearance of samples of FSs during the process of drying at 40°C with and without air-circulation. **A.** Wet FSs at zero time point, **B and C.** FSs dried with air-circulation after 26 and 47 hours; **D and E.** FSs dried without air-circulation after 27 and 51 hours.

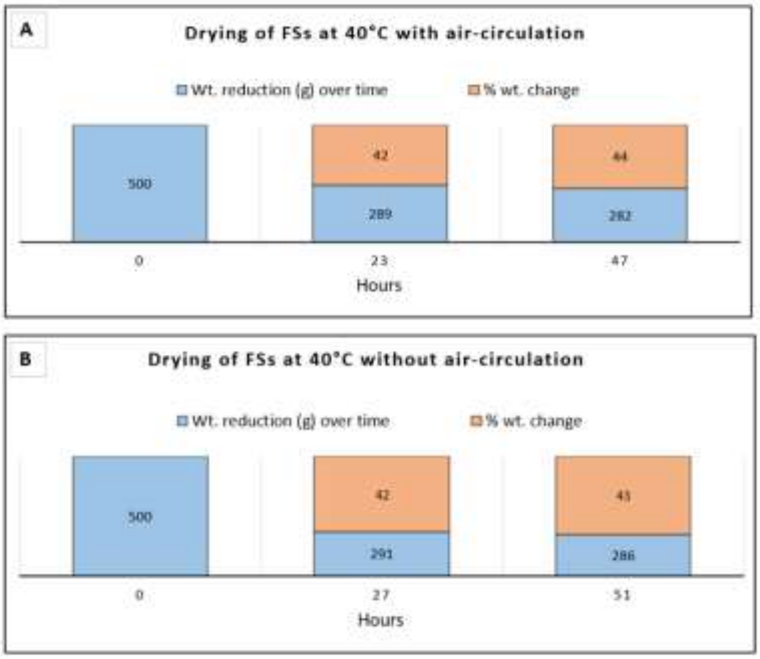
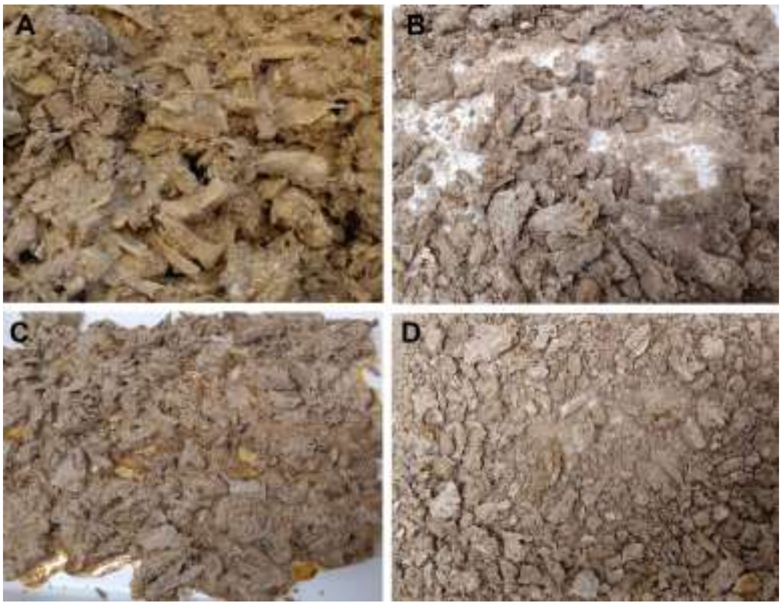


Figure 2. Average weight (g) and the percentage weight change in samples of fish sediments (FSs) at different time points (hours) during the drying process in a drying cabinet at 40°C with and without air-circulation. **A.** With air-circulation (n = 2), **B.** Without air-circulation (n = 2).

3.1.1.3 Drying of FSs at 80°C in a drying cabinet

Picture 9 shows the appearance of the samples of FSs during and at the final time point (48 hours) of the drying process after being dried at 80°C with and without air-circulation. Irrespective of drying with or without air-circulation, no huge differences were observed for the percentage weight change in samples of FSs at the final time point.



Picture 9: Appearance of samples of FSs during the process of drying at 80°C with and without air-circulation. **A.** Wet FSs at zero time point, **B.** FSs dried without air-circulation after 48 hours; **C and D.** FSs dried with air-circulation after 24 and 48 hours.

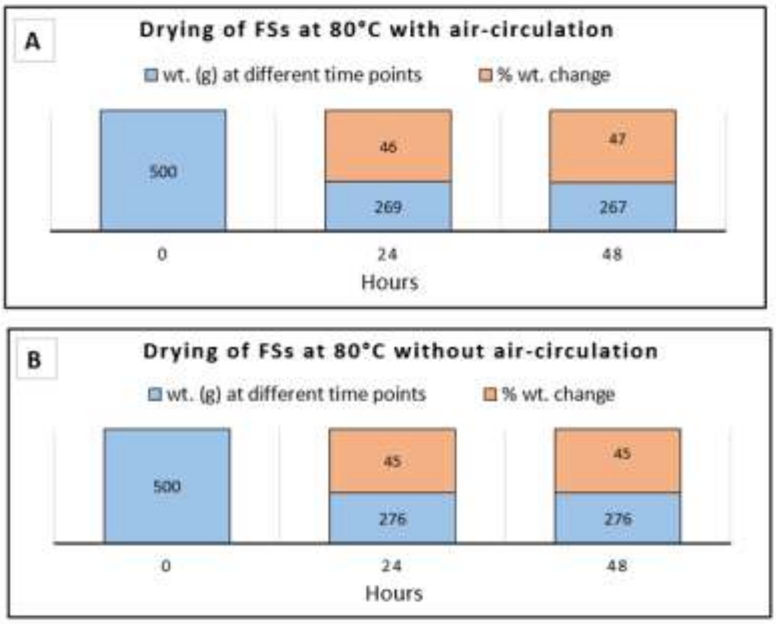


Figure 3. Average weight (g) and the percentage weight change in samples of fish sediments (FSs) at different time points (hours) during the process of drying at 80°C in a drying cabinet at 80°C with and without air-circulation. **A.** With air-circulation (n = 2), **B.** Without air-circulation (n = 2).

3.1.1.4 Vacuum freeze-drying of FSs at -86°C

The samples of FSs were dried for 192 hours (8 days) until a constant weight (Picture 10). A weight change of about 17.7% was observed at the end point of drying (data not shown). This method is energy demanding and requires investment in special equipment.

Picture 10. The appearance of freeze-dried samples of FSs (Photo: Ola Ween).

3.1.1.5 The moisture content of FSs at the final point of the drying process

Figure 4 shows the moisture content in samples of FSs, observed at the final point after drying in drying cabinets at different temperatures (25°C, 40°C and 80°C) with- and without air-circulation. The average moisture content in wet samples of FSs was about 50%. The moisture content in the cabinet-dried samples of FSs ranged between 27 – 31%, where the exception was the samples that were dried at 25°C without air-circulation (48%) (Figure 4). The drying of samples of FSs at 25°C without air-circulation did not reduce the moisture content very much compared to the wet sample, highlighting that the drying of FSs at 25°C requires air-circulation.

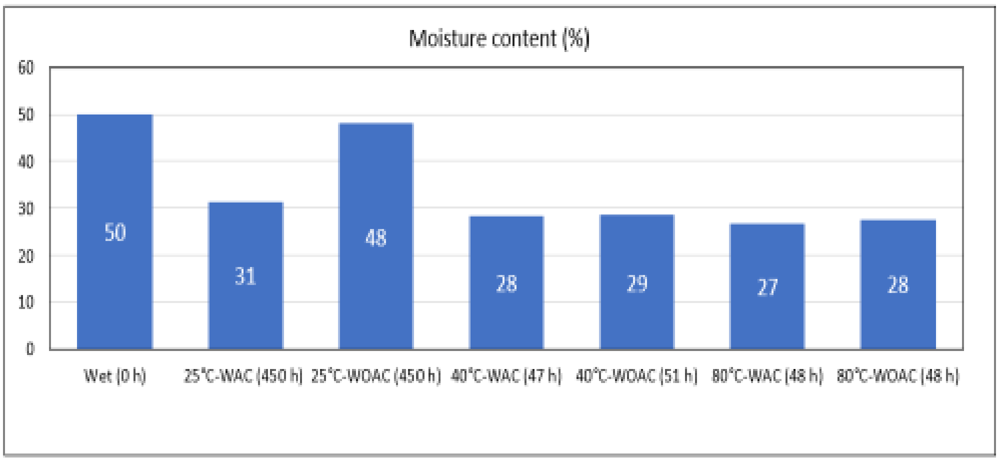


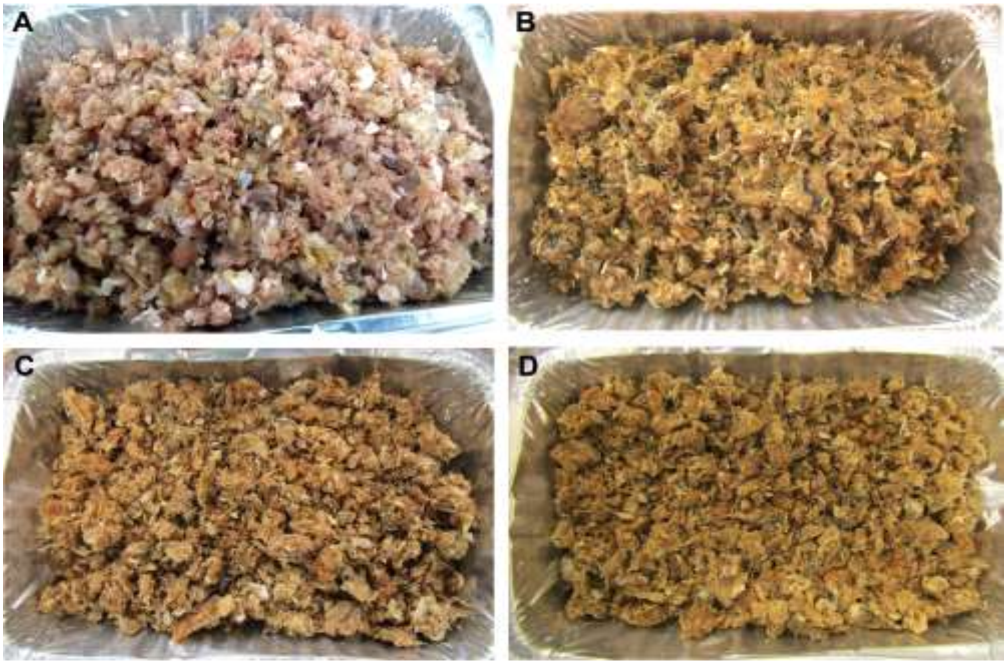
Figure 4. Average moisture content in samples of the fish sediments (FSs) at the final point of the drying process, after drying in drying cabinets at different temperatures with and without air-circulation. WAC: with air-circulation, WOAC: without air-circulation.

3.1.2 Effect of drying methods on the weights of MFBs

3.1.2.1 Drying of MFBs at 25°C in a drying cabinet

Pictures 11 and 12 show the appearance of samples of MFBs at different time points during the drying process in drying cabinets, set at 25°C with and without air-circulation. The drying of samples of MFBs at 25°C with air circulation took 99 hours (Figure 5A), while the drying of the samples of MFBs without air-circulation took 170 hours (Figure 5B). At the final time point (99 hours), the weight reduction of MFBs samples, dried with the air-circulation, was 66%. In contrast, the weight reduction for the MFBs samples, dried without air-circulation, at the final time point (170 hours) was 69%.

Picture 11. Appearance of samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 25°C with air-circulation. **A.** Wet MFBs at zero time point, **B.** MFBs after 24 hours of drying, **C.** MFBs after 29 hours of drying, **D.** MFBs after 48 hours of drying, **E.** MFBs after 99 hours of drying.



Picture 12. Appearance of samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 25°C without air-circulation. **A.** Wet MFBs at zero time point, **B.** MFBs after 96 hours of drying, **C.** MFBs after 120 hours of drying, **D.** MFBs after 170 hours of drying.

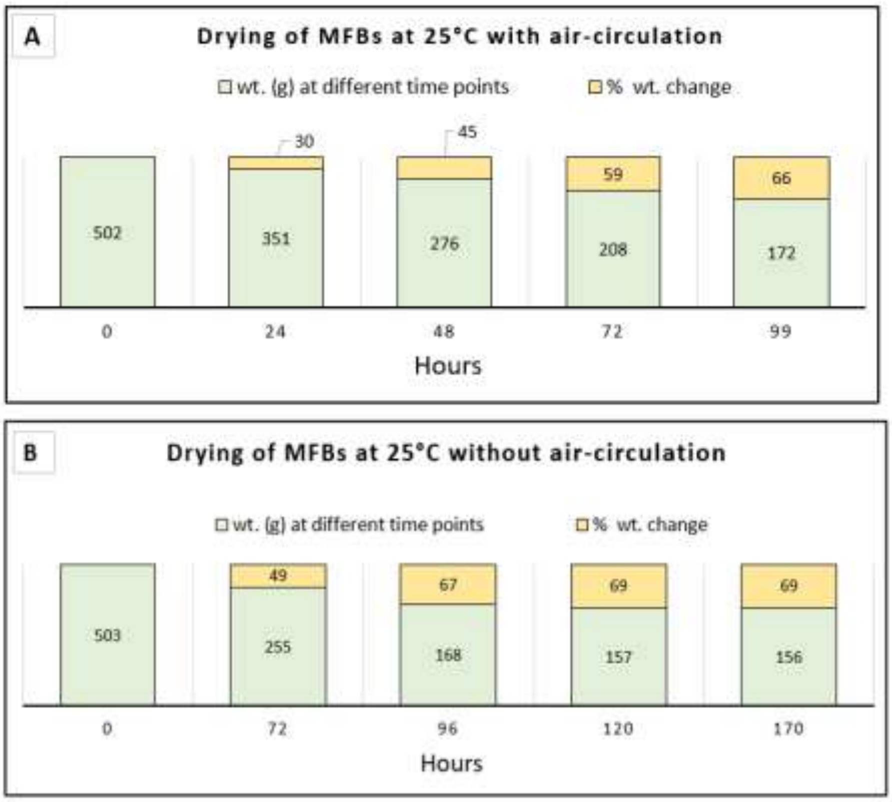


Figure 5. Average weight (g) and the percentage weight change in samples of minced fish backs (MFBs) at different time points during the process of drying at 25°C with and without air-circulation. **A.** MFBs dried with air-circulation (n = 4) **B.** MFBs dried without air-circulation (n = 4).

3.1.2.2 **Drying of MFBs in a drying cabinet at 40°C**

Pictures 13 and 14 show the appearance of the samples of MFBs at different time points during the drying process in a drying cabinet at 40°C with and without air-circulation. The drying of samples of MFBs at 40°C with air-circulation took 80 hours (Figure 6A), while the drying of samples without air-circulation took 96 hours (Figure 6B). At 52 hours, the average weight of MFBs, dried with air-circulation, was 158 g; however, for the samples dried without air-circulation, it was 165 g. The final average weight of samples of MFBs dried with air-circulation after 80 hours of drying was 134 g. The final average weight of MFBs samples dried without air-circulation after 96 hours of drying was 151 g (Figure 6).

Picture 13. Appearance of samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 40°C with air-circulation. **A.** Wet MFBs at zero time point, **B.** MFBs after 26 hours of drying, **C.** MFBs after 52 hours of drying, **D.** MFBs after 80 hours of drying.

Picture 14. Appearance of samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 40°C without air-circulation. **A.** Wet MFBs at zero time point, **B.** MFBs after 26 hours of drying, **C.** MFBs after 52 hours of drying, **D.** MFBs after 73 hours of drying.

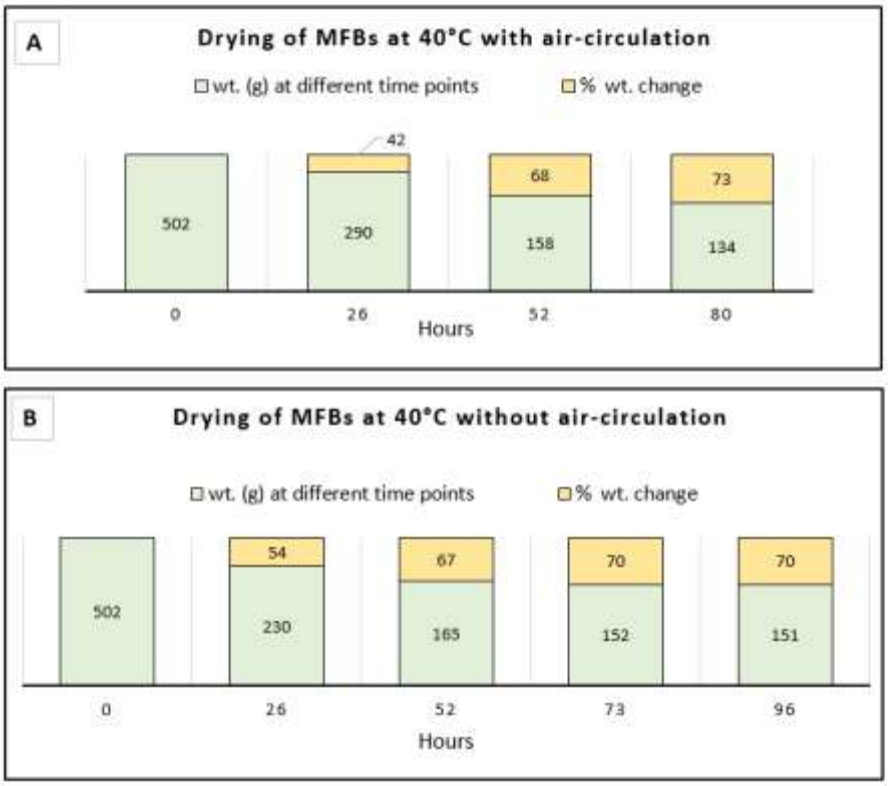
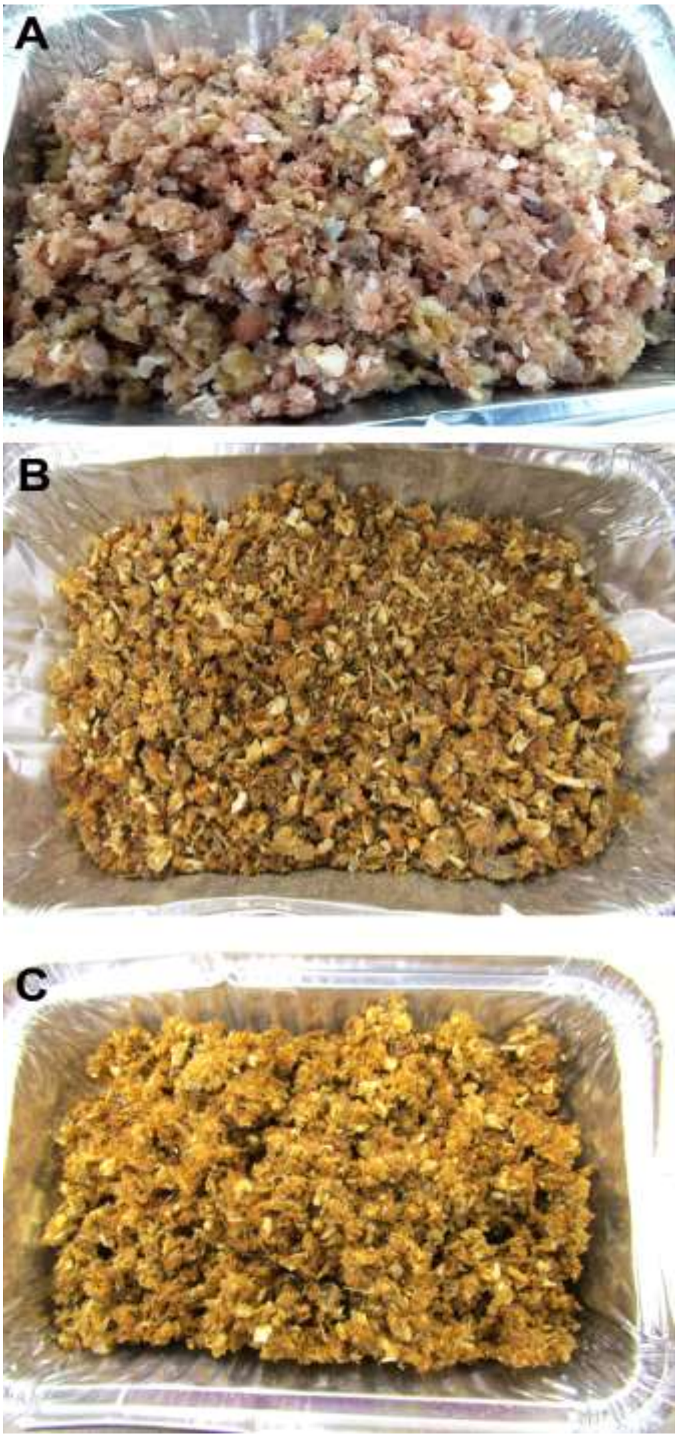


Figure 6. Average weight (g) and the percentage weight change in samples of minced fish backs (MFBs) at different time points (hours) during the drying process in a drying cabinet at 40°C with and without air-circulation. **A.** MFBs dried with air-circulation (n = 4), **B.** MFBs dried without air-circulation (n = 4).

3.1.2.3 **Drying of MFBs in a drying cabinet at 80°C**

Picture 15 show the appearance of wet and dried samples of MFBs after drying in a drying cabinet for 26 hours at 80°C with and without air-circulation. At the time point of 26 hours, the average weight of MFBs, dried with air-circulation, was 118 g (Figure 7A), while for the samples dried without air-circulation, the average weight was 137 g (Figure 7B).



Picture 15. Appearance of samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 80°C with and without air-circulation. **A.** Wet MFBs at zero time point, **B.** MFBs after 26 hours of drying with air-circulation, **C.** MFBs after 26 hours of drying without air-circulation.

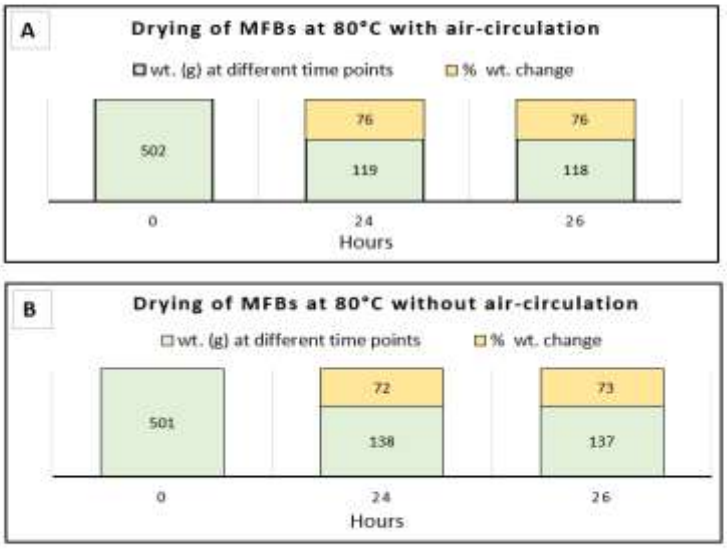


Figure 7. Average weight (g) and the percentage weight change in samples of minced fish backs (MFBs) at different time points during the drying process in a drying cabinet at 80°C with and without air-circulation. **A.** MFBs dried with air-circulation (n = 4), **B.** MFBs dried without air-circulation (n = 4).

3.1.2.4 Drying of MFBs in a microwave oven

Picture 16 shows the appearance of wet and dried samples of MFBs at specific time points during the process of drying in a microwave oven. The drying of MFBs in a microwave oven took about 105 minutes. At the final point of drying, the weight of MFBs was 138 g. After 45 minutes, the sample weight reduction was almost 30%, and at the final point (105 minutes), it was 72% (Figure 8). These 105 minutes don't include the time that was used to take out the plate from the microwave oven and mix the material.

Picture 16. Appearance of samples of minced fish backs (MFBs) at different time points during the process of drying in a microwave oven. **A.** Wet MFBs at zero time point, **B.** MFBs after 90 minutes of drying, **C.** MFBs after 105 minutes of drying.

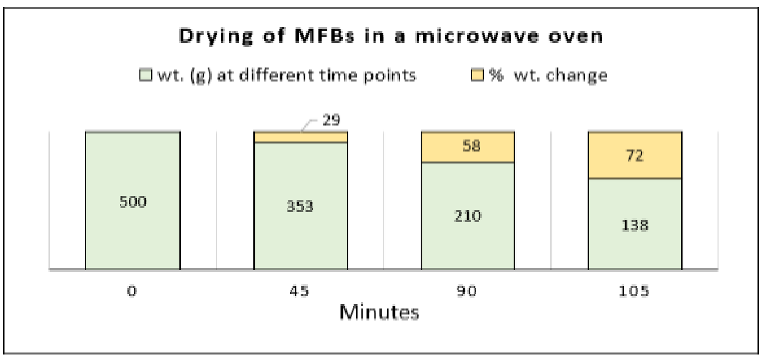


Figure 8. Average weight (g) and the percentage weight change in a sample of minced fish backs (MFBs) (n = 1) at different time points during the process of drying in a microwave oven.

3.1.2.5 Weights and moisture content of MFBs at the final point of the drying process

Figure 9 shows the weights, and moisture percentage in samples of MFBs observed at the final point after drying in drying cabinets at different temperatures (25°C, 40°C and 80°C), with- and without air-circulation. The average moisture content in wet samples of MFBs was about 70%. The cabinet-dried samples of MFBs showed variations in the moisture content, where the samples of MFBs that were dried at 80°C with air-circulation had the lowest moisture content (Figure 9). However, the drying of samples of MFBs at 80°C with- or without air-circulation showed only minor variations in the moisture content at the final point of drying (26 hours). Overall, the drying with air-circulation was more effective as it took fewer hours as compared with air-circulation, in particular for the samples that were dried at 25°C and 40°C (Figure 9).

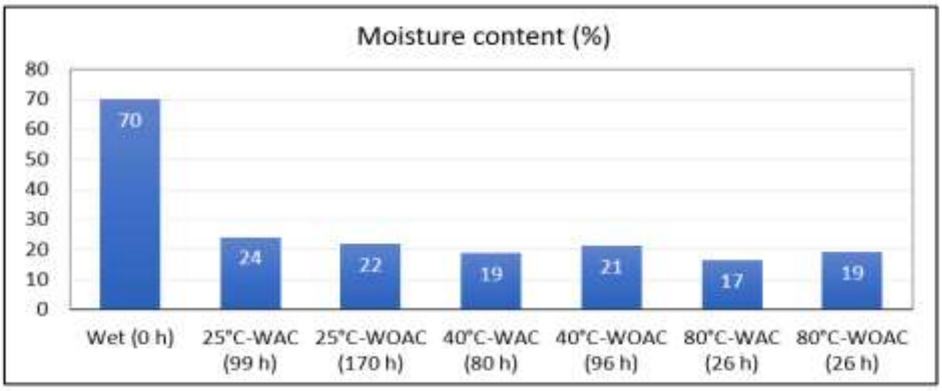


Figure 9. Average moisture content (%) in samples of the minced fish backs (MFBs) at the final point of the drying process, after drying in drying cabinets at different temperatures with and without air-circulation (n = 4). WAC: with air-circulation, WOAC: without air-circulation.

3.1.3 Effect of drying methods on pH, total nitrogen, and ammonium nitrogen in FSs

3.1.3.1 Effect of drying methods on pH of FSs

The pH of wet samples of FSs was 4.5. The dried samples of FSs showed higher pH values compared to the wet sample, although minor variations were observed among samples from different treatments/temperatures (Figure 10). The measurement uncertainty for pH was ± 0.2 of the measured value, and the variations that are observed among samples from different treatments/temperatures can be just by chance.

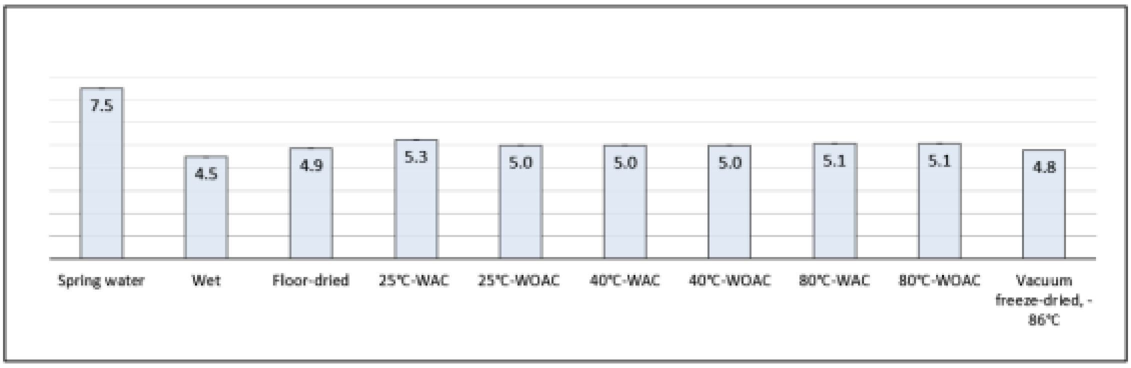


Figure 10. The pH of the samples of fish sediments (FSs) after drying- at floor, in drying cabinets at different temperatures (with and without air-circulation), and in a freeze dryer. Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

3.1.3.2 Effect of drying methods on concentrations of total nitrogen and ammonium nitrogen in FSs

The average concentrations of total nitrogen and ammonium nitrogen in the wet samples of FSs was 44.7 g/kg DM (Figure 11A). As explained in section (2.3.2), the standard method of measuring dry matter content is based on the drying of samples at 105°C. The DM content, as shown in Figure 12, was used to calculate the concentrations of total nitrogen and ammonium nitrogen in samples, given as g/kg DM (Figure 11).

Among the cabinet dried samples, the samples of FSs, dried at 25°C without air-circulation, showed an average concentration of total nitrogen 50.7 g/kg DM (Figure 1A). This concentration is an average of three representative samples, where two samples had concentrations of 48.8 g/kg DM, and one sample had a concentration of 54.5 g/kg DM. The high concentrations of total nitrogen in these samples can be due to the sample material itself and not the effect of drying. The sample may have been comprised of more solid or liquid material, bones and other offal. Similarly, a slightly higher average concentration of total nitrogen (47.8 g/kg DM) in the samples of FSs, dried at 80°C without air-circulation, compared to the wet sample, can be due to the variation in the sample material itself. Here, three representative samples had concentrations of total nitrogen of 45.1, 48.4 and 50.0 g/kg DM, respectively. The measurement uncertainty for total nitrogen was ± 15 g/kg DM of the measured value., and the variations that are observed among samples from different treatments/temperatures can also be just a coincidence.

The average concentration of ammonium nitrogen in the wet sample of FSs was 4.4 g/kg DM (Figure 11B). The average concentrations of ammonium nitrogen for the FSs samples dried at 25°C, 40°C and 80°C with air-circulation were lower than those dried without air-circulation. Among the samples that were dried in a cabinet without air-circulation, the average concentrations of ammonium nitrogen ranged between 2.5 to 3.5 g/kg DM (Figure 11B).

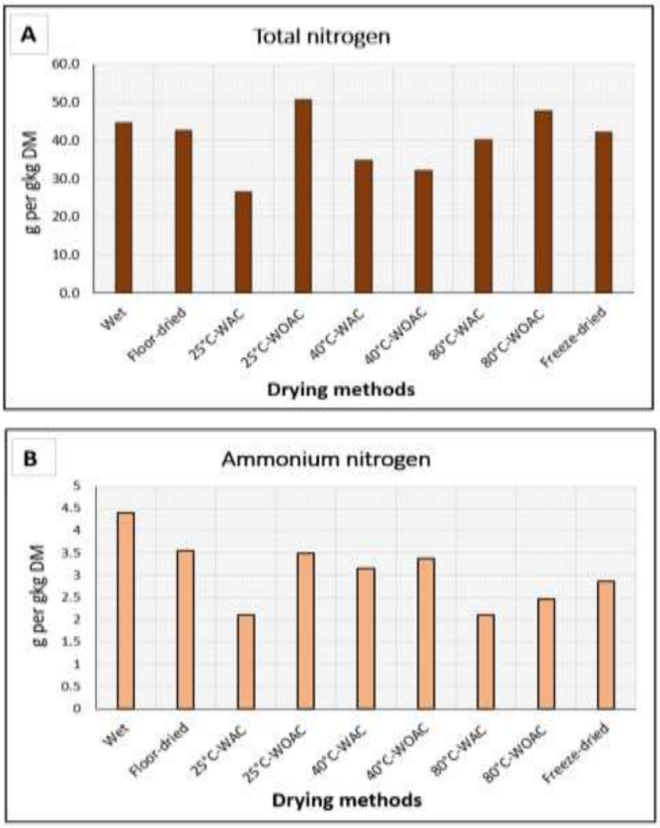


Figure 11. Average concentrations (g per kg DM) of total nitrogen and ammonium nitrogen measured from wet and dried samples of fish sediments (FSs). **A.** Total nitrogen, **B.** Ammonium nitrogen.
The concentrations were measured from three representative wet samples of FSs, and from three representative samples of dried samples, which were taken from the final products of the drying process, after drying in cabinets at different temperatures with and without air-circulation, drying at floor, and in a freeze drier.
Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

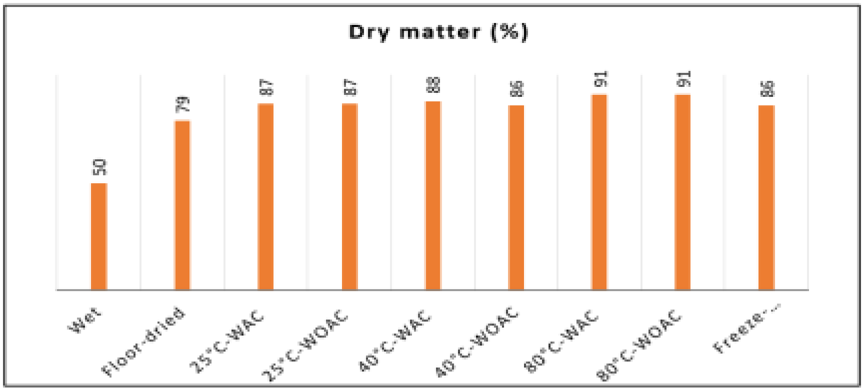


Figure 12. Dry matter content (%) in samples of fish sediments (FSs) measured after drying of samples at 105°C. Wet FSs and FSs at the final point of the drying process, after drying in cabinets at different temperatures with and without air-circulation, drying at floor, and in a freeze drier. Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

3.1.4 Effect of drying methods on pH, total nitrogen, and ammonium nitrogen in MSBs

3.1.4.1 Effect of drying methods on pH of MSBs

The pH of a wet sample of fresh MSBs was 7.1, and the average pH value of two samples of MSBs after a storage period of 10 months was 7.5 (Figure 13). The cabinet and microwave oven-dried samples of MSBs showed slightly reduced pH values, ranging between (6.7 – 7.0). The measurement uncertainty for pH was ± 0.2 of the measured value, and the variations that are observed among samples from different treatments/temperatures can be just by chance.

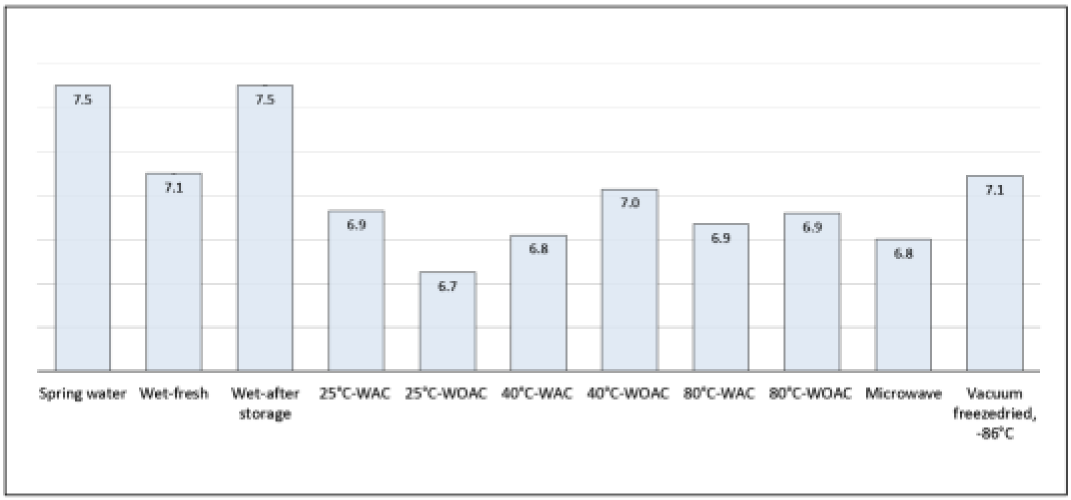


Figure 13. The pH of the samples of minced fish backs (MFBs) after drying in drying cabinets at different temperatures with and without air-circulation, in a microwave oven and in a freeze dryer.
Wet fresh (pH measured from a fresh sample). Wet-after storage (pH measured after a period of storage of 10 months in the freezer). Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

3.1.4.2 Effect of drying methods on concentrations of total nitrogen and ammonium nitrogen in MSBs

The concentrations of total nitrogen were found to be the same when measured from a fresh sample of wet MSBs, and from wet samples of MSBs that were stored in a freezer for a period of about ten months (Figure 14A). As explained in section (2.3.2), the standard method of measuring dry matter content is based on the drying of samples at 105°C. The DM content (Figure 15) was used to calculate the concentrations of total nitrogen and ammonium nitrogen in samples, given as g/kg DM (Figure 14). The average concentrations of total nitrogen were either the same or slightly low in MSB samples after drying with different methods except for the samples dried at 40°C with air-circulation (113 g/kg DM) (Figure 14). The three representative samples dried at 40°C with air-circulation showed concentrations of total nitrogen (110, 110 and 120 g/kg DM). The high concentration (120 g/kg DM) in one of the samples can be just a coincidence and not due to the drying effect. The measurement uncertainty for total nitrogen was ± 15 g/kg DM of the measured value. The MSBs samples that were dried at 80°C without air-circulation and in the microwave oven showed the same concentrations of total nitrogen as it was observed for wet samples.

The concentration of ammonium nitrogen in the wet sample of MFBs was 5.3 g/kg DM, which was observed to be reduced to 0.6 g/kg DM after a storage period of 10 months (Figure 14B). The average concentration of ammonium nitrogen was lower (0.2 g/kg DM) in samples of MSBs that were dried at 25°C with air-circulation compared to dried without air-circulation, which showed an average concentration of 0.9 g/kg DM. Among all dried samples, the microwave oven-dried sample showed the greatest concentration of ammonium nitrogen (Figure 14B).

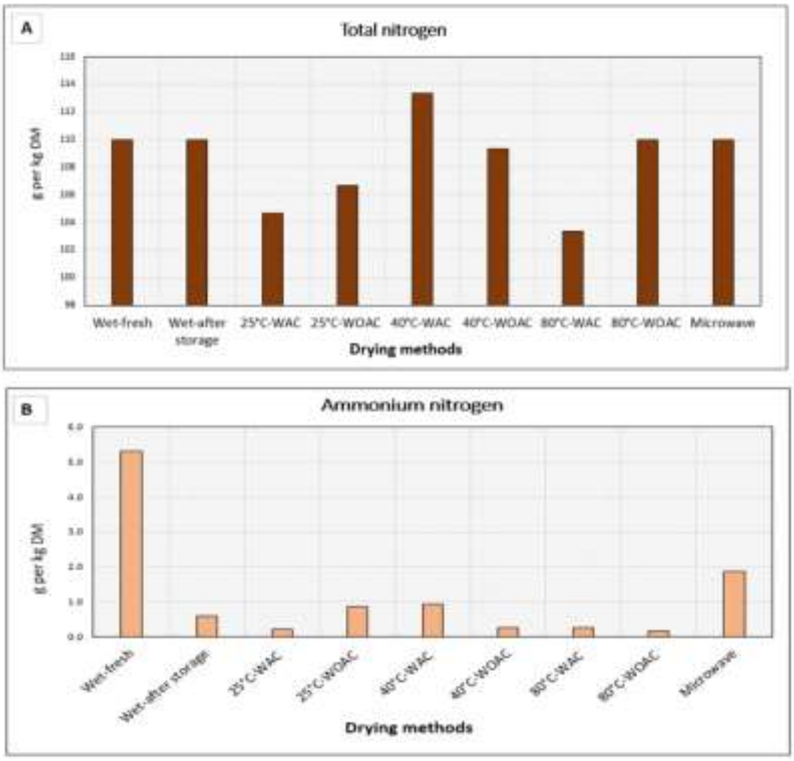


Figure 14. Average concentrations (g per kg DM) of total nitrogen and ammonium nitrogen measured from wet and dried samples of minced fish backs (MFBs). **A.** Total nitrogen, **B.** Ammonium nitrogen.
The concentrations were measured from one representative sample of wet-fresh, two representative samples of wet-after storage of minced fish backs (MFBs), and from three representative samples taken from the final products of the drying process, after drying in cabinets at different temperatures with and without air-circulation, and in a microwave oven. Wet fresh (measured from the fresh sample). Wet-after storage (measured after a storage period of about ten months in the freezer).
Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

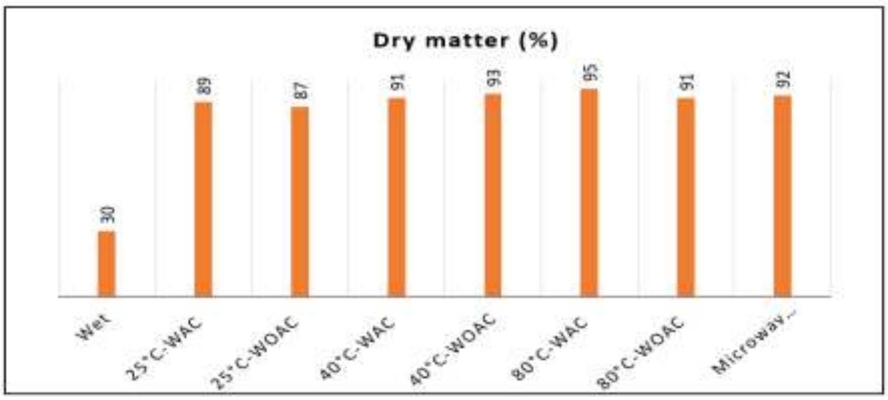


Figure 15. Dry matter content (%) in samples of minced fish backs (MSBs) measured by drying of samples at 105°C. Wet MSBs and MSBs at the final point of the drying process, after drying in cabinets at different temperatures with and without air-circulation, drying at floor, and in a microwave oven.
Drying in cabinets: WAC: with air-circulation, WOAC: without air-circulation.

3.2 Discussion about studying the effect of drying methods on FSs and MSBs

3.2.1 Drying methods/drying temperatures affect the appearance of FSs and MFBs

With drying at different temperatures with and without air-circulation, we observed differences in the appearance of samples of FSs (Pictures 7 - 10) and MFBs (Pictures 11 - 16), especially change in the sample- colour and texture during the drying process and at the final point of drying. The differences in the appearance can be due to the drying temperature, the duration, and the sample material. The FSs sample may contain bones/skin/eyeballs/ear stones or liquid, as the FSs are a mixture of these. Air-circulation also seem to affect the colour and the texture, as the samples of FSs that were dried at 25°C without air-circulation appeared darker than those dried with air-circulation (Picture 7C), and that can be possibly due to the presence of more moisture or deterioration of the sample material. Also, the sample of MFBs that was dried in a microwave oven (Picture 16) appeared quite different in colour and texture than the cabinet dried samples of MFBs (Picture 11 - 15). In future, it would be interesting to study how different drying methods affect the physicochemical characteristics and textural properties of FSs and MFBs. A recent study showed that the low-temperature vacuum drying method was more effective in drying yellow croaker (*Larimichthys polyactis*) compared to freeze-drying and hot drying methods, as it provided good qualities of the dried fish (Kim et al., 2020). In our investigation, we have not tested the low-temperature vacuum drying method, but in future, for drying of FSs and MSBs, that method can also be investigated.

3.2.2 Drying methods/drying temperatures affect moisture content and weights of FSs and MFBs

The moisture content was greatest in the samples of FSs, dried at 25°C without air-circulation (Figure 4). The weight reduction was higher, and the time duration was shorter for the FSs samples that were dried with air-circulation at 40 and 80°C (Figures 2A and 3A) in comparison to drying at 25°C with air-circulation (Figure 1A). Nevertheless, there were not big differences in weight reduction and the time durations for FSs samples if the temperature was raised from 40 to 80°C with or without air-circulation (Figures 2 and 3).

For MFBs, the moisture content was lowest in the samples that were dried at 80°C with air-circulation (Figure 9). Furthermore, the effect of air-circulation was observed to be more effective at drying temperatures of 25°C and 40°C than at 80°C (Figures 5 and 6). Air-circulation at 80°C showed only a slight change in percentage weight reduction (Figure 7). Drying of samples of MFBs at 80°C was more effective when it comes to the time consumption compared to drying at 40 and 25°C.

These variations in samples after drying using different drying methods/drying temperatures possibly can be due to the sample material itself (more bones or skin or other offal), or due to the presence of more solid material or liquid, the duration period, or can be due to other unknown factors. Another possible reason for variations in final weights of samples of MSBs can be the fat content. If there was more fat in a particular sample, it could have possibly made a layer on top of the material, which could have hampered the evaporation process.

3.2.3 Drying temperature, air-circulation or other unknown factors can affect concentrations of nitrogen

If drying with air-circulation can intensify the drying process, contrary, it can lower the concentrations of total nitrogen and ammonium nitrogen. The concentrations of ammonium nitrogen were lowest in FSs samples dried at 25°C and 80°C with air-circulation (Figure 11). We also observed low concentrations of total nitrogen and ammonium nitrogen in samples of MFBs, dried at 25°C and 80°C with air-circulation (Figures 11 and 14). A recent study showed that during the drying process of lay hen manure, the higher drying temperature caused the greater loss of ammonium nitrogen (Li et al., 2020).

Taken together, we can consider that the results that we have obtained in this study about concentrations of total nitrogen and ammonium nitrogen in samples of FSs and MFBs can be due to an outcome of several factors. It can be an effect of drying temperature, air-circulation, time duration, variation in the sample material, storage or thawing.

3.3 Characteristics and chemical composition of FSs and MSBs

The characteristics and chemical composition of floor dried FSs and wet MFBs are presented in tables 2 and 3.

Table 2. Characteristics and chemical composition of FSs and MSBs.

Parameter	Floor dried FSs (n = 2)	Wet MSBs (n = 1)
pH	5.0	7.1
DM (g/100g)	84	27
Total N (g/kg DM)	35	110
P (g/kg DM)	81	60
K (g/kg DM)	1.2	12
Ca (g/kg DM)	135	110
Mg (g/kg DM)	0.895	2.5
S (g/kg DM)	3.0	6.1

DM dry matter, total N nitrogen, P phosphorous, K potassium, Ca Calcium, Mg magnesium, S sulphur.

Box 1 shows the proposed limits of concentrations of potentially toxic elements currently allowed in soil conditioners and organic fertilisers in Norway (LOVDATA 2003; Norwegian Agriculture Agency 2018). In FSs, the concentrations of Cd, Pb, Hg, Ni, Cu, Cr, and arsenic were below the proposed limit of class 0 soil amendment products (Box 1 and Table 3), while Zn (210 mg/kg DM) in the proposed limit of class II soil amendment products. In MFBs, the concentrations of Cd, Pb, Hg, Ni, Zn, Cu, and Cr were below the proposed limit of class 0 soil amendment products, while arsenic (6.9 mg/kg DM), in the proposed limit of class I soil amendment products (Box 1 and Table 3).

Box 1: Limits of concentrations of potentially toxic elements (heavy metals, mg/kg DM) currently allowed in soil conditioners and organic fertilisers in Norway (LOVDATA 2003; Landbruksdirektoratet 2018).

Quality classes:	*0*	*I*	*II*	*III*
Cd	0.4	0.8	2	5
Pb	40	60	80	200
Hg	0.2	0.6	3	5
Ni	20	30	50	80
Zn	150	400	800	1500
Cu	50	150	650	1000
Cr	50	60	100	150
As	5	8	16	32

As arsenic, Cd Cadmium, Cr Chromium, Cu Copper, Hg Mercury, Ni Nickel, Pb Lead, Zn Zinc.

The soil conditioners in class 0 may be applied to all types of land, such as agricultural areas, private gardens, parks, green areas, and the amount added must not exceed the plants' need for nutrients. The soil conditioners in class I may be used in amounts up to 4 tonnes of dry matter per decare (da) of agricultural land over a period of ten years or applied in layers of thickness of up to 5 cm on land not used for growing of food or feed crops. Soil conditioners in class II may be used in amounts up to 2 tonnes of dry matter per da of agricultural land over a period of ten years or applied as a top layer as described for the soil conditioners in class I. Soil conditioners in class III may be used as a top cover applied in layers of thickness of up to 5 cm during a period of ten years or used as a top layer up to 15 cm to cover the waste deposits. The soil conditioners of quality classes I, II and III should be mixed into the soil at the place of use (LOVDATA, 2003).

Table 3. Concentrations of potentially toxic elements (mg/kg DM) in FSs and MSBs.

	Floor dried FSs (n = 1)	Wet MSBs (n = 1)
Cd	0.24	0.02
Pb	1.3	0.34
Hg	0.019	< 0.70
Ni	2.4	2.1
Zn	210.0	67.0
Cu	4.2	1.8
Cr	4.5	0.68
As	2.3	6.9

Cd Cadmium, Pb Lead, Hg Mercury, Ni Nickel, Zn Zinc, Cu Copper, Cr Chromium, As Arsenic.

3.4 Characteristics and chemical composition of algae fibre, bottom ash and crab shells

The chemical analysis of representative samples of algae fibre showed an average pH value of 9.0 and DM of 25% (Table 4). In algae fibre, the concentrations of potentially toxic elements, such as arsenic was 32 mg/kg DM, which is the same value as the proposed limit of quality class III; while Zn, lead, Hg, Ni, Cu, and Cr were within the proposed limit of class 0 soil amendment products; and Cd (1.0 mg/kg DM), within the proposed limit of quality class II soil amendment products (Box 1 and Table 5).

Table 4. Characteristics and chemical composition of algae fibre, bottom ash and crab shells.

Parameter	Algae fibre* (n = 4)	Bottom ash (n = 2)	Crab shells** (n = 2)
pH	9.0	13.5	9.0
DM (g/100g)	25	100	76
Total N (mg/kg DM)	0.85	0.870	22.5
P (g/kg DM)	3.7	20.5	9.8
K (g/kg DM)	47.8	83	1.27
Ca (g/kg DM)	54.3	300	240
Mg (g/kg DM)	18.0	44	13.5
S (g/kg DM)	10.5	2.0	2.0

DM dry matter, total N nitrogen, P phosphorous, K potassium, Ca Calcium, Mg magnesium, S sulphur.

* **Algae fibre:** an average value of fresh and samples (under storage) from different batches I 2019 and 2020, where DM and total nitrogen represent an average of six samples, while other parameters an average of four samples.

** **Crab shells:** an average value of dried and wet samples. Therefore, the moisture content is presented as 76%. The DM of the wet sample was 56%, while the DM of the dried sample was 96%.

The concentration of Ca was very high in the samples of bottom ash 300 g/kg DM (Table 4). The analysis of samples from the wood ash, brought from 19 different factories in Norway, showed very high contents of calcium (Dibdiakova and Horn, 2014). The contents of calcium were also observed to be high in the ash samples that were taken from the sawmill wood chips and the fuel wood chips (Tingvoll Biovarme) (Sørheim et al., 2015).

In bottom ash, the concentration of arsenic, lead, Hg, and Cr were below the proposed limit of quality class 0 soil amendment products. The concentrations of Zn and Ni were within the proposed limit of quality class I, while the concentrations of Cu and Cd were within the proposed limit of quality class II soil amendment products (Box 1 and Table 5). The analysis of ash samples from the sawmill wood chips and the fuel wood chips (Tingvoll Biovarme) showed levels of arsenic (< 2.6 mg/kg DM), zinc (420 – 840 mg/kg DM), lead (5.6 – 41 mg/kg DM), and cadmium (8.6 – 15 mg/kg DM) (Sørheim et al., 2015).

Table 5. Concentrations of potentially toxic elements (mg/kg DM) in algae fibre, bottom ash and crab shells.

	Algae fibre (n = 2)	**Bottom ash (n = 2)**	**Crab shells (n = 2)**
Cd	1.0	1.0	0.04
Pb	0.5	1.8	0.3
Hg	0.03	0.006	0.04
Ni	6.8	28.5	0.3
Zn	91.5	325.0	21.5
Cu	1.9	185.0	7.2
Cr	2.5	15.5	0.4
As	32.0	< 0.5	8.7

Cd Cadmium, Pb Lead, Hg Mercury, Ni Nickel, Zn Zinc, Cu Copper, Cr Chromium, As Arsenic.

The analysis of samples of crab shells showed a pH value of 9.0. In crab shells, the concentrations of Cd, lead, Hg, Ni, Zn, Cu and were below the proposed limit of class 0 soil amendment products. The concentration of arsenic was 8.7 mg/kg DM, which was a bit over the proposed limit of quality class I soil amendment products (Tables 4 and 6).

3.5 Model calculations

3.5.1 Contents of nitrogen, phosphorous and potassium in FSs, MFBs, algae fibre, bottom ash and crab shells

From percentage contents of nitrogen (N), phosphorus (P), and potassium (K) for FSs, MFBs, algae fibre, bottom ash and crab shells, presented in Table 6, we wanted to see if these materials possess similar contents of N, P, and K as these are present in the commercially available organic fertilisers, which are commonly applied in Norway.

Table 6. Percentage average contents of nitrogen (N), phosphorus (P), and potassium (K) in fish sediments (FSs), minced fish backs (MFBs), algae fibre, bottom ash and crab shells.

	N (%)	P (%)	K (%)
FSs, dried*	2.9	6.7	0.1
MFBs, wet	3.0	1.6	0.3
Algae fibre	0.2	0.1	1.1
Bottom ash	0.1	2.0	8.3
Crab shells	1.9	0.7	0.1

* Nitrogen represents an average value of FSs, dried using different drying methods (Table 1).

The data (Table 6) showed that none of these materials is well-balanced to fulfil the requirements of agricultural crop plants in comparison to one of the commonly applied organic fertilisers, for Example, Eco 8K (8-3-5). FSs have a high content of P, and MFBs has some contents of N and P. Bottom ash has a very high content of K, algae fibre also has some K, and crab shells has some contents of N and P.

FSs and MFBs can be useful in some situations when there is a lack of P in the soil. The bottom ash can be an additional fertiliser when there is a lack of K and P in the soil.

Through calculations, we have presented six examples of fertilisation with and without cattle manure by adding materials: FSs, MSBs, algae fibre, bottom ash and crab shells (Tables 7 – 9). With a lack of cattle manure, it would be necessary to add commercially available organic fertilisers in combination with these materials. In the examples, we have used the commercially available fertiliser Eco 16-1-0 (Grønn Gjødsel, 2021).

3.5.2 Fertiliser combinations for growing grass-clover ley

The nutritional requirement of ley with an expected yield of 650 kg dry matter per decare (DM/da) is 15 kg N /da, 2.2 kg P/da and 7.8 kg K/da (Table 7). Since clover fixes nitrogen from the air, we do not need to add all the required amount of 15 kg N/da.

The example I that is presented in Table 7 shows that if we use FSs, then there will be a lack of N of about 7.7 kg/da. However, if we use MFBs instead of FSs, there will be a lack of N about 5.6 kg/da, which is more acceptable. As shown in example II, if we use 100 kg/da of MFBs rather than FSs, then we can also reduce the amount of the expensive fertiliser Eco 16-1-0 from 70 to 40 kg/da (Table 7). The lack of N will then be 4.3 kg/da with P and K in a balanced proportion.

Table 7. Two examples (I and II) of fertilisers with possible combinations of fish waste (FSs and MFBs), algae fibre, and cattle manure / Eco 16-1-0 that can fulfil the nutritional requirement of growing grass-clover ley with an expected yield of 650 kg dry matter (DM) per decare (in Norwegian: dekar) (DM/da).

Nutrient requirement (NR) of grass-clover ley * (650 kg DM/da)		**Nitrogen (N), kg/da 15**	**Phosphorus (P), kg/da 2.2**	**Potassium (K), kg/da 7.8**
Example I				
Fertiliser combinations of FSs/MFBs, algae fibre and cattle manure / Eco 16-1-0	**Amount, kg/da**	**N**	**P**	**K**
Cattle manure	2000	6.2	1.0	6.8
FSs / MFBs	30 / 100	0.9 / 3.0	2.0 / 1.6	0.0 / 0.3
Algae fibre	100	0.2	0.1	1.1
Total nutrients added (TNA)		7.3 / 9.4	3.1 / 2.7	7.9 / 8.2
Difference (TNA – NR)		-7.7 / -5.6	0.9 / 0.5	0.1 / 0.4
Example II				
Algae fibre	700	1.4	0.6	7.8
FSs / MFBs	100 / 100	1.9 / 3.0	0.7 / 1.6	0.1 / 0.3
Eco 16-1-0	70 / 40	11.0 / 6.3	0.3 / 0.2	
Total added (TNA)		14.3 / 10.7	1.6 / 2.4	7.9 / 8.1
Difference (TNA – NR)		-0.7 / -4.3	-0.6 / 0.2	0.1 / 0.3

*Pers. communication Maud Grøtta, Adviser at Norwegian Agricultural Advisory Service.

3.5.3 Fertiliser combinations for growing organic oats

Farmers who cultivate organic oats usually have a crop rotation. In this practice, nutrient consuming plants are grown in the same field where nutrient supplying plants were grown in the previous season. Fertiliser combinations that are shown in examples III and IV (Table 8) can fulfil the nutritional requirement for the expected yield of oats (*Avena sativa*). If there was ley on that field a year before oats, the after-effect would be about 3 kg N/da (NIBIO, 2021). In that case, a lower amount of nitrogen will be added than that is presented in table 8. Hence, here it is not appropriate to use FSs or MFBs alone because the supply of P will become too high and the supply of N and K too low. FSs (20 kg/da) or MFBs (85 kg/da) can fulfil the requirement of P, but then there will be a lack of N and K.

Table 8. Two examples (III and IV) of fertilisers with possible combinations of crab shells, algae fibre, and cattle manure / Eco 16-1-0 that can fulfil the nutritional requirement of growing oats with an expected yield of 400 kilos per decare (kg/da) (in Norwegian: dekar).

Nutrient requirement (NR) of oats* (400 kg/da)		**Nitrogen (N), kg/da 8.8**	**Phosphorus (P), kg/da 1.4**	**Potassium (K), kg/da 4.8**
Example III				
Fertiliser combinations of crab shells, algae fibre with addition of cattle manure or Eco 16-1-0	**Amount, kg/da**	**N**	**P**	**K**
Cattle manure	1500	4.7	0.7	5.1
Crab shells	200	3.7	1.5	0.2
Total nutrients added (TNA)		8.4	2.2	5.3
Difference (TNA – NR)		-0.4	0.8	0.5
Example IV				
Algae fibre	500	1.0	0.5	5.6
Crab shells	100	1.9	0.7	0.1
Eco 16-1-0	35	5.5	0.1	
Total nutrients added (TNA)		8.4	1.3	5.7
Difference (TNA – NR)		-0.4	-0.1	-0.9

*Pers. communication Maud Grøtta, Adviser at Norwegian Agricultural Advisory Service.

3.5.4 Fertiliser combinations for growing organic leek

Leek (*Allium porrum* L.) is a nutrient-demanding plant, and the growing season must be long to achieve high yields (Solberg, 2021). Fertiliser combinations that are shown in Examples V and VI (Table 9) can fulfil the nutritional requirement for the expected yield of leek, and the differences between the requirements and the supply of N, P and K that are presented are acceptable. For leek, there is a need of commercially available fertilisers in addition to the algae fibre and ash or other materials that we have analysed (Table 6).

Table 9. Two examples (V and VI) of fertilisers with possible combinations of bottom ash, algae fibre, cattle manure / Eco 16-1-0 that can fulfil the nutritional requirement of growing leek with an expected yield of 2000 kilos per decare (kg/da) (in Norwegian: dekar).

Nutrient requirement (NR) of leek* **(2000 kg DM/da)**		**Nitrogen (N), kg/da** **14.7**	**Phosphorus (P), kg/da** **3.0**	**Potassium (K), kg/da** **10.7**
Example V				
Fertiliser combinations of bottom ash, algae fibre with addition of cattle manure or Eco 16-1-0	**Amount, kg/da**	**N**	**P**	**K**
Cattle manure	2000	6.2	1.0	6.8
Bottom ash	100	0.0	1.0	4.1
Eco 16-1-0	50	7.9	0.2	0.0
Total nutrients added (TNA)		14.1	2.2	10.9
Difference (TNA – NR)		-0.6	-0.8	0.2
Example VI				
Algae fibre	400	0.8	0.4	4.5
Bottom ash	80	0.1	1.6	6.6
Eco 16-1-0	90	14.1	0.3	0.0
Total nutrients added (TNA)		15.0	2.3	11.1
Difference (TNA – NR)		0.3	-0.7	0.4

*From Solberg, 2021

It is not appropriate to use FSs or MBFs in combination with manure for leek as it would provide too much P but with deficiency of N and K.

Nevertheless, if there is a lack of phosphorus in the soil, then phosphorous demand for leek can be increased to 13 kg/da (NIBIO, 2021). In this condition, 160 kg/da of FSs could be an alternative fertiliser in addition to 2.5 tonnes/da with cattle manure and 40 kg/da with commercially available Eco 8-3-5.

If there is lack of potassium in the soil, the K-demand for leek can be increased to 16 kg/da (NIBIO, 2021), then the amount of bottom ash in Example V (table 9) should be increased to 115 kg/da.

3.6 Discussion about chemical composition of materials and fertilisation

3.6.1 FSs, MFBs and other RRMs should achieve the status of quality class 0 soil amendment products

Even though the materials (fish sediments, minced fish backs, bottom ash, algae fibre, and crab shells) that we have investigated in this study are not balanced in terms of contents of N, P and K, but they still can be applied in combination with cattle manure and purchased fertiliser and would be beneficial for fertilising organic grass-clover ley, oats and leek. But before they can be used as fertilisers, the contents of potentially toxic elements (Tables 3 and 5) need to be reduced. To come up to the level of applying these materials as fertilisers on all types of land and for all kinds of plants, these materials should achieve the status of class 0 in the classification system of soil amendment products (Box 1). For fish sediments, there is a need to reduce the amount of zinc which was classified in class II. Fish backs and crab shells also have high contents of arsenic. The bottom ash also had high contents of zinc, nickel, copper, and cadmium.

We assume that the area where the fish will be caught would affect the concentrations of toxic elements as well as the nutritional content. In that perspective, it will be difficult to catch fish that contain contents of toxic elements, which can come under the classification of quality class 0. Thus, to reduce the amount of these toxic elements, the fish sediments, fish backs, and crab shells would require some kind of rinsing before they can be mixed with other materials/directly applied as fertilisers.

The area and soil where the trees are grown (the trees that become wood chips) affect the content of heavy metals in the wood chips. This is consecutively important for how much of these elements will be in the bottom ash that is coming from the wood-chip combustion plant. But it is not realistic to use trees with low contents of heavy metals to make wood chips, and thus it is necessary to invest in cleaning technology. Maybe it is possible to install some type of equipment in the grate-fired incinerators or the wood chip combustion plants that can reduce the concentration of heavy metals in the bottom ash and achieve classification in category 0 for the ash. A technology that separates the heavy metals so that these heavy metals can be reused in other industry where they are required would be a significant advantage. A recent article has discussed the technologies to extract heavy metals from fly ash (Meer and Nazir, 2018), where they concluded that the selection criteria for the possible process depends very much on the nature of ash and the metal under consideration.

3.6.2 FSs, MFBs and other RRMs require processing/pelleting, investments, and costs

The fish waste and the crab shells need to be dried to keep them in a stable form or/to apply as additives in other fertilisers. If the materials that we have investigated should be convenient for farmers to use as fertilisers, then there is a need for processing or pelletising. This would require investments and costs by the fishing industry, and there will probably be no investment without a market that need these residual products.

4 Conclusions and future prospects

1. The research experiments have provided us with the basic information about how the drying-method, the drying temperature or air-circulation can reduce the weights of wet samples of fish sediments and minced fish backs over time and what can be the outcome.
2. Different drying methods/drying temperatures showed variations in the weights of samples at the final point of drying and the duration it takes for samples to dry. These variations can be due to the sample material, the duration period, or can be due to other unknown factors. At the same time, a limited number of samples don't provide sufficient knowledge, and hence this should be investigated further by taking a greater number of samples, performing the experiment under the same set-up, and repeating the drying experiments at least twice.
3. Duration wise, the most efficient method was drying at 80° where the dry material was obtained within 12 hours. This method is energy demanding (costly) but would likely reduce unwanted microbial growth and thus improve the stabilisation of the dried material. At 25°C with air-circulation, it is possible to have a dry material within a reasonable duration. But this method may not be suitable for drying of non-conserved (fresh) marine by-products as microbial growth may occur in the final product. That would be an interesting topic for further study.
4. Future studies should also aim at conducting drying experiments on a large scale by selecting the most effective drying temperatures/methods. The drying of fish sediments on the floor in a closed ventilated room represents a good option for farmers as this method will consume less energy and is economically more feasible. Nevertheless, the stability of the final product should also be checked by the analysis of microbial growth in storage experiments.
5. Drying with most of the methods showed slightly reduced pH values of samples of minced fish backs (MSBs), with the exception of vacuum freeze-dried samples of MSBs. In contrast, the pH of fish sediments (formic acid-treated) samples showed slightly greater values after drying with different methods. Irrespective of the material (FSs or MSBs), the circulation of air does not seem to affect the pH of samples.
6. Air-circulation reduced the concentrations of ammonium nitrogen in samples of fish sediments after drying at different temperatures, especially after drying at 25°C and 80°C. However, the results based on three representative samples just give us an understanding. This needs to be studied further by repeating the drying experiments and analysing a greater number of samples to get sufficient information.
7. The concentrations of ammonium nitrogen almost reduced to half in wet samples of minced fish backs after a storage period of 10 months in a freezer, where a slight increase in pH (7.1 to 7.5) was also observed. But this information is based on a very limited number of samples, and thus it is difficult to draw any concrete conclusion. Hence, in future, it would be interesting to perform a comprehensive study about how the storage of material affects pH and the contents of ammonium and total nitrogen in minced fish backs or a similar kind of fish waste.
8. Neither fish waste (fish sediments or minced fish backs) nor other residual raw materials (algae fibre/bottom ash/crab shells are well-balanced individually or in combination to be applied as

fertilisers for grass-clover ley, oats, or leek. However, these materials can be valuable as additive fertilisers.

9. It is possible to combine cattle manure, fish sediments or minced backs and algae fibre to provide fertilisation for organic grass-clover ley. Eco 16-1-0 fertiliser can be used if cattle manure is not available.
10. Cattle manure with the addition of crab shells / or Eco 16-1-0 in combination with algae fibre and crab shells can be a good fertiliser for oats. For a nutrient demanding crop, such as leek, Eco 16-1-0 fertiliser must be included to satisfy the nutrient requirements.
11. The bottom ash, together with cattle manure and Eco 16-1-0, supplies organic leek with the required amount of nitrogen, phosphorus, and potassium. If cattle manure is not available, then there is a need to add more amounts of Eco 16-1-0.
12. If there is a lack of P in the soil, then fish sediments and minced fish backs can provide suitable fertilisation, and if there is a lack of potassium, then bottom ash can be applied.
13. To apply fish waste, crab shells or bottom ash as fertilisers, the contents of heavy metals that exceed the limit of class 0 soil amendment products must be reduced.
14. There is a need for further development and processing in the form of drying and/or pelleting in order to be practically possible for farmers to apply these materials directly as fertiliser. Alternatively, these materials can be mixed with other commercially available fertilisers.

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