Fish silage as feed ingredient for fish and livestock

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IMARES report C135/14

IMARES Wageningen UR

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BO-27.04-002-105

Publication date: 12 December 2014

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Summary

Fish processing results in a big volume of by-products which are valuable sources of proteins for agriculture and aquaculture. Offal can range between 50% and 70% during fish filleting depending on the fish size and species. Wastes include frames, rests from trimming, guts, skins, fats, fillet rejects, viscera, fats, roes/eggs, fish maws, heads, breasts, scales and deteriorated filets.

The present report analyses through a literature review the potential of fish silage to valorise fish processing by-products into economically relevant protein sources for fish and livestock feed production in East Africa. Fish silage is a liquefied fish protein made from fish by-products by the action of enzymes in the presence of added acids or acid-producing bacteria. Information comprises fish silage production technology, composition and previous use in fish and livestock diets in Western countries. Field data collected during a short field visit in Kenya and Ethiopia show two different trends in the availability and use of freshwater fish by-products. In Kenya, by-products from fish processing are mainly from Nile perch and are used for human consumption. In Ethiopia, by-products are mainly from Nile tilapia and are dumped into the lake. Regarding marine fish by-products in the region, a tuna processing and canning plant in Somalia can produce 12 tonnes of fish silage per day. In Kenya, a tuna processing factory generates 40 tonnes of fish wastes per day which are converted into fish meal, a process which is energy inefficient. Compared to fish meal production, fish silage production uses a simple technology, requires a low investment and is economically viable already at small scale. Business plans and business models demonstrate a quick and sustained return on investment starting after the 1st year of investment.

To provide a solution to shortage in protein sources in developing countries, IMARES and Livestock Research, both parts of DLO/ Wageningen UR, have identified research still needed in this area. A partnership with Dutch companies, research and industrial partners in East Africa has been made and a project proposal has been submitted to the Top Sector Agri&Food to conduct research on the production and use of fish silage in fish and livestock feeds.

1. Introduction

1.1. Definition

Fish silage is a liquefied fish protein made from whole fish, parts of fish or fish offals by the action of naturally present enzymes or added enzymes that hydrolyse the proteins in the fish in the presence of added acids or acid-producing bacteria via carbohydrate fermentation. The endogenous enzymes break down further fish proteins into smaller soluble units, and the acid helps to speed up their activity while preventing bacterial spoilage (Tatterson and Windsor, 2001). In addition to reducing the pH and preventing the growth of spoilage bacteria, the acids will help to solve the bones and cartilage (Tatterson, 1982). The end product is a semi-liquid product which can be concentrated into a paste-like product after removal of solids, oil and water.

1.2. Production and use

Fish silage was produced first in the 1930's in Sweden followed by Denmark 10 years later. Fish silage has been produced at commercial scale in Poland and Denmark for the production of poultry and pig feed or as a protein complement incorporated in feeds for domestic animals and fish (Arruda *et al.*, 2007). In Denmark, Poland and Norway, the production of fish silage for inclusion in pig, poultry and mink diets is a common practice (Jackson *et al.*, 1984). A pilot scale trial has been set up in UK (Tatterson and Windsor, 2001). Although interest in the production, use and research on fish silage existed in other countries within and outside Europe, the production has remained of small or experimental scale. In Indonesia, silage was produced at experimental scale and used in rations which substituted fish and soy meals in the feed of swine, fish and birds (Kompiang, 1981). In Iceland, silage has been tested on experimental scale and produced by companies on a commercial scale in the 1980's (Arason *et al.*, 1990). In New Zealand, a project tested the use of fish silage on livestock and concluded on a reduction of peak rumen methanogenesis, a reduction of faecal egg counts of internal parasites and an increase in omega fatty acids in milk of dairy cows (Gibbs, 2012). Fish silage is mainly used as an animal feeding stuff but is also used in soil health improvement in agriculture and in horticulture.

1.3. Production technology

The raw materials for silage production consist of by-products from fish processing made of heads, cut-offs, frames, skin bones and viscera, fish discards, fish refuses from fresh commercialisation markets, fishing produce inadequate for consumption or of low commercial value, and fish that are damaged or unsuitable for human consumption or further processing. In most fish species, heads represent the biggest by-product fraction amounting 10% in Atlantic salmon (Rustad, 2007) and between 20% and 25% in carp (Bukovskaya and Blockhin, 2004)). The viscera accounts for 14% in Atlantic salmon and 3 to 5% in carp.

The most important factor in successful fish silage production is the freshness of the raw material. Whole fish or processing waste in which some spoilage or bacteria breakdown has occurred is not suitable for silage-making, because the resulting product will be poor in quality, with a high bacteria content and unpleasant odour (Winter and Feltham, 1983).

Three methods may be used for the production of silage by the addition of acids, enzymes or lactic acid bacteria. However, the most common is the acid production method. After grinding and acidification of fish by-products, a crude silage also called cold silage is produced. From crude silage obtained after acidification, a concentrated silage product is produced after removal of solids (bones), oil and water (Figure 1).

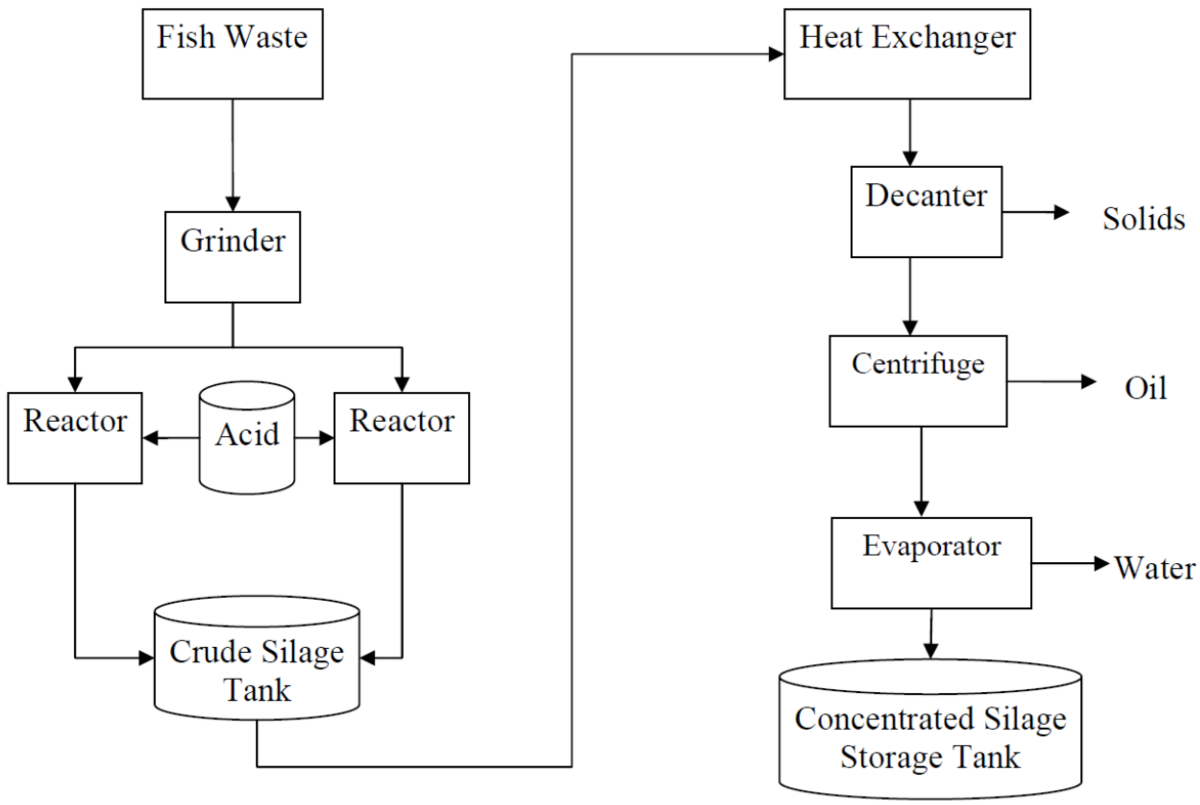


Figure 1. Flow diagram for the traditional production of crude and concentrated fish silage

1.3.1. Acid production method

Fresh raw material is first minced or grounded in small particles before mixing with appropriate acids or mixtures of acids. By grinding and mixing, already present enzymes are spread throughout the fish mass and the acidity adjusted to favour the rapid action of these enzymes and to inhibit bacterial action. The silage is thoroughly mixed to ensure it is completely acidified and the operation is repeated on several successive days to prevent spoilage and to have a homogenous silage product. The enzymes mainly responsible for the liquefaction are those of the gut, skin and other parts of the fish other than flesh; those of the last are only marginally implicated (Backhoff, 1976).

The rate of autolysis depends on the activity of the present enzyme, the pH, the temperature and the types of preservative acids used. The optimal pH of the most important enzymes, the proteases, ranges between 2 and 5 depending on the enzyme and tissue being digested. A pH in the range of 4-4.5 appears to favour rapid autolysis. In larger, mechanised operations, the acidified mixture must be heated to about 30^{o}C to hasten the breakdown of the of tissue proteins. The warmer the mixture, the faster the process is. Fish silage protein is about 80% liquefied after one week at temperatures ranging between 23-30^{o}C. Silage made from fresh white fish offal takes about two days to liquefy at 20°C, but takes 5-10 days at 10°C, and much longer at lower temperatures.

Various acids and their mixtures may be used. Inorganic acids such as hydrochloric acid and sulphuric acid, organic acids such as formic acid, acetic acid, propionic acid or combinations of these acids (Table 1) are added to minced or ground fresh fish material to lower the pH to a point at which intrinsic enzymes naturally present in the raw fish waste liquefy the fish protein.

Table 1. Acids commonly used in the production of acid fish silage (Winter and Feltham, 1983)

Preservatives	pH of the silage	Characteristics
Sulfuric acid 4-5%	2.5-3.5	Very low pH. Requires neutralisation use in animal diets
Sulfuric acid 2.6% plus acetic acid 1.1%, 200 ppm ethoxyquin	3.5-4.0	Low pH restricts amount used
Sulfuric acid 2.5% plus 0.5% acetic or formic acid	3.5-4.0	Low pH restricts amount used
Formic acid 3.5%	4.0-4.5	
Formic acid 2% plus propionic acid 0.3-0.5%	4.5-5.0	Used for viscera silage with a low mineral content

Inorganic acids are strong in reducing the pH but have limited antimicrobial properties. Since they are able to reduce the pH below 4 they indirectly work antibacterial against gram-negative bacteria, leaving the remaining microbes unaffected (Figure 2). Organic acids are known for their anti-microbial power, nevertheless each organic acid has its own specific anti-microbial strength.

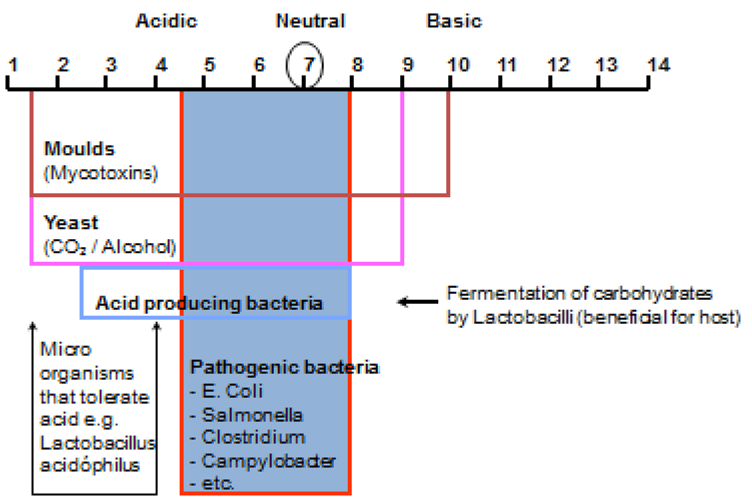


Figure 2. pH tolerance of different microorganisms (source: Selko-Feed Additives)

Organic acids, such as formic acid, are generally more expensive than the mineral ones. A mixture of formic and propionic acids has been recommended. If a 1:1 formic-propionic ratio is used as well as the addition of 3% volume/weight to the biomass, the silage obtained is stable, with an acidified aroma (Kompiang, 1981).

Acids and their combinations present different advantages (Winter and Feltham, 1983; Tatterson and Windsor, 1974):

- Sulphuric acid is one of the cheapest and most readily available acids for fish silage making. Because of the very low pH (2.5-3.0) required to prevent gram-negative bacterial growth, fish silage must be neutralized before use for feeding purposes.
- Formic acid is the most widely used organic acid. It is more expensive than sulphuric acid and since preservation is achieved at higher pH of 4.0-4.5 because of antiseptic properties of formic acid, it does not require neutralisation before feeding to animals. Formic acid is less corrosive than stronger mineral acids and has a good bacteriostatic effect. The least expensive mixture for the preservation of sardine offal was found to be a 3% mixture of sulphuric acid and formic acid at a ratio of 3:1 (Lisac, 1961).
- Hydrochloric acid and heat have the advantage of speeding up digestion considerably.
- Propionic acid (organic) is used only in combination, generally with formic acid. Propionic acid kills or inhibits bacteria at higher pH, preserving fish silage at a pH of 4.5-5.0.

The most economical preservatives are a mixture of organic and inorganic acids. Inorganic acid which is less costly is used to lower the pH to the point at which the organic acid exerts its antimicrobial effect. Although more expensive, organic acids have greater efficacy than inorganic acids and produce less acidic silage that does not require neutralisation before use. Among organic acids, formic acid (4%) treated fish silage was found to be superior to acetic or lactic acid preserved silages (Olivo *et al*., 1998). Organic acid are also less corrosion aggressive to silage container. The production tank must be acid resistant: steel containers with a polyethylene liner to prevent corrosion, concrete tanks treated with bitumen for large quantities.

The use of inorganic acids results in acidic silage that must be neutralized before use to avoid a low pH level in the complete diet. Different products have been used to neutralise the silage and include limestone, trona powder (sodium sesquicarbonate, $Na_2C0_3{\cdot}NaHC0_3\ 2H_20$) (Fagbenro and Jauncey, 1998), (sodium hydroxide and calcium hydroxide (Hardy *et al.* 1983).

1.3.2. Microbiological production method

An alternative method is the lactic acid fermentation technique using acid-producing bacteria (Vázquez *et al.*, 2011; Dapkecivius *et al.*, 2000; Borghesi *et al.*, 2008). This process requires the addition of a source of carbohydrate and anaerobic storage. Minced fish material is mixed with a carbohydrate source, for example molasses added to a level of 10% of the fish by weight, and inoculated with a lactic acid bacteria (*Lactobacillus* sp.) culture. Lactobacilli convert sugar into lactic acid which lowers the pH of the fish material to 4.5 or lower, resulting in a stable product. Lactic acid bacteria produce also antibiotics which destroy competing spoilage bacteria. Lactobacilli are also considered to prevent the oxidation of fats. Fish silage production by the fermentation method has not reached yet a commercial scale of production, but the method is attractive since preservation by fermentation does not depend on acids which are dangerous to handle (Raa *et al.*, 1982).

1.3.3. Enzymatic production method

The enzymatic production method of silage involves the addition of external enzymes, mainly proteolytic enzymes to the fish minces. Borghesi *et al.* (2008) produced enzymatic silage by the addition of 10 g of protease type II from *Aspergillus oryzae*.

1.3.4. Oil removal

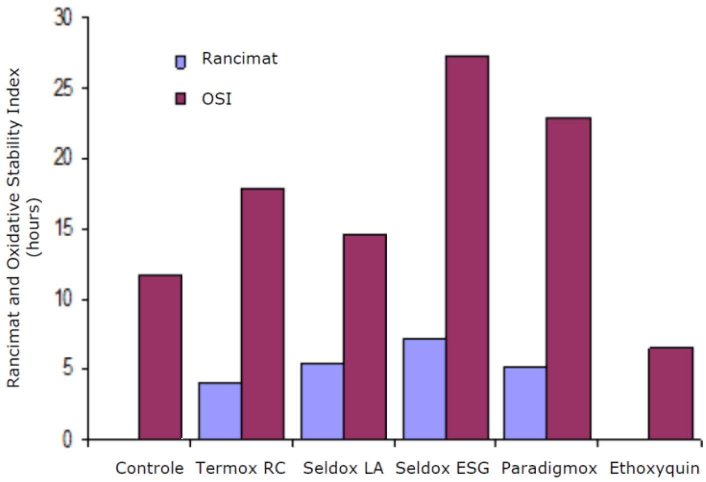
Fish oil from fatty fish deteriorates very rapidly during silage and must be removed and used for other purposes. Following liquefaction, the silage may be further heated to 80-90°C to allow for oil separation after centrifugation. While the oil content of fish silage can be up to 40% oil in fatty fish like herring and mackerel, fish silage made from the heads and frames of low-oil species can contain less than 5% oil.

1.3.5. Controlling excessive hydrolysis

Prolonged hydrolysis of fish silage can result in high levels of free amino acids which in diets may interfere with the mechanisms of both amino acid and polypeptide absorption in fish (Goddard and Al-Yahyai, 2001). It has also been suggested that free amino acids may depress fish appetite (Wilson *et al.,* 1984). Prolonged hydrolysis can also lead to the loss of essential amino acids such as tryptophan, phenylalanine, tyrosine and arginine (Lall, 1991). Autolysis can be arrested by cooking the raw fish prior to addition of acid or the start of fermentation, pasteurisation, addition of formalin, addition of enzyme inhibitors or further reduction of the pH.

1.3.6. Preservation

Lipid oxidation is an important factor that lowers the quality of fish products, particularly during storage. Well-preserved fish silage has normally a pH of 3-4 which is the optimum pH for pepsins (Rustad, 2007). The oxidative process can be accelerated if the fish silage is in contact with light and air. Lipid oxidation in the silage during storage might be prevented by using antioxidants along with acids (Shahidi, 2007). Ethoxyquin or butylated hydroxytoluene (BHT) at 150-200 ppm are commonly used anti-oxidants (Winter and Feltham, 1983) and fresh onion was successfully used as antioxidant by Fagbenro and Jauncey (1998). Selko B.V. found good results with Seldox ESG in the prevention of oxidation of salmon oil (Figure 3). Seldox ESG consists out of a combination of Propyl Gallate and Citric acid.



Antioxidant	Rancimat (h)	OSI (h)
Controle	n.d.	11.7
Termox RC	4.1	17.9
Seldox LA	5.4	14.6
Seldox ESG	7.2	27.3
Paradigmox	5.2	22.9
Ethoxyquin	n.d.	6.5

Figure 3. Oxidative stability of salmon oil with different antioxidants.
(Source: Trouw Nutrition The Netherlands, 2010)

2. Composition of fish silage

2.1. Chemical composition

In a number of studies the chemical composition, including amino acids, of fish silage has been analysed. In general, the main components in fish silage dry matter (DM) are crude protein, mainly in the form of free amino acids, and crude fat, mainly in the form of free long-chain fatty acids. The chemical composition depends on numerous factors such as origin of the fish (marine of fresh water), fish species (e.g. herring/mackerel versus cod/haddock), ratio between viscera (liver) and frames in fish offal, ensiling process (acidified versus fermented) and the extend of fat extraction. Increasing the ratio between viscera and frames will increase the proportion of fat at the expense of protein and ash (Haard *et al.*, 1985). Mineral and vitamin content varies between studies and depends on the composition of fish offal (inclusion of frames and viscera) and the fish species that are included. Some data on the chemical composition of fish silage of acidified marine fish silage, with or without fat extraction are presented in table 2.

2.1.1. Dry matter

The dry matter content of fish silage varies between approximately 10% and 50%. Dry matter content is influenced by processing method. Concentrating fish silage by water evaporation increases the dry matter content.

2.1.2. Crude protein

Crude protein content varies, depending on the fish species and the type of offal that is used and the addition of other ingredients. The reported protein content was 16.9% for cod frames, between 17.4% and 18.2% in salmon frames, between 12 and 22% in cut-offs of wild and cultured carp, 10.6% in salmon viscera and between 15-26% in viscera of wild and cultured carps (Liaset *et al.*, 2000; 2002; Michelsen *et al.*, 2004; Bukovskaya and Blokhin, 2004)

For the production of fermented fish silage, soluble carbohydrates, often molasses, are added as a substrate for lactic acid bacteria, which dilutes the other chemical components (Vidotti *et al.*, 2003). Although the crude protein content of fish silage is in general similar to that of fish meal, the true protein content will be different. In fish silage, the protein has been hydrolysed enzymatically resulting in an increase in free amino acids and peptides. Within 4 to 7 days, the degree of protein hydrolysis can increase to 30 to 50% (Tomczak-Wandzel and Medrzycka, 2013), the rate and degree of hydrolysis depending on the storage temperature.

In an earlier review on the use of fish silage (Raa et al., 1982), a degree of hydrolysis of 80% within 1 week at a temperature range between 23 and 30^{o}C was reported. Within 1 week of ensiling cod fish, almost 20% of the nitrogen was in the form of free amino acids raising to about 45% after 4 weeks (Haard *et al.*, 1985). Because peptides and free amino acids are more vulnerable for ruminal microbial degradation, protein hydrolyses will have an impact on the nutritive value of fish silage for ruminants (see § 4.7).

2.1.3. Amino acids

Fish silage contains considerable amounts of free amino acids released in the hydrolysis process which are suspected to act as attractants (Berge and Storebakken, 1996). Differences in amino acid profile between acidified and fermented silage from salt and fresh water fish were studied by Vidotti *et al.* (2003). In this study, acidified silages from salt water fish and tilapia residues were relatively short in tryptophan, valine and isoleucine, whereas acidified silage from fresh water fish residues was relatively short in valine and isoleucine in comparison to the protein standard according to FAO/WHO.

In a technical bulletin, Winter and Feltham (1983) mentioned a loss of tryptophan and possible histidine during storage. However, after storage of cod and Pollack silage for 24 days no reduction in tryptophan was observed (Strøm and Eggum, 1981). In another study, using marine fish residues (Ramasubburayan *et al.*, 2013), level of formic acid application had a large influence on amino acid concentration and amino acid composition. With increasing acidity of the fish silage, the total amino acid concentration decreased from 292 g/kg DM with 2.0% added formic acid (initial pH 5.2) to 68 and 48 g/kg DM with 2.5% (initial pH 4.8) and 3% formic acid (initial pH 4.6), respectively. Meanwhile with increasing acidity the proportion of threonine and glycine decreased concomitant with an increase in aspartic and glutamic acid (Table 3). However, the relatively low amino acid concentrations of the fish silages with 2.5 and 3.0% formic acid also raise questions on the sampling and analytical methods in this study.

The essential amino acid profile of fresh water fish (carcass fish) silage appears similar to that of marine fish silage (Ristić *et al.*, 2002). Amino acid composition of acidified marine fish silage with or without fat extraction is presented in table 3.

Table 2. Chemical composition of acidified fish silage

Type / batch	Dry matter g / kg	Ash g / kg dry matter	Crude protein	Crude fat	Reference
Acidified, defatted marine fish silage					
Salmon offal 1	492	171	709	57	Kjos *et al*., 1999ab & 2000
Salmon offal 2	521	144	764	69	
Coalfish	127	87	787	47	Krogdahl, 1985
Haddock&Cod1	134	97	700	30	
Haddock&Cod2	436	85	731	48	
Haddock&Cod3	474	86	725	78	
Haddock&Cod4	420	129	714	48	
Atlantic cod	177	96	757	6	Strom & Eggum, 1981
Saithe	136	125	779	7	
Unknown (commercial plant)			699		Vidotti *et al*., 2003
Cod offal	260		485		Winter & Feltham, 1983
Cod offal	280		561		
White fish offal	180		599	26	
Sole heads & frames	240		483		
Acidified marine fish silage					
Mackerel	338	67	435	440	Green *et al*., 1988
Herring	289	0	438	373	Nicholson & Johnson, 1991
Grouper, 2% FA	93	142	384	107	Ramasubburayan *et al*., 2013
Grouper. 2.5% FA	170	142	367	112	
Grouper, 3% FA	191	140	361	122	
Cod	217	127	558	143	Rose et al, 1994
Dogfish	256	133	732	223	Strasdine *et al*., 1988

Table 3. Amino acid concentration (g/16 g nitrogen) of acidified fish silage

EAA											NEAA								
Type, batch	**Arg**	**His**	**Ile**	**Leu**	**Lys**	**Met**	**Phe**	**Thr**	**Trp**	**Val**	**Ala**	**Asp**	**Cys**	**Glu**	**Gly**	**Pro**	**Ser**	**Tyr**	**Reference**
Acidified, defatted marine fish silage																			
Pollack		1.7	3.7	6.5	5.1	2.9	3.6	3.6	0.6	4.3									Krogdahl, 1985
Haddock & Cod1		1.7	3.4	6.5	6.0	2.2	3.3	4.3	0.3	4.3									
Haddock & Cod2		1.7	3.5	6.4	5.9	2.4	3.4	4.0	0.4	4.3									
Haddock & Cod3		1.7	3.5	6.4	5.9	2.2	3.3	3.8	0.4	4.3									
Haddock & Cod4		2.0	4.3	6.8	6.0	1.9	2.9	4.2	0.8	5.1									
Atlantic cod	5.2	2.0	5.1	8.6	5.7	2.4	3.9	4.6	1.1	5.5	6.0	7.3	1.1	10.2	7.5	4.9	4.7	2.2	Strom & Eggum, 1981
Pollack	5.1	2.6	4.3	8.0	6.8	2.3	4.1	6.1	1.1	6.3	6.8	8.4	1.1	11.8	7.3	5.0	5.0	1.0	
Marine	6.1	5.7	3.1	7.3	7.9	3.8	4.1	4.6	0.7	4.2	7.4	7.8	1.5	14.0	8.2	5.7	4.5	3.5	Vidotti *et al.*, 2003
Acidified marine fish silage																			
Mackerel	8.5	2.6	5.6	9.8	11.7	3.1	4.4	4.5		5.8	8.4	12.4	1.0	18.6	8.4	4.8	3.9	3.4	Green *et al.*, 1988
Herring	3.8	5.7	2.3	4.7	2.8	2.1	2.5	3.2		3.4	3.0	7.1	0.2	9.4	3.0	2.5	2.8	2.1	Nicholson & Johnson, 1991
Herring	6.1	1.5	3.2	5.7	4.0	2.2	2.7	1.9		4.1	2.1	6.6		8.8	5.0	4.3	1.7	2.1	
Grouper 2% FA	6.4	2.0	4.7	2.3	5.5	2.0	3.8	8.4	1.2	2.0	4.4	3.4	0.7	4.3	9.3	2.0	6.1		Ramasubburayan *et al.*, 2013
Grouper 2.5% FA	1.2	0.9	0.9	0.3	1.2	0.9	0.3	0.3	0.3	0.3	0.8	3.1	0.6	4.1	0.9	0.3	0.3		
Grouper 3% FA	0.3	0.6	0.3	0.3	0.3	0.3	0.3	0.6	0.3	0.3	0.2	3.1	0.3	3.7	0.3	0.3	0.9		
Cod			4.3	6.6	7.0	2.2	3.4	8.6		4.3								2.9	Rose *et al.*, 1994
Dogfish	5.1	1.6	2.9	4.9	4.9	1.8	2.3	3.4		3.4	4.6	6.1	0.5	9.7	8.1	4.9	4.2	1.8	Strasdine *et al.*, 1988

In figure 4, the average values for the essential amino acids extracted from this table are compared to fish meal and soybean meal. From this figure it can be concluded that the average concentration of lysine and methionine – often regarded as the main limiting amino acids – in fish silage are comparable to those in soybean meal.

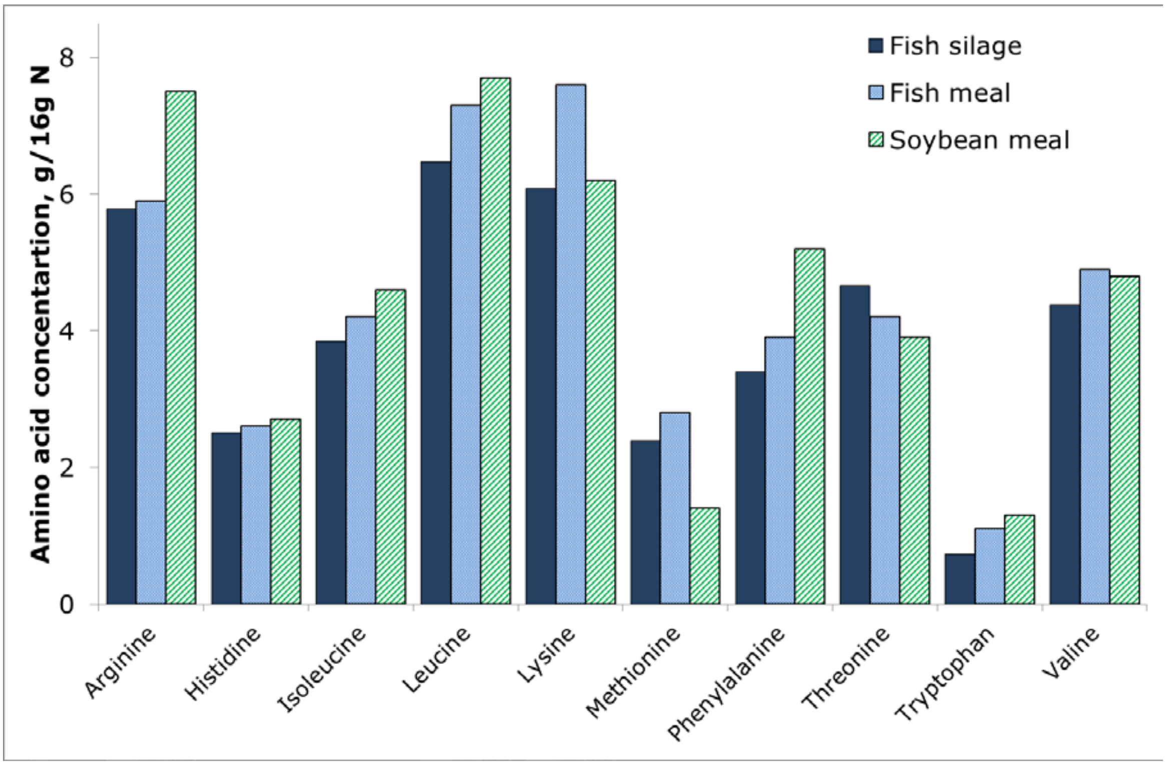


Figure 4. Comparison between average essential amino acid concentration of acidified fish silage and of fishmeal and soybean meal. References for fish silage: see Table 3, but data for high formic acid treated silage by Ramasubburayan *et al*. (2013) have been excluded. Amino acid composition of fishmeal and soybean meal from (CVB, 2011).

Although no reports in literature were found on specific beneficial effects of fish silage on animal performance, a possible health effect of bioactive peptides present in fish silage cannot be ruled out. In fish protein hydrolysate, in which protein hydrolysis can be controlled by using different enzymes, the presence of bioactive peptides has been demonstrated (Chalamaiah *et al.*, 2012). These peptides can have an antioxidant, antihypertensive, immuno-modulatory and anti-microbial activity.

2.1.4. Fat

Fish silage contains relatively high levels of fat (oil). The oil content depends on the type of fish offal and on the proportion of viscera (liver) in the offal (Haard *et al.*, 1985). After storage, more than 80% of fatty acids in fish may be in the form of free fatty acids (Johnsen and Skrede, 1981). The main fatty acids in fish silage are palmetic acid (C16:0), oleic acid (*n*-9 C18:1), gondoic acid (*n*-9 C20:1) and docosahexaenoic acid (DHA; *n*-3 C22:6) (Johnsen and Skrede, 1981).

2.1.5. *Vitamins*

Vitamin levels of marine fish silage vary with the level of acidity. Increasing the acidity by increasing application rate of formic acid, decreased the levels for thiamine (B_1), Riboflavin (B_2), Cyanocobalamine (B_{12}) and niacinamide and increased the levels of vitamins C, D and E (Ramasubburayan *et al.*, 2013). Livers can be high in vitamin A content. Thus, in fish silage with a relatively high proportion of liver, vitamin A content of fish silage may be high, increasing the risk of vitamin A toxicosis in growing animals (Coates *et al.*, 1998). Because vitamin A is soluble in fat, defatting fish silage will reduce the vitamin A concentration in fish silage. Thiamine in the diet can be destroyed by thiaminase, which can be present in fish silage prepared from fresh water fish (Winter and Feltham, 1983). This may result in a vitamin B_2 deficiency.

2.1.6. *Minerals*

Fish silage can be a good source of readily available minerals, especially of calcium and phosphorous. However silage from viscera is lower in mineral content than silage from whole fish, heads or frames.

2.1.7. *Toxins, heavy metals and pesticides*

Some fish species of the order Tetraodontiformes contain toxins with the most known the puffer fish. Before using these toxic fish species, usually from by-catch, in silage, it has to be determined whether the toxin is inactivated by the acidity, heating or the enzymes in the silage (Raa *et al*., 1982). Contaminated fish with heavy metals, organ chlorines, organophosphates, PCBs, or any other form of toxicants make the fish and their processing by-products unsuitable for both consumption and silage use, respectively. This is also the case for those microbial contaminated fish and fish by-products.

2.2. Microbiology

The microbial aspects of fish silage should be regarded as a food safety aspect. The survival of pathogenic micro-organisms (bacteria, parasites, viruses, fungi) depends on the processing method. It is assumed that heat treatment (autoclaving) prior to ensiling will inactivate most of these pathogens. Heating at > 85^{o}C for at least 25 minutes and storage at a pH < 4.5 has been legally classified as a safe method for inactivating non-spore-forming bacteria (*Salmonella, Escheria coli, Listeria, Mycobacterium*), *Clostridia perfringens*, moulds, *Saprolegnia*, parasites and viruses in fish residues (Norwegian Scientific Committee for Food Safety, 2010). It is also assumed that spores of *Clostridia perfringens* (latent in decomposing freshwater fish) will not germinate as long as a pH < 4 is maintained and that preformed toxins of type E (botulin) will be destroyed by this processing method. Although this so-called FSP method does not inactivate mycotoxins and potential prions, it is considered unlikely that these pose any hazard to animal or human health (Norwegian Scientific Committee for Food Safety, 2010). Within the European Union, feeding fish meal to ruminant is prohibited, not because of potential presence of prions in fish products *per se*, but because of potential contamination of fish meal with other products from animal offal, such as meat and bone meal (European Food Safety Authority, 2007). After autoclaving and 3-day storage at pH=3.5 of offal from carcass and other freshwater fish, no Salmonella, Clostridia and other pathogenic micro-organisms could be detected (Ristić *et al.*, 2002), while the number of saprophytic bacteria was < 10^5 and fungi and moulds < 10^3.

Using cereals in combination with lactic acid bacteria to produce fermented fish silage may increase the risk of contamination with aflatoxin or other mycotoxins. This can originate from the growth of fungi if cereals are not-well preserved (Reddy *et al.*, 2010). However, no cases on the presence of mycotoxin in fermented fish silage have been reported.

3. Fish silage in fish diets

Feed is the most expensive component in intensive aquaculture, where it represents over 50% of operating costs depending on the fish species, the production system and feed management, with protein being the most expensive dietary source. The major and commonly used source of protein in fish and animal feed formulation is the fish meal which is a challenging ingredient in developing countries. It is either not readily available, too expensive or of low quality. For the development of commercial, cost effective feeds using locally available, cheap and unconventional resources, fish silage is therefore an attractive alternative to fish meal since the production process is virtually independent from the scale; the technology is simple and the investment is not high. Due to the similarity of the protein source with the raw material and low cost, especially when compared to fish meal, silage has a potential use in aquaculture (Vidotti *et al.*, 2003). Several authors have already demonstrated the nutritional value of fish silage in diets of different fish species (Fagbenro and Jauncey, 1995a;b; Goddard and Al-Yahyai, 2001; Vidotti *et al.*, 2002; Goddard and Perret, 2005). The digestibility of fish silage crude protein and amino acids is high and depend on the test silage fish species, the test fish species and the production process. It is nearly 90% and higher in different fish species (Borghesi *et al*., 2008; Stone and Hard (1986); Stone *et al*., (1989). Some studies reported higher digestibility of fermented fish silage compared to acid fish silage (Vidotti *et al.*, 2002).

3.1. Tilapia (*Oreochromis niloticus*)

Tilapia is the most widely cultured fish in tropical and subtropical regions and constitute the third largest group of farmed fish after carps and salmonids. In Africa, Nile tilapia (*O. niloticus*) is the first most farmed fish followed by African catfish (*Clarias gariepinus*).

Several studies conducted on the use of fish silage as a fishmeal (FM) replacer in tilapia feeds showed varying, but promising, results. From these studies, it is evident that fish silage has potential as a protein source for tilapia. Lapie and Bigueras-Benitez (1992) found that the growth of Nile tilapia fed formic acid preserved fish silage (FFS) blended with FM at 1:1 ratio was similar to that of fish fed a fish meal (FM)-based diet. When FFS:FM ratio was increased to 3:1, growth performance was significantly reduced, presumably due to acidity of the diet and high proportion of free amino acids in fish silage. 30% to 75% fish silage can be successfully incorporated in tilapia feed (Fagbenro, 1994; Fagbenro and Jauncey, 1994; Fagbenro *et al.*, 1994). Inclusion of fermented fish silage and soybean meal in replacement for 25; 50 or 75% of fish meal protein in juvenile Nile tilapia diets supported body weight for 70 days (Fagbenro *et al.*, 1994). The nutritional value of diets containing microbial fish silage partially dehydrated by the addition of soy meal, poultry by-products, or bone and meat powder did not differ significantly with fish meal based diets (Fagbenro *et al.* (1994) and Fagbenro and Jauncey (1998). These diets, especially the ones including silage and soy meal, could be used to feed tilapias, *O. niloticus* (omnivorous) and the North African catfish, *C. gariepinus* (carnivorous), with no changes in its performance, use of protein and carcass composition (Fagbenro *et al.*, 1994). Acid fish silage prepared from a mixture of inedible parts from Nile tilapia with 1.5% concentrated sulphuric acid and 1.5% concentrated formic acid was used to formulate three experimental diets for tilapia in which fish meal was replaced by fish silages (50,75 and 100% silage). After 13 weeks of feeding, a significant difference in growth performance and protein productive value were noted between tilapia fed on 100% fish silage and other treatments; however feed conversion ratio and protein efficiency ratio showed no significant differences between all treatments (El-Hakim *et al.*, 2007). Feeding trials of juvenile tilapia showed that sardine silage can replace fish meal at levels up to 40% of total diet without significantly affecting the growth rate. Apparent digestibility of protein, dry matter and energy of acid silage (formic and propionic) from sardine was comparable to that of fish meal in tilapia (Goddard and Al-Yahyai, 2001).

3.2. African catfish (*Clarias gariepinus*)

Fagbenro *et al*. (1994) reported that inclusion of fermented fish silage and soybean meal in replacement for 25; 50 or 75% of fish meal protein in juvenile Nile tilapia diets or *C. gariepinus* diets supported body weight for 70 days. Fagbenro and Jauncey (1995b) evaluated the performances of different fermented tilapia silage blends on African catfish. Catfish fed on different fish-silage diets showed some differences in mean weight gain, specific growth rate and protein productive value, but feed conversion and protein efficiency ratios were similar. Protein digestibility was reduced in catfish fed diets containing fish silage (FS): Hydrolysed feeder meal (HFM) while digestibility of energy content was lower in those fed diets containing FS : Soybean meal (SBM). He concluded that fermented fish silage co- dried with protein feedstuffs was a suitable protein supplement, which can provide up to 50% of dietary protein without affecting feed efficiency, fish growth or health.

3.3. Other fish species (carps, rainbow trout, salmon)

In a feeding trial of mirror carps fed acid silage produced from minced frozen whiting (*Merlangius merlangus*) and stored for 6 months prior to use, the silage fed fish did not perform well (Wood et al., 1985). This was probably due to reduced palatability and leaching of nutrients, or the law quality, of the silage made from frozen raw by-products. In contrast, other feeding studies involving fish silage in diets reported positive results with carps. Fish silage gave better growth than fish meal when fed to carp (Djajasewaka, 1986) and nutrient digestibility in fish silage was high (Cetinkaya *et al.*, 1995). When three different inclusion levels of acid silage were tested on the growth of common carp fingerlings, 2% acid silage diet had higher weight gain, higher specific growth rate and significant increase in biochemical constituents than other diets (2.5% and 3%) (Ramasubburayan *et al.*, 2013).

In a feeding trial on rainbow trout, Stone *et al.* (1989) reported that incorporation of fish processing wastes silage in rainbow trout diets in replacement of fish meal depressed significantly growth performance compared to fish meal or silage of whole fish bodies.

Fish silage based diet supported similar growth to that of the dry pelleted feed in Atlantic salmon. Fish fed diets based on dry pelleted feed, a mix of dry feed and fish silage (50%) and concentrated fish silage showed few differences in feed conversion, protein efficiency ratio (PER) and protein productive value (PPV). Only groups fed partly defatted fish silage concentrate diet had reduced growth and slightly depressed food and protein conversion (Lie *et al.*, 1988). Diet containing defatted silage concentrate showed reduced feed acceptance by the fish.

4. Fish silage in livestock diets

4.1. Broilers

Fish silage can be used as a protein source for broiler chicks. Replacing fish meal protein by fish silage protein resulted in similar or increased weight gain and feed conversion ratio in broiler chicks, slaughtered at 4 or 5 weeks of age (Krogdahl, 1985b and 1985a; Kjos *et al.*, 2000). In the experiment of Kjos *et al.* (2000), fish meal was fed at a level of 3% in the total diet. The improved growth performance when replacing fish meal by acidified (formic and propionic acid) and defatted fish silage was attributed to the increase in the availability of most amino acids from fish silage. In this experiment, growth performance of the chicks was also influenced by the level of replacement of rendered fat with fat extracted from the fish silage. Rendered fat was included at a level of 2.4% in the diet and was gradually replaced by fish fat. At replacement rates below 40%, fish fat had a positive effect on growth performance, at higher levels a negative effect. Although replacement of rendered fat by fish fat increased the proportion of omega-3 fatty acids (in particular docosapentanoic acid (C22:5) and DHA), it increased the intensity of rancid taste, which was attributed to lipid oxidation during storage. Fish fat reduced blood plasma levels of vitamin E and ceruloplasmin, indicating that these antioxidants are more challenged, thereby increasing vitamin E requirements.

Krogdahl (1985a), (Krogdahl, 1985b) replaced herring meal by acidified (formic and propionic acid) and defatted fish silage at levels supplying 0, 10, 20 or 40% of dietary crude protein by silage. In these experiments, including fish silage in the diet had no significant effect on weight gain and other growth performance parameters: weight gain and other growth performance parameters of fish silage fed chicks were similar or even better than chicks fed a control diet. Including defatted fish silage had no effect on the sensory quality of chicken meat. In an additional treatment the rendered fat in the diet was completely replaced by fish fat. Including more fish fat reduced the sensory quality of chicken meat stored for 4 months at -20^{o}C (Krogdahl, 1985a). The fishy taint of poultry meat occurring at high marine fat intake has been attributed to the oxidation products of the accumulated poly-unsaturated (> 4 double bounds) fatty acids in the carcass (Krogdahl, 1985b).

In another study, fermented fish silage was included at 25 or 50% of the diet in broiler chickens between d30 and d51 of age (Hammoumi *et al.*, 1998). Weight gains of the chicks fed diets with 25% fermented fish silage were similar to chicks fed a commercial diet. Including 50% fermented fish silage reduced weight gain, particularly in the first week of the trial.

4.2. Laying hens

Krogdahl (1985b) replaced herring meal by acidified (formic and propionic acid), defatted fish silage in diets for laying hens at levels supplying 0, 20 or 40% of dietary crude protein by fish silage. Although small differences between treatments were found, no significant relationship between inclusion level of fish silage and laying performance or egg quality was observed. Hens fed the highest inclusion rate of fish silage showed a severe loss of feathers during the summer, which recovered during autumn. Feather pecking has been related to a low activity of the serotonergic system. Serotonin, also known as 5-hydroxytryptamine, is synthesised from tryptophan. Indeed, feeding extra tryptophan resulted in a reduction in feather pecking (van Hierden *et al.*, 2004). As mentioned in § 2.1.3, fish silage has a relatively low tryptophan content.

In an additional treatment supplying 20% of dietary crude protein by fish silage, Krogdahl (1985b) replaced the rendered fat in the diet completely by fish fat. Including more fish fat in diets for laying hens did not affect the sensory quality of the meat from these hens, slaughtered at 61 weeks of age and stored for 6 months at -20^{o}C (Krogdahl, 1985b). The absence of a fishy taint in the meat of laying hens was attributed to the preferred partitioning of poly-unsaturated fatty acids towards yolk fat. But in this experiment, more fish fat did not affect the sensory quality of eggs.

The effect of increasing levels of fish fat in the diet was further studied by Kjos *et al.* (2001). They replaced fish meal in the control diet (included at 2.9%) by concentrated, acidified (formic acid) defatted fish silage (5% in the diet, providing 12% of dietary crude protein). In the diets with fish silage, rendered animal fat in the control diet (included at 2.4%) was gradually replaced by fish fat to obtain inclusion levels of 0, 0.7, 1.7 and 2.5% in the diet. Replacing fish meal by concentrated, acidified (formic acid) defatted fish silage did not affect feed intake and laying performance. At 1.7 and 2.5% of fish fat in the diet, feed intake, egg production and egg weight were lower than at 0 and 0.7% fish fat in the diet. Although the level of fish fat at which a negative effect was observed in this study was lower than observed by Krogdahl (1985b), Kjos *et al.* (2001) stated that their observations agreed with other studies in which the effect of fish oil in laying hens was reported. In this latter study, adding fish fat affected the fatty acid profile in yolk: the proportions of erucic acid (C22:1) and DHA were increased concomitant with a reduction in oleic acid and eicosanoic acid (C20:1). Yolk cholesterol was not affected by diet composition. Sensory quality was affected at the highest inclusion level of fish fat (2.5%). Feeding poultry with fish silage and high levels of oil can cause carcasses having a fishy taint, but the eggs are not tainted (Raa et al., 2009).

4.3. Ducks

Krogdahl (1985a) repeated her study with broiler chicks in Peking ducks, replacing herring meal by acidified (formic and propionic acid), defatted fish at levels supplying 0, 10, 20 or 40% of dietary crude protein by fish meal. Ducks were slaughtered at 8 weeks of each. Including fish silage in the diet reduced the utilization of metabolisable energy but had no significant effect on weight gain and the other growth performance parameters. In an extra treatment rendered fat was completely replaced by fish fat, which reduced sensory quality of the duck meat after 3 month storage at -20^{o}C.

4.4. Quails

Soybean meal was partly replaced by oven-dried, fermented marine fish silage up to a level of 15% in the diet of quails, without an adverse effect on feed conversion ratio (Ramírez-Ramírez *et al.*, 2013). Adding fish silage to the diet increased the proportions of C20 and C22 fatty acids, but this did not affect the sensory quality of the quail meat.

4.5. Fattening pigs

Cameron (1962) fed acidified fish silage as the main protein source to growing and fattening pigs at inclusion levels of 33% fed on a basal diet of ground barley and ground oats. The maximum inclusion level without a negative effect on feed intake was 45%. Fish silage diets were compared with diets including soybean meal and animal protein (tankage). Including fish meal at a level of 33% did not affect feed intake and feed conversion rate, whereas at an inclusion level of 45%, pigs grew slower and less efficiently. In a second experiment the effect of the inclusion of 10% fish silage on growth performance and meat quality was studied. In that experiment, growth performance of pigs fed the fish silage diet was not different from pigs fed the control diet with soybean meal and animal protein. However, including fish silage affected meat quality: the off-flavour made the carcasses of these pigs unmarketable.

In another study with pigs, soybean meal in the diet was partly replaced by fermented fish silage from shrimp offal to obtain inclusion levels of 0, 3, 6 and 9% of the diet (Tibbets *et al.*, 1981). At the highest inclusion level a tendency for a lower growth rate was observed. Feed conversion ratio increased linearly with the level of inclusion of fish silage. Including fish silage did not affect carcass quality or the taste of meat.

Feeding acidified or fermented fish silage to weaned piglets reduced feed intake and consequently live weight gain (Rose *et al.*, 1994). Soybean meal and fish meal were partly replaced by acidified (formic acid) or fermented (lactic acid bacteria + barley + dried malt) fish silage from cod fish to obtain inclusion levels of 0, 6, 8, 10 or 12% of the diet. Diets were fed to piglets from 3 days after weaning at day 21 (at a live weight of approximately 6 kg) until a live weight of 10 kg. Feed intake decreased curvilinear with increasing inclusion level, whereas live weight gain decreased linearly with increasing inclusion level. Dry matter intake of diets including fermented fish silage was higher than diets including acidified fish silage. The higher feed intake of diets with fermented fish silage was attributed to the lower value for digestible energy of fermented fish silage compared to acidified fish silage. The lower feed intake was attributed to palatability problems, originating either from oxidized polyunsaturated fatty acids or from the bitter taste of free amino acids (Rose *et al.*, 1994).

In an experiment with finishing pigs (final weight 99 kg), soybean meal was partly replaced by concentrated, acidified (formic acid) defatted fish silage (5% in the diet, providing 9% of dietary crude protein) (Kjos *et al.*, 1999). Additionally, the effect of level of fish fat was investigated by replacing rendered fat in the diet by fish fat to provide levels of 0, 0.3 and 0.7%. Treatments had no effect on feed intake, weight gain, number of days to market, feed conversion rate and animal health. Increasing the level of fish fat in the diet decreased blood plasma concentrations of vitamin E, but not of ceruloplasmin and glutathione peroxidase. Except for eicosanoic acid, which was increased by feeding fish fat, no differences between treatments were observed in the fatty acid profile of back fat. At the higher levels of fish fat inclusion, sensory quality was reduced as an increased sense of off-taste. After 6 months of storage a fish taste was identified which was attributed to oxidation of the poly-unsaturated fatty acids.

The effect of marine fat on growth performance and carcass quality of finishing pigs has been investigated by partly replacing soybean meal by increasing levels of acidified (formic acid) fish silage from mackerel (Green *et al.*, 1988). Mackerel silage was included at levels of 0, 5, 10 and 15% of total dry matter, resulting in dietary crude fat concentrations of 18, 41, 63 and 86 g/kg dry matter, respectively. As also observed by Kjos *et al.* (1999), including fish silage resulted in similar or improved growth performance of pigs slaughtered at a weight of 55 kg. A slight reduction in feed intake was attributed to palatability problems as a result of fatty acid oxidation. Dietary treatments did not affect carcass measurements and the fatty acid profile of subcutaneous fat. However, at the highest inclusion rate of fish silage, approximately 50% of the carcasses were unacceptable for the market due to the presence of soft, yellow fat which made the carcasses.

A potential health risk of feeding oil-rich fish silage to growing pigs is an oversupply of vitamin A (Coates *et al.*, 1998). In an experiment feeding diets with 40 to 50% of fish silage, growing pigs developed severe symptoms of vitamin A toxicosis, such as gastric ulcers and other mucosal damages and lameness concomitant with histological irregularities in the physis of the femur. The high intake level of vitamin A was confirmed by the high serum concentrations of retinyl palmitate. A relatively high proportion of liver in fish offal and cool weather conditions preventing vitamin A degradation will increase the risk for vitamin A toxicoses when feeding high-fat fish silage (Coates *et al.*, 1998). Although there are no indication that the use of fish silage in animal rations causes more fishy carcass taint than fish meal having the same oil content, it is recommended to limit the level of fish oil and to give conventional meal the last day or two (Raa et al., 2009).

4.6. Sows

Reports on feeding fish silage to sows are scarce. In a relatively limited experiment, the effect of partly replacing soybean meal by fermented fish silage to obtain a level of 6% fish silage in the diet, on weight gain and litter information was assessed (Tibbets *et al.*, 1981). Results of 7 sows fed a control diet were compared to 7 sows fed the 6% fish silage diet. I n this study, no differences between treatments in breeding parameters were observed.

4.7. Ruminants in general

Because of the abundant microbial degradation of free amino acids in the rumen, fish silage in ruminant diets should be mainly regarded as a source of nitrogen and branched chain volatile fatty acids ("isoacids") and not as a source of metabolisable true protein (absorbable amino acids). This implies that for ruminant diets, fish silage can be used to replace other relatively cheap sources of rumen-degradable protein as well as non-protein nitrogen sources such as urea. The use of fish silage in ruminant diets will therefore depend on the prize and availability of these other nitrogen sources. With an adequate amount of rumen-available energy, rumen-degradable protein will be incorporated in microbial biomass. Because nitrogen of fish meal will be incorporated in microbial protein, approximately 25% of this protein will be incorporated in microbial nucleic acids, which cannot be used for protein synthesis but are largely excreted via urine (Dijkstra *et al.*, 2013). However, this can be regarded as a loss of valuable nitrogen.

With low quality, fibrous diets, ruminal cell wall degradation is of high importance, because the rate of cell wall disappearance from the rumen determines the intake of fibrous feeds (Allen, 2000). Higher intake of energy and nutrients will contribute to a better animal performance. Adding urea of soybean meal to a diet of low-quality hay only, improved the rate of ruminal cell wall digestion and consequently hay intake (Mlay *et al.*, 2003). In that study supplementing soybean meal had a better effect on cell wall digestion than supplementing urea. This difference can be attributed to the higher ruminal microbial activity as a result of a more synchronic availability of nitrogen from soybean meal than from urea with the energy availability from the low-quality hay. Other possible explanations for an improved ruminal microbial activity when supplementing soybean meal are the supply of iso-acids (2 methyl-, 3 methyl- and iso-butyric acid, iso-valeric acid) which results from the deamination of amino acids and required to synthesise microbial branched-chain amino acids and the supply of dipeptides and amino acids to be taken up directly by ruminal microbes. In an earlier study, ruminal degradation of cellulose and hemicellulose of barley straw was higher when supplementing soybean meal and fish meal than when supplementing urea or casein (Stritzler *et al.*, 1992). The higher response for soybean meal and fish meal was attributed to a higher microbial activity, and particularly for fish meal of those microbes which are intimately associated with cell walls. In an in vitro study, adding iso-acids to incubations with ammoniated rumen fluid improved cell wall (NDF) digestibility (Yang, 2002), but larger improvements were observed when adding dipeptides to the medium.

From the studies referenced above (Stritzler *et al.*, 1992, Yang, 2002, Mlay *et al.*, 2003) it can be concluded that fish silage may not only act as source of available nitrogen, but also as a source of peptides and branched-chain amino acids which can stimulate the activity of ruminal microbes, either by direct uptake and incorporation of these amino acids or indirectly by supplying branched-chain volatile fatty acids.

An increased activity of cellulolytic bacteria can increase cell wall digestibility. Ensiling straw with fish offal improved cell wall (NDF) digestibility in sheep from 17% (straw) to 34% (fish offal:straw, 1:1) (Samuels *et al.*, 1991). In another study, fish meal but not fish protein hydrolysate improved total-tract cellulose digestibility (Ouellet *et al.*, 1997). However, in that study fish meal and fish protein hydrolysate were added to a grass silage-based diet with a relatively high crude protein content (184 g/kg dry matter), probably already supplying adequate amounts of nitrogen and branched-chain amino acids and volatile fatty acids.

Ruminal degradation of acidified and fermented fish silage from tilapia residues was compared to that of commercial fish meal (Geron *et al.*, 2007) using the NRC crude protein fractionation method (NRC, 2001). This study confirmed the relatively high values of rumen-degradable protein of fish silage compared to fish meal. Ruminal degradability of fish silage was approximately twice as high as that of the used fish meal source. Because of the higher crude protein content of fish meal compared to fish silage (551 versus < 370 g/kg dry matter), the differences in ruminal-degradable protein were smaller,

being 270, 240 and 210 g/kg dry matter for acidified and fermented tilapia fish silage and fish meal, respectively.
In another study, using ammonia production during in vitro incubation as an indicator for ruminal protein degradation (Mandell *et al.*, 1989), net production of ammonia from fish silage was similar to that from fish meal, suggesting that ruminal crude protein degradability of fish silage is not much higher than that of fish meal (Nicholson and Johnson, 1991). This would imply that fish silage would be a good supplier of absorbable amino acids to the small intestines, contrary to the conclusion based on the study of Geron *et al.* (2007). Comparing fish meal with fish protein hydrolysate as a protein supplement for grass silage-fed heifers, Ouellet *et al.* (1997) observed surprisingly similar post-prandial patterns in ruminal ammonium concentrations, suggesting that the rate of amino acid deamination of fish protein hydrolysate is not very different from that of fish meal.
Although the nature of nitrogenous components in fish silage predicts extensive crude protein degradation in the rumen, other studies suggest that adding fish silage to other proteins sources will reduce ruminal crude protein degradation of these other protein-rich feed material. Mixing fish hydrolysate with soybean meal at a rate of 1.5 litres per kg soybean meal reduced the estimated rumen-degradable protein content from 340 to 170 g/kg dry matter (Mir *et al.*, 1984). However, a similar treatment for canola meal did not affect ruminal protein degradation.

Ensiling low-dry matter fish offal in combination with dry, low-quality roughages would result in mixture with suitable dry matter content to be fed to ruminants. With this objective, fish or crab offal was ensiled with ground maize stover, peanut hulls or Johnson grass with or without the addition of molasses or formic acid (Samuels *et al.*, 1992). Favourable silages were obtained with fish offal, especially when molasses was added. Silage with Johnson grass was better than with maize stover which was better than with peanut hulls. Silages with crab offal were badly fermented, producing high ammonia concentrations and offensive odour. Authors concluded that satisfactory silage of roughages with crab offal can only be produced when the product is preserved by large quantities of acetic acid, which makes this method of ensiling not economically feasible. As mentioned in § 2.2 adding cereals or other preserved feeds may increase the risk of mycotoxin contamination of fish silage.

4.8. Growing cattle

The use of fish silage as feed ingredient in diets for weaned calves has been assessed in an experiment where grain/fish silage mixtures have been compared with a control, soybean meal-based diet (Winter and Hamid Javed, 1980). Calves were fed the soybean control diet or the grain/fish silage mixtures at levels of 9 or 13% of total diet dry matter between 3 and 13 weeks of age. Weight gain of the calves on the diets with fish silage was similar to the control diet between weeks 3 to 7, but was lower between weeks 7 to 13. Despite this lower growth rate, authors recommend fish silage as a potential inexpensive protein source, being also rich in calcium and phosphorus.

Replacing soybean meal by oil-rich herring silage in a hay/potato-based diet, did not significantly affect feed intake and average daily gain of heifers between 300 and 400 kg live weight (Nicholson and Johnson, 1991). Higher feed intake and daily gain were observed when including the oil-rich herring silage to a grass-legume silage/potato-based diet. Including herring silage in the diets increased ruminal ammonia concentrations, especially 1 hour after feeding, suggesting a faster ruminal protein degradation of the herring silage than of soybean meal.

When comparing fish protein hydrolysate with fish meal as a protein supplement for beef cattle fed on grass silage, fish meal but not fish protein hydrolysate increased silage dry matter intake (Ouellet *et al.*, 1997). The fish meal supplement increased the average daily gain by 25% compared to grass silage only, whereas fish protein hydrolysate increased the average daily gain by only 11%.

4.9. Dairy cattle

Although no publications were retrieved in literature databases on the use of fish silage in diets for dairy cows, it is likely that defatted fish silage can be used as a protein source for dairy cows, especially for supplementing low protein diets. As mentioned above, fish silage could serve not only as a source of ammonia for ruminal micro-organisms, but probably also as a source for branched-chained volatile fatty acids, amino acids or small peptides which can stimulate the growth and activity of ruminal micro-organisms, especially of cellulolytic bacteria. This can result in an improved intake and digestion of low-quality feeds and consequently results in an improved animal performance. Because of a potential negative effect of poly-unsaturated fatty acid on ruminal cell wall degradation, high concentrations of fish oil should be prevented. Feeding fish oil to dairy cows reduces milk fat content and milk fat yield, but increased the proportions of poly-unsaturated fatty acids (C18:2, C20:5, C22:6 and especially C20:0) in milk fat (Cant *et al.*, 1997). he ruminal microbial population hydrogenates most of the dietary poly-unsaturated fatty acids, which goes together with a reduction in methane production. Thus, addition of fish oil may reduce enteric greenhouse gas by ruminants.

4.10. Goat and Sheep

Fish silages either high or low in oil were mixed with hay and fed to sheep (Haard *et al.*, 1985). From this study it was concluded that defatted fish silage can be used as a protein source in sheep, although the dry matter intake of the mixture of hay and defatted fish silage was 20% lower than of hay alone. Preventing protein hydrolyses by adding formaldehyde to the fish silage improved dry matter intake of the fish silage/hay mixtures.
Replacing sunflower meal by fermented fish silage meal in rations for growing lambs did not affect their daily weight gain during the 60-days trial (Guerouali *et al.*, 1995).

5. Potential of fish silage production and use in Eastern Africa

Worldwide, solid wastes generated from seafood factories range from 30% to 85% of the weight of the landed fish. Fish wastes from processing plants are estimated at 50% of the total processed fish (Arruda *et al*., 2007), up to 30-40% in Eastern Africa depending on the fish species processed (Gumisiriza *et al*., 2009). In general, fillet constitutes about 37-40% of the total fish and the remaining 60-63% is basically by-products which in most cases have low commercial value (Kabahenda and Hüsken, 2009). In fish processing factories along Lake Victoria, Nile perch frames account for 40-43% of the by-products weight followed by red meats (7.8%), skins (6.8%), fats (1.5 -2.6%), fish maws (2%), trimmings (0.3%), and eggs (0.2%) (Reynolds and Greboval, 1989; FRRI, 2003). Scales and guts, which constitute 2% of the whole fish, are often discarded (FRRI, 2003).

In Ethiopia, total fish offals range between 55% for catfish, 60.2% for labeobarbus and 68% for tilapia filleting (Table 5). Globally a small amount of fish by-products is used for human consumption, the rest is used for production of fish meal, fish silage and animal feed. But there are exceptions depending on countries and regions. Some by-products are dumped near the production and processing sites or end in landfill sites. Using the fish silage as a partial protein source in fish and livestock feed can mitigate sanitary and environmental problems caused by the dumping of wastes from fish processing industry. It would also lower the feed cost, consequently improving the fish aquaculture productivity. The protein-rich by-product fraction include cut-offs, backbones, heads, skin, roe, milt, stomachs, viscera and blood.

Although potentials for the use of fish silage exist, there is little use of silage in the tropics. The limited use of fish silage probably results from the failure to optimise methods of manufacture, use and storage under local conditions (Disney *et al*., 1978). Fish silage represent a useful alternative to fish meal manufacture since it can be applied to relatively small amounts of raw materials in isolated areas, thereby eliminating the need for expensive processing equipment and its maintenance (Goddard and Al-Yahyai (2001). Commercial use of fish silage is up till now largely restricted to northern Europe, primarily in moist feed for fish, fur animals and pigs. Although many studies in Africa have tested silage of the same fish species, it is important to know whether the use of fish silage compile with legislation in place. In Europe for example, the international feed legislation does not allow to include products/ingredients of fish in feed to same species.

To understand the opportunities of fish silage production and use in fish and animal feed in Eastern Africa, data are presented below on fish production, consumption and by-products from fish processing as well as information of fish markets and prices in Ethiopia, Kenya and Somalia. Only limited and old information is available for Somalia.

5.1. Opportunity for fish silage production and use in Ethiopia

Fish production and consumption data are obtained from project and FAO reports and field interviews. Elaborated examples and market data are given on fisheries of two important lakes: Lake Tana and Lake Ziway from key resource persons. Lake Tana, the largest lake in Ethiopia, is located in the highlands at more than 500 km from Addis-Ababa. Lake Ziway is found in the Rift Valley together with many other lakes, and is about 170 km away from Addis Ababa with a good tarmac road. The Fisheries Resources Research Centre and the Fish Production and Marketing Enterprise (FPME), both located on the shores of Lake Ziway, were visited during the field mission to search for research partnerships.

5.1.1. Fish production in Ethiopia

Ethiopia has several water resources including 9 lakes and 1 reservoir with a total area of 7 400 km^2 and 7 185 km of major rivers. Water bodies support a large diversity of more than 180 fish species of which about 40 are endemic. Empirical estimations suggest that current total fish production potential is about 51 500 tonnes annually (Yalew, personal communication). According to FAO/SFE Ethiopia, 24 257 tonnes of fish were produced in Ethiopia between July 2011 to June 2012, mainly from fisheries and were dominated by Nile tilapia (16 279 tonnes, 68%) followed by African catfish (3 279 tonnes, 14%), Barbus (1 843 tonnes, 8%), Common carp (929 tonnes, 4%) and Nile perch (844 tonnes, 4%). Aquaculture (0.07% of the total fish production) produced only 16.1 tonnes made of Nile tilapia (16 tonnes) and trout (0.1 tonnes) from pond farming. Import of fish is very small, estimated to 421 tonnes in 2010, mainly canned marine fish and high value fishery products destined for big hotels and supermarkets (Lemma, 2012).

The main fish species in order of their economic importance in Ethiopia are the Nile tilapia *(Oreochromis niloticus*), Nile perch *(Lates niloticus*), the African catfish *(Clarias gariepinus*), *Bagrus docmak* and *Barbus* spp. Most typically, these are limited to Nile tilapia, the African catfish, and Nile perch when available depending on the region.

Fish production of Lake Tana fluctuates between 7 000 and 10 000 tonnes per year and combines both artisanal and commercial fishing. Fishery on Lake Ziway is artisanal, involving beach seines when the lake is not full. The fish catch at Lake Ziway amounted to 2 122 tonnes in 2007 and included large-sized catfish. Catfish is increasing in the Lake, maybe due to increasing selected fishing of Nile tilapia. Fish catch has declined with increasing irrigation both around the lake and the rivers.

5.1.2. Fish consumption in Ethiopia

Ethiopia has the lowest per capita fish consumption (0.224 kg fish per person per year in 2010). Fishery products do not make part of the traditional foods of Ethiopians although fasting periods, equal to no less than half of the year, are known as peak fishing-consumption season by Orthodox Christians which make the majority of the population. The country tends to rely more on protein sources such as beef, mutton and chicken and additionally camels for Muslims.

For those few who eat fish, tilapia is the preferred fish sold in different forms, gutted whole fish or filleted. The African catfish (*C. gariepinus*) is disliked by Ethiopians who consider its appearance as not appealing for consumption or a fish for socially low regarded communities. With the food shortage among the increasing population in Ethiopia and the relative cheapness of African catfish, this fish is attracting more people to it. Cyprinid fishes have strong diversity but have very low popularity in the Ethiopian market. Their consumption also varies from place to place. One reason for the low consumption of *Barbus* spp. in the Rift Valley is presence of small bones in the muscle of the fish.

5.1.3. Fish prices and markets in Ethiopia

Fish produced in Lake Tana fisheries is mainly for domestic and export market. Tilapia is the highest-valued species among the local population. The produce is stored in a cold store or deep freeze as gutted whole fish or filleted fish wrapped with plastic bags and sold mainly (90%) to Addis Ababa. Distribution of this produce is mainly using vehicles equipped with refrigeration facilities. Fish which is not presented to domestic market and kept as dried whole fish is exported to Sudan. Especially catfish is less popular as scale-less fish are traditionally considered unclean. Nevertheless, catfish are highly demanded in regional markets such as the Sudan and South Sudan. Much of the catfish is dried and salted and exported to Sudan (Berihun Tefera *et al*., 2009). Fish caught in excess during peak production season, like July to September and March to May, is always dried using table salt and stored until exported to Sudan market. Total exported amount of fish increased from 33 tonnes in 2007 to 64 tonnes in 2012.

The price of one kilo of whole fish has almost doubled and the selling price of filleted fish increased almost by three fold within five years between 2008 and 2012 (Table 4). The selling price of salt dried and salt+air dried was 6, 16, 10 Birr/kg for Tilapia, Catfish and Labeobarbus, respectively.

Table 4. Selling price of fish from Lake Tana (Birr/kg)

Fish species product	Year				
	2008	2009	2010	2011	2012
Tilapia – whole fish	6.0	7.0	7.8	8.5	12.5
Tilapia – fillet	23.8	27.0	32.0	40.0	65.0
Catfish - Whole fish	4.0	4.0	5.0	5.0	6.0
Catfish – fillet	14.5	15.0	20.0	22.0	40.0
Labeobarbus -whole fish	2.5	3.0	3.0	3.0	4.0
Labeobarbus –fillet	11.5	12.0	15.0	17.0	30.0

Source: 2000-2004 Ethiopian fiscal years (whole fish prices); Fish Production and Marketing Industry (fillet prices)

Fish price data provided by the manager of the fish processing factory in Ziway include:

Whole fish (July 2014):

- Buying price from fishermen in the Rift valley by traders and processors: 12 birr/kg tilapia (or catfish)
- Buying price at landing sites in the Western part: 7 birr/kg of tilapia (or catfish)
- Selling price from fishermen to consumer during fastening of Christian orthodox (2 months: march-april and 2 weeks in august): 30 birr/kg
- Farm gate price for trout (trout farm): 80-100 birr/kg

Fillet in Addis Ababa (July 2014):

- Selling price: 80 birr/kg tilapia, 60 birr/kg catfish
- Selling price during fastening: 120 birr/kg tilapia
- Profit margins of fish processor on fillet: 20 birr/kg

The price in Addis Ababa in 2012 of one kg of tilapia was 83.95 Birr (4.9 USD), one kilo of catfish fillet cost 48.3 Birr (2.8 USD), while one kilo of Nile perch fetched 176 Birr (10.4 USD), respectively.

5.1.4. By-products or wastes from fish processing in Ethiopia

The loss made during the preparation of fillet in the processing units is as high as only 32% for Tilapia, 40% for Labeobarbus and 45% for Catfish are recovered into fish fillet (Table 5).

Table 5. Ratio of by-products (%) from fish filleting in Ethiopia

Product and by-products	Tilapia	Catfish	Labeobarbus
Fillet	32.0	45.0	39.8
Offal-potential for human use	32.5	0.0	33.9
Offal-potential for animal use	16.5	50.0	21.5
Gut content	19.0	5.0	4.8
Total offal including gut content	68.0	55.0	60.2

Source: average data from 20 1-kg fish (Yalew, 2012).

All parts of a fish removed during processing are thrown and dumped into the lake water unless it is eaten by the pelicans and other predators. The quantity of fish offal at Lake Tana that could be used for human and/or animal, but dumped to the environment, during 2011 is estimated at 210 tonnes representing 210,000 birr per year if sold (1 birr/kg) to processor to change it into feed. The only processing unit which took the fish offal on Lake Tana is Abawengele animal feed processing unit. The processing unit has a very small mill and it can accommodate taking 100 kg of fish waste per day.

Only in Lake Tana is off-take dramatically less than potential. In contrast, lakes in the south (Rift valley) are heavily exploited and fish size, especially of tilapia in these lakes is getting smaller and the catch is reducing. This increase the amount of wastes produced during processing of small-sized fish. The Fish Production and Marketing Enterprise (FPME), adjacent to the Oromia Agricultural Research Institute (Ziway Fisheries Resources Research Centre) on the shores of Lake Ziway, processes fish from Lake Tana (2454 tonnes per year) and from Langano (673 tonnes in 2007), situated at 60 km away. Most of the catch and products from these lakes is sold to hotels in Addis Ababa. The fish processing facility in Ziway has trucks to collect fish on landing sites and processes up to 4 tonnes of fish per day. No ice is used during fish transport nor during processing. Fish entering the processing factory range from 20 to 180 g for Tilapia (Figure 5). Tilapia below 40 g are considered as by-catch and those above 40 g are processed (filleted). Catfish weight between 3 to 4 kg.

Figure 5. Tilapia sized between 20 to 180 g processed at the FPME processing factory at Lake Ziway, Ethiopia. Photo (2014) by Rurangwa.

During the visit at the filleting plant in Ziway, by-products from tilapia and catfish processing were laying everywhere in the factory exceeding more than 70% of the processed fish (Figure 6). 70% of the tilapia are offals (55-60% for catfish) made of whole fish carcass, viscera, catfish heads and catfish eggs. Wastes were dumped several times a day on the shores of Lake Ziway where thousands of pelicans have aggregated to feed on them.

Figure 6. Whole tilapia carcass (left, middle photos) and tilapia viscera and gills (right photo) at the FPME processing factory at Lake Ziway before disposal on the lake shores. Photo (2014) by Rurangwa

The exact amount of fish processed and fish by-products produced across the country is not easy to estimate since more fish are processed on the lakes shores than in known processing plants (Adefris Kasaye, fish processor Lake Ziway, personal communication). It is not uncommon to see that fish are gutted, filleted and packed in bags right at the dusty grounds of landing sites and filleted fish are left to dry under the sun. More than 99% of the processing by-products are dumped in open air. Minor amount is used for fish meal production (dairy fattening) and human consumption (soup) after boiling of fish carcass. The human use differs from region to region: soup being promoted on Lake Hawasa, very few poor people use it on Lake Ziway and no one use it on Lake Tana.

5.1.5. Fish silage production and use in Ethiopia

The source of raw material for silage production is abundantly available in Ethiopia at almost no cost (Table 6). It might be by-products from fish processing and by-catch with low economic value or unsuitable for human consumption (Table 6). The fish species of economic relevance for farming and for which fish silage based diets can be developed include in this order of importance: Nile tilapia (countrywide), African catfish in the western part (Sudanese export market) and trout near big cities (hotels). There is an increasing interest to develop tilapia farming in the Rift valley region due to depleting fisheries in most lakes, the proximity of the fish market in the capital Addis-Ababa and the higher temperatures compared to the highland area. Besides tilapia, the market demand for catfish in Sudan, mainly in the North Western part of Ethiopia (Lake Tana) and the high prices fetched by the trout provides also a support to develop feeds for these 2 potential fish species for aquaculture in Ethiopia. Livestock constitutes historically and will remain for the coming years the main source of animal proteins in Ethiopia. Development of fish silage-based diets for livestock animals (cattle, sheep and chicken) is of big relevance in Ethiopia. Fish processing companies in Ethiopia can benefit from recycling fish by-products into fish silage since the raw by-products are abundantly available.

Table 6. Availability of raw material for silage production in Ethiopia

Raw material (from processing and by-catch)	Region	
	Rift Valley	Highlands (Lake Tana)
Nile tilapia	++++++++++	++++++++
African catfish	+++++	+++
Barbus	+	++++
Cyprinids	+	++
Nile perch	+	-
Trout	-	-

+: available; -: not available

5.2. Opportunity for fish silage production and use in Kenya

5.2.1. Fish production in Kenya

According to the Kenyan Ministry of Fisheries (2012), Kenya produced 159 000 tonnes from inland fisheries, 20 000 tonnes from aquaculture, 8 000 tonnes from marine fisheries in 2011.

5.2.2. Fish consumption in Kenya

Kenya derives only 5.8 % of total animal protein intake from fish and seafood (3.4 kg per capita per year).

5.2.3. Fish prices and markets in Kenya

Extended information on fish market and prices in Kenya is available in IMARES/LEI report "Market Analysis of Aquaculture in Kenya (Turenhout *et al*., 2013)". The price of farmed fresh fish is around USD 1,00/kg for carp, USD 2,00 per kg for African catfish, USD 2,50-3,00 per kg for tilapia, USD 6,00-8,00 per kg for trout.

5.2.4. By-products or wastes from fish processing in Kenya

In the three countries Kenya-Uganda-Tanzania, sharing the Lake Victoria (inland fisheries), fish processing is only of Nile perch from Lake Victoria. Along the lake, 32 fish processing factories belonging to 18 companies were located in the major urban centres (PC. Goudswaard, personal comm.). The processing factories in Mwanza city in Tanzania generate most fish solid processing wastes (16 500 tonnes per year). The recovery of marketable by-products in Mwanza is limited to fishmeal production on a small scale and the rest of the solid waste is sold for different human use (Table 7). The total solid waste production is estimated at 36 000 tonnes per year (Gusimiriza *et al*., 2009).
According to Gumisiriza *et al*., 2009, fish solid wastes from processing factories around Lake Victoria are fish rejects from fishing, skins, frame/bony skeletons (carcass) from filleting, fillet rejects and pieces of bones from trimming, viscera, fats, roes/eggs, fish maws or swim bladders, heads, breasts, scales and deteriorated filets from grading and packaging. Some waste fractions are sold locally for food and or fuel (Table 7) at a very cheap price that undermines their real economic value if compared to the price of fish meal (USD 2000/MT) on international markets.

Table 7. Local sale price and potential use for some fish wastes around Lake Victoria

Waste fraction	Price (USD/MT)	Use
Fish frames	40.30	Food
Chips/trimmings	363.70	Food
Fat	378.50	Food and fuel
Skin	54.60	Food
Roes/eggs	265.70	Food
Head	75.00	Food
Breast	378.00	Food

Source: Gumisiriza *et al*., 2009

According to Kiwale (2003)) there are eleven (11) Nile perch processing factories in Tanzania alone. These include: the Omega Fish Ltd., Mara-Fish packers Ltd., Prime Catch Ltd., Tanzania Fish Processors Ltd., VIC –Fish Ltd., Nile Perch Fisheries Ltd., Tan perch Ltd., Mwanza Fishing Industries Ltd., Chain Food International Ltd., Musoma Fish Processors Ltd., Victoria Fisheries (T) Ltd. Most of these factories at the moment are operating under capacity and some of them have closed due to in adequate fish supply from natural waters.

In Kenya, 5 companies processing Nile perch are registered within the AFIPEK (Kenya Fish Processors & Exporters Association). These include: Peche Foods Ltd, East African Sea Food Ltd, Fish Processors (2000) Ltd., W.E. Tilley Ltd, J Fish Ltd and are based either on the shores of Lake Victoria or have offices in Nairobi. By-products of Nile perch processing also feeds into a major industry dealing in skins, scales and other by products employing mainly women (http://www.afipek.org/lakevictoriafisheries.html). Fish carcasses with heads are sold by the factories at KSH32/kg and fish maws (swim bladders) are sold at USD40/kg in Asia where they are a delicacy in making soup stocks (Nsimbe-Bulega and Akankwasa, 2002) or exported to Europe for use as beer clarifiers. Skin is used locally in soups. Only fish intestine are not used directly. Post-harvest loss which are not suitable for consumption, are not fresh, are available wastes and in many cases are used in the poultry feed industry.

Processing companies based in Mombasa process marine fishery products and include among the biggest: Wananchi Marine Products Ltd that processes tuna from European fishing fleets, Alpha Group that processes black tiger prawns, banana prawns, octopus, crabs, lobsters (*Panulirus*), rock lobster, sand lobster, squid, cuttle fish (Sepia spp.), scampi, shrimp, langoustine, and Sea Harvest that processes octopus, lobsters, cuttlefish, squids and red snappers. Companies processing other seafood than fish have limited waste production, below 10%.

During the field mission for search for partnership, the tuna processing factory of Wananchi Marine Products Ltd was visited and following information collected:

- Wananchi Marine Products Ltd in full operation processes up to 70-80 tonnes of tuna per day
- From processed tuna, 50-60% constitute by-products (almost 40 tonnes per day) and the rest 38-44% are tuna loins depending on the size of the fish.
- In the past, tuna processing wastes have been dumped or sold as small amounts to crocodile growers at 4KSH/kg. This is a growing farming industry in Mombasa using also fish wastes with crocodile meat sold at 2,000KSH/kg in super markets.
- Currently tuna processing by-products are used to produce fish meal and fish oil sold at 80-90 KSH/kg and 243KSH/kg, respectively. Processing tuna by-products into fish meal is costly since it involves squeezing- cooking-drying and separating processes which are energy consuming. The company still produces tuna processing by-products into fish meal and is interested to process tuna by-products from Somalia as longer as the prices for fish meals remain high and the cost for transportation is low.
- The tuna (yellow fin tuna) price fluctuates between 80-120 KSH/kg.

5.2.5. Fish silage production and use in Kenya

Practically there are no fish wastes readily available for fish silage production in Kenya. All-processing by-products are used for different purposes. Fish by-products resulting from Nile perch filleting are used for human consumption and targeting these for silage production would cause undue competition for the resource and may present a social problem. As such, the project would target silage production from fish waste from processing of marine fish. Currently by-products from tuna processing are used for fish meal production but the biggest tuna processing factory is interested in silage production as an alternative cheap process. Even in freshwater fish processing, opportunity for fish silage production and use can be created within processing industry if studies demonstrate that the returns from silage production are higher than the actual use. The actual prices for by-products of Nile perch processing (except for swim bladders) are even far below the price of farmed fresh fish. Studies involving comparisons of fish meal diets and silage based diets will show whether the product (fish silage) can be produced at a competitive price to available fish meals, gives good performances in feeds for fish and livestock animals.

Economically important fish species for farming in Kenya and for which fish silage based diets can be developed include in this order of importance: Nile tilapia and African catfish in the Lake Victoria region (Kisumu) and Nairobi, milkfish on the coast (Mombasa, marine aquaculture), and to a less extent trout in the highlands (cold temperatures). Development of fish silage-based diets for ruminants (cattle, sheep and goats) and non-ruminants (chickens and pigs) near big cities is important for Kenya.

5.3. Opportunity for fish silage production and use in Somalia

5.3.1. Fish production in Somalia

Roughly half of the fisheries production from Somalia waters (19 546 tonnes in 1987) comes from the artisanal fishermen and the remainder derives from licensed foreign trawlers (van Zalinge, 1987). Estimates state that the production from the Somali waters should reach annually 200 000 tonnes, around 10 times the current yield consisting of large and small pelagics and a range of demersal and reef fish. The seasonal abundance of these species (particularly sardines, scads, anchovies and herring types) is estimated to vary between 120 000 and 370 000 MT, of which about 70 000 to 100 000 MT could be caught annually without endangering stocks (estimates from Habo Fish and Tuna canning factory).

5.3.2. Fish consumption in Somalia

Somalis are not traditional fish-eaters and with poor infrastructures much landed fish goes to waste (ACP Fish II). The per capita fish and seafood consumption is 2.4 kg of fish per year.

5.3.3. Fish silage production and use in Somalia

There are two main tuna processing factories in Somalia, Las Koray Tuna processed and Habo Tuna. Habo Tuna Fish Processing and Canning has a processing capacity of 40 tonnes a day. Production of silage is expected to become 12 tonnes a day. In 2013, AECF decided to finance HABO by adding a canning line for small pelagic fish to the current canning line for tuna. There are already abundant by-products from Habo tuna processing that could be used for silage production and use in fish and animal diets.

Unfortunately for security reasons, it is impossible to conduct at this time fish and animal feeding trials in Somalia. In case tuna processing by-products or silage from fish processing in Somalia might be transported from Bosaso (Habo Tuna factory) in the gulf of Aden to the users in Ethiopia or in Kenya, transport costs are to be considered. Transport costs of fish silage (liquefied) with bad infrastructure (roads, cooling, insecurity) are expected to be high and prohibitive. Therefore home-grown solution (i.e. local production and in situ usage of fish silage) are more appropriate. The fish silage can be co-dried with feed energy source ingredients such as cereal bran to produce feed mixtures with a lower water content which are easy to transport. For information and alternative source of tuna processing by-products, one of the largest tuna canning plants in the world, the Indian Ocean Tuna (IOT) factory, is located in the Seychelles, 1 500 km east of mainland Southeast Africa. According to Limmen (pers. comm.), tuna by-products from processing at IOT factory may be taking destination to Asia for adding-value.

6. Partnership on fish silage research in Eastern Africa

Research institutions, researchers in fish & fisheries and in livestock, fish producers and fish processors have been visited during a 4-day mission in Kenya and Ethiopia. The mission aimed at finding partnerships for silage production, research and use in Eastern Africa. Potential partnerships and partners are highlighted in bold in the following sub-sections and their contacts are provided in Annex 1.

6.1. Ethiopia

Ethiopian Institute of Agricultural Research (EIAR) is the main agricultural research institute under which agriculture research is organised through federal and regional research centres in Ethiopia. Most research centres of EIAR focus on crop production, with only a few on fish and animal production. Federal governmental research centres have qualified human resources but lacks sometimes good research infrastructures and research funds. Regional research centres have an autonomous management and participate in different projects calls. Some research activities are conducted at Universities and sometimes in collaboration with regional research centres.

The headquarter of International Livestock Research Institute (ILRI) which used to be in Addis-Ababa has been transferred to Nairobi, Kenya. Research animals have been since given to Ethiopian government research centres with which ILRI does research on a contract basis (information not verified). Researchers at ILRI-Addis Ababa are involved in research programmes of ILRI-Nairobi.

Discussions in Ziway and Addis Ababa resulted in expression of interest for partnership on the silage project and recommended to consider 2 types of environments (**lowlands and highlands**) for both fish and livestock research.

6.1.1. Partners identified in FISH RESEARCH in Ethiopia

✓ Oromia Agricultural Research Institute (RIFT VALLEY)
Contribution: Administrative authority for both fish and livestock research in the low land areas, dissemination of research results

- ✓ **Ziway Fisheries Resources Research Center**
    - Contact person: Getachew Senbete Buta (MSc), Center Director.
    - Team: Alemu Lema Abelti, researcher post-harvest fish technology; Demeke Tekiu, assistant researcher post-harvest fish technology; Megerssa Endebu (MSc), associate researcher aquaculture.
    - Contribution: research on fish, dissemination of research results

✓ Amhara Regional Agricultural Research Institute (HIGHLANDS)
Contribution: Administrative authority for both fish and livestock research in the highland areas, dissemination of research results.

- ✓ **Bahir Dar Fishery and Aquatic Life Research Center (BFALRC)**
    - Contact person: Alayu Yalew Teferra (Drs), Centre Director
    - Contribution: research on fish, dissemination of research results

✓ Bahir Dar University (HIGHLANDS)

- ✓ **Department of Agricultural Biotechnology, Biotechnology Research Institute**
    - Contact person: Sileshi Andualem (MSc.), Head Department of Agricultural Biotechnology
    - Contribution: Last year and master thesis students on the project; analytical and laboratory facilities, on fish nutrition research

- ✓ Addis Ababa University
  - ✓ **Department of Zoological Sciences**
    - o Contact person: Prof. Abebe Getahun, Head of Department
      - o Contribution: Last year and master thesis students; analytical and laboratory facilities, expertise in aquaponic systems and fish nutrition research.

      - o Akewake Geremew, PhD researcher on alternative feeds for tilapia grow-out,
      - o Link with the Department of Biology at Dilla University
      - o Contribution: Last year and master thesis students on the project; feed testing facilities and possibly analytical and laboratory facilities on fish nutrition research

      - o Alayu Yalew, PhD researcher African catfish (re)production,
      - o Link with Bahir Dar University, "Fish for All" NGO, Urk Fishing Community

6.1.2. Partners identified in LIVESTOCK RESEARCH in Ethiopia

- ✓ Ethiopian Institute of Agriculture Research (EIAR)

  - ✓ **EIAR-Debre Zeit Agricultural Research Center**
  - o Contact person: Dawud Ibrahim, poultry research
  - o Contribution: poultry research

- ✓ Oromia Agricultural Research Institute (RIFT VALLEY)

Contribution: Administrative authority for both fish and livestock research in the low land areas, dissemination of research results

  - ✓ **Adami Tulu Agricultural Research Centre (ATARC)**
    - o Contact person: Dr. Tesfaye Alemu, Director for livestock research at OARI
    - o Team: Kedir Wako, Centre Director of ATARC
    - o Contribution: livestock research in the low land areas, dissemination of research results

- ✓ Amhara Regional Agricultural Research Institute (HIGHLANDS)
    - o Contribution: Administrative authority for both fish and livestock research in the highland areas, dissemination of research results

  - ✓ **Andasa Livestock Research Center**: Center of Excellency in Poultry and Dairy
    - o Contact person: Shigdaf Mekuriaw Zewdu, Center Director
    - o Team: Dr. Likawunt Yiheyis
    - o Contribution: research on livestock, dissemination of research results

- ✓ Bahir Dar University (HIGHLANDS)
  - ✓ **Department of Agricultural Biotechnology, Biotechnology Research Institute**
    - o Contact person: Sileshi Andualem (M.Sc.), Head Department of Agricultural Biotechnology
    - o Contribution: Last year and master thesis students on the project; analytical and laboratory facilities, on livestock nutrition research

- ✓ ILRI-Addis Ababa
    - o Contact person: Azage Tegegne (PhD), Deputy to Director General's Representative in Ethiopia International Livestock Research Institute
    - o Possible contribution: participation in livestock research through regional research centres, collaboration in livestock research with ILRI-Nairobi.
    - o Team (recommended by ILRI-Nairobi): Allan Duncan (livestock nutritionist); Michael Brummel

6.1.3. Partners identified in FISH PRODUCTION and PROCESSING in Ethiopia

Fish processor at Lake Ziway:

- ✓ **Fish Production and Marketing Industry-Ziway branch**
    - o Contact person: Adefris Kasaye, Branch manager and fish technologist
    - o Contribution: continuous supply of tilapia and catfish processing by-products for silage production

Fish processors at Lake Tana:

- ✓ **Fish Production and Marketing Industry-Bahir Dar branch**
    - o Contact Person: Tadesse Kebede, Manager of the enterprise
    - o Contribution: continuous supply of tilapia, catfish and labeobarbus processing by-products for silage production

- ✓ **Lake Tana No. 1 Fishers Cooperative**
    - o Contact Person: Tadesse Melaku, Chairperson of the cooperative
    - o Contribution: continuous supply of tilapia, catfish and labeobarbus processing by-products for silage production

- ✓ **ASA Ethiopia: Africa Sustainable Aquaculture**: Commercial fish (tilapia) producer
    - o Alwin Quispel (MSc), Manager Operations ShareBusiness, Modern Model Aquaculture farm near Awassa river?, annual production of 500-700 tonnes of tilapia per year starting end of the summer
    - o Contribution: Up-scaling of research findings, supply of input for tilapia silage production; Link with the Chamber of Commerce (receives already NL support)

- ✓ **URK FISH COMMUNITY**
    - o Petra Spliethoff (WUR/CDI)
    - o Contribution: Link and involvement with the Fishery Community on Lake Tana ISE-Urk, Interchurch Foundation Ethiopia is a Dutch NGO.

6.2. Kenya

6.2.1. Partners identified in FISH RESEARCH in Kenya

- ✓ Kenya Marine Fisheries and Research Institute (KMFRI)
  - ✓ **KMFRI-Sagana**
    - o Contact person: Dr. Jonathan Munguti, Senior Assistant Director KMFRI, Aquatic feed specialist.
    - o Team: Dr. Harrison Charo-Karisa, Deputy Director of Fisheries, Alternative feeds and dissemination.
    - o Contribution: freshwater fish research Nile tilapia, African catfish, Rainbow trout, *Labeo victorianus;* Research infrastructures: ponds (up to 1ha), hapas, small research tanks
  - ✓ **KMFRI-Mombasa**
    - o Contact person: Mirera Oersted David (B.Sc, M.Sc, Ph.D), Research Officer
      - o Team: Dr. James Mwaluma; Morine Mukami Ngarari, PhD researcher (University of Ghent, Belgium); Stephen Mwangi
    - o Contribution: marine fish research, feeding trials on milkfish (*Chanos chanos*)

- ▪ University of Nairobi
  - ✓ **Hydrobiology research group**
    - o Contact person: Dr. James Gordon, Expertise in Aquafeeds & Fish Physiology.
    - o Contribution: Last year and master thesis students; possibly analytical and laboratory facilities.

6.2.2. Partners identified in LIVESTOCK RESEARCH in Kenya

- ✓ **ILRI-Nairobi**
  - o Contact person: Fidalis Mujibi Denis (PhD), cattle geneticist
  - o Team: Okeyo A. Mwai; Ben Lukuyu
  - o Contribution: Livestock feeding research

- ✓ **The University of Nairobi- School of Biological Sciences**
    - o Contact person: Dr. Lillian Wambua. Expertise in livestock health, development of cheap protein sources for animal feeds (chickens).
  - o Contribution: Last year and master thesis students; analytical and laboratory facilities; collaboration with ILRI-Nairobi.

- ✓ **Kenya Agricultural and Livestock Research Organisation (KALRO, formerly KARI**):

- ✓ **KALRO** Nairobi:
  - o Contact person: David Miano Mwangi, assistant director, cattle and non-ruminant research
- ✓ **KALRO** Mtwapa:
    - o Contact person: Michael Ngunjiri Njunie (PhD), Centre Director and researcher in forage production
    - o Team: Derrick M. Mwamachi (BVM, MSc), Centre outreach & partnerships officer, animal scientist; Gideon S. Munga, animal scientist; Leonard Changawa Mambo;

- ✓ **KALRO** Naivasha: center of excellence on poultry research
  - o Contact person: John N. Kariuki (PhD), Centre Director, indigenous (village) chicken and poultry research
  - o Team: Ann Mumbi Wachira (PhD), cattle and non-ruminant research

6.2.1. Partner identified in FISH PRODUCTION and PROCESSING in Kenya

- ✓ Tuna processing factory
  - ✓ **WANAINCHI Marine Products (KENYA) Limited**
    - o Contact person: Mr. Salim Nyowe; General Manager Wanainchi Marine Products (Kenya) Ltd.
  - o Team: Samia Tung, fish meal production from tuna processing by-products
  - o Contribution: supply of tuna processing by-product for silage production and fish meal from processing by-products for trials

- ✓ AFIPEK (Kenya Fish Processors & Exporters Association).
  - ✓ Beth Wagude, Secretary of AFIPEK
    - o Contribution: Link with Fish Processors and Fish industry

6.3. Fish silage production, research and dissemination network

The proposed chart (Figure 7) illustrates different linkages possible between fish silage production, research and dissemination for use in feeds for fish and livestock in Eastern Africa.

Knowledge and technology are provided from The Netherlands by Wageningen UR and the Dutch industry to produce and use quality fish silage in East Africa. The latter is incorporated in formulated feeds for fish and livestock and tested under local conditions at universities and/or in research centres or in collaboration between these 2 institutions in East Africa under the research supervision of Wageningen UR. This framework can be used for the setup of fish silage implementation projects in practice.

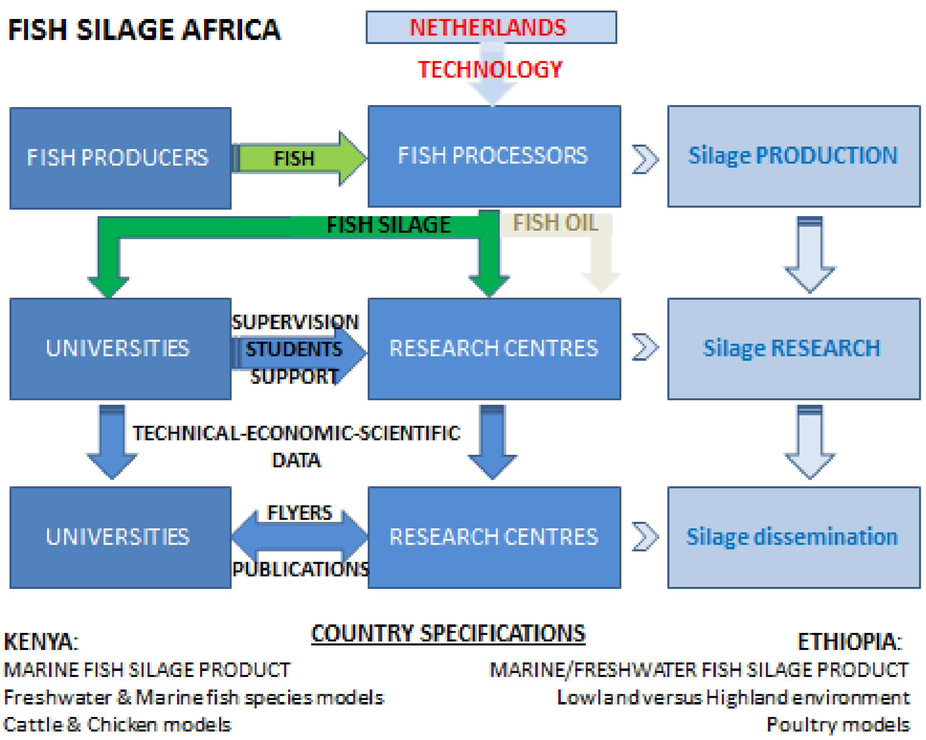


Figure 7. Proposed linkage flow chart: from production through research to dissemination

7. Business plan and business model for fish silage production

7.1. Business plan for fish silage production (contribution by Rainbow Agro, John Limmen)

The business plan comprises the economic exploitation of a fish silage plant and the economic viability of manufacturing of these plants to be sold to customers worldwide. The benefits of a fish silage plant especially compared with fish meal plants are:

- Low investment
- Easy to operate. Technology is quite simple and therefore easy to maintain.
- Already economically viable at small volumes
- Almost no smell.

Especially in developing countries like in most countries of Africa, fish wastes are dumped at landfills or back into the sea or lakes. In the same countries there is a large demand for protein rich cattle and fish feed, which has to be imported at high prices. This demand can now easily be replaced by local produced products. According to Nutreco, it is a promising solution for Africa.

Fish silage is a liquid organic product made entirely from ground up fish waste (e.g. heads, guts, skin and cartilage). The waste, which contains minerals, trace elements, complex nutrients and amino acids, can be used as a fertiliser for soil or as a supplement to animal food.

Silage production begins with chopping or mincing fish waste into small particles. Formic acid is added to aid in the liquefaction process; the entire mixture should be thoroughly mixed so that all of the material comes into contact with the acid, otherwise, any untreated fish particles would putrefy. The proportion of acid is 3.5% by volume (i.e. 350 ml acid to 10 kg of fish waste). The acidity of the mixture was kept at pH 4 or lower to prevent bacterial action. The natural silage process then begins. The rate of liquefaction depends on the type of fish, the parts used, freshness of the raw material and the temperature of the mixture. Once ready it can be stored in airtight containers for over six months.

When processing fish waste from oily fish like herring or tuna, it is advisable to extract the fish oil first. This has two advantages: The fish oil can be sold at high prices, while the fish silage is of higher quality as well. Fish oil can make the silage more rancid.

For the exploitation, it is opted as an example for a fish silage plant with a processing capacity of 500 kilo per hour or 6 tonnes per day by two shifts of 6 hours. For such an installation the total investment will be as in Table 8.

Table 8. Investment costs of fish silage plant (processing capacity: 6 tonnes per day)

Fixed asset	Price in US$
Land & buildings	65,000
Fish silage installation	170,000
Cool room	50,000
Diesel generator 25 KvA	18,000
Tractor + Lorry + Small crane	26,000
Office furniture & Equipment	5,000
Total Investment	334,000

Startup costs include construction, transport costs and training and are estimated at $ 48,000.

We assume that there is already a good local demand for animal, poultry, pig or fish feed. The end product is fish silage mixed with rice bran and supplied as cake or pellets. The price difference is neglectable for both sales as cost price.

Table 9. Revenues of a fish silage plant

Revenue ($)	Units	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Animal/Poultry feed							
Volume	In tons	1,661	1,922	2,121	2,344	2,593	2,874
Price	P/ton	420	420	420	420	420	420
Total Sales		697,410	807,030	890,757	984,369	1,089,269	1,207,110
Cost of Sales							
Opening Stock		-	69,649	54,080	59,690	65,963	72,993
Closing Stock		69,649	54,080	59,690	65,963	72,993	80,889
Raw materials		110,700	128,100	141,390	156,249	172,900	191,605
Silage materials		228,463	263,178	290,395	320,785	354,787	392,918
Repair & maintenance		30,000	33,000	36,000	36,000	36,000	36,000
Wages		50,400	59,447	68,493	77,540	86,586	95,633
Cost of Sales		349,914	499,293	530,668	584,300	643,244	708,259
Gross Profit		**347,496**	**307,737**	**360,089**	**400,068**	**446,026**	**498,850**
Expenditure - Overhead							
Salaries		16,800	17,956	19,112	20,268	21,424	22,580
Start-up costs		16,000	16,000	16,000			
Total Expenses		**32,800**	**33,956**	**35,112**	**20,268**	**21,424**	**22,580**
EBITDA							
Net Profit / Loss before tax		**314,696**	**273,781**	**324,977**	**379,800**	**424,602**	**476,270**
Interest, Tax and Depreciation							
Interest expense							
Tax expense	5%		14,107	12,065	14,629	17,373	19,616
Depreciation		32,550	32,472	32,404	32,344	32,291	32,246
Net Profit		**282,146**	**227,202**	**280,508**	**332,828**	**374,938**	**424,409**
In % of Gross profit		**81%**	**74%**	**78%**	**83%**	**84%**	**85%**

According to the table of revenues of a fish silage plant (Table 9), the profit margins are quite high, but realistic. The sales price of the feed is much higher in most African countries, while quality is almost the same like the FCR (Feed conversion rate).
Other assumptions made: Raw materials (Fish waste) are purchased at US$ 50 per tonne. In most cases it will be zero as it is produced by the same factory.
The ratio fish silage : rice bran is set at 4 : 1, while the loss of moisture due to drying of the end product is set at 63%.

7.2. Business model for fish silage production

Based on accumulated information a business model is presented in Figure 8 for the production and use of fish silage in Eastern Africa.

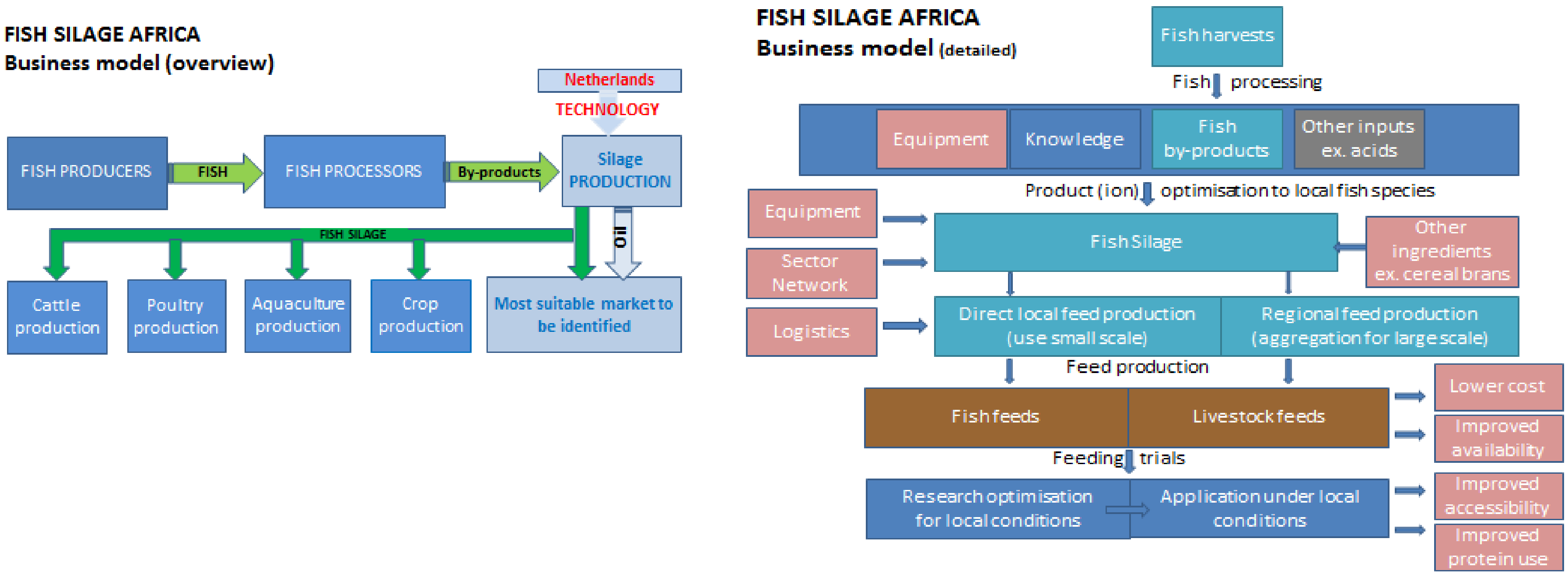


Figure 8. Overview and details of the fish silage business model

The supply chain of the fish silage business model comprises knowledge and technology providers as well as input providers of raw materials and equipment for the production of fish silage and fish silage based animal feeds. The potential consumers of fish silage include manufacturers of fish and animal feeds and soil fertilisers, and definitely producers of fish and animals feeds derived from fish silage or crop producers using fertilisers prepared from fish silage. To scale up the fish silage production, small scale units of fish silage production are aggregated together in a fish(ing) by-product producing region to create a volume for the production of feeds on large scale in that particular region. Research to prove the biological and economic performance of fish silage in fish and animal feeds, is carried out and optimised in local conditions in collaboration between knowledge institutes. Results of the research are disseminated via the research institutions in the region to a wide audience of end-users comprising fish processors, animal feed producers, fish and animal farmers. The expected outputs of the model are the local availability of silage producing plants, cheaper fish silage based feeds compared to fish meals based feeds, an improved local availability and accessibility of fish silage based feeds, and improved use of protein in fish and animals nutrition in East Africa.

8. Conclusions and recommendations

8.1. Conclusion

Acidified, defatted fish silage appears a valuable source of amino acids for poultry and pigs and can be a potential source of nitrogen and branched-chain amino acids for ruminal micro-organisms.
In broiler diets, acidified, defatted fish silage can be incorporated to levels in which fish silage supplies 40% of the total protein requirement. The inclusion level will also depend on the dry matter content of the final diet. Other important issues are that only marginal concentrations of crude fat may be present in fish silage (< 1%) (Krogdahl, 1985b) to prevent a fishy taint of chicken meat and vitamin A toxicosis and a high microbial quality.

Also in laying hens 40% of the protein requirement can be supplied by acidified, defatted fish silage under the same conditions as for broiler chicken. However, laying hens may tolerate more marine fat (< 1.5%) in their diets than broilers (Kjos *et al.*, 2001). In the final diet, the required level of tryptophan should be guaranteed in order to prevent feather pecking caused by a tryptophan deficiency.
In finishing pigs at least 10% of the total protein requirement can be supplied by acidified, defatted fish silage, again under the restriction that the fat content is below 3.4 g/kg dry matter.

The nutritive value of acidified, defatted fish silage for ruminants is not very clear. Most studies suggest that fish silage can be used as a source for ruminal-degradable protein and possibly also for branched-chain amino acids to be used by the ruminal microbial population. In this respect, acidified, defatted fish silage may stimulate the activity of ruminal micro-organisms and consequently and the degradation of other feed components when low-quality, low-protein diets are being fed. This may result in higher feed intake, higher nutrient supply and consequently better animal performance. Some studies suggest that a considerable part of the free amino acids and peptides of fish silage will not be degraded in the rumen, thereby directly supplying absorbable amino acids to the animal. In small ruminants palatability of diets with fish silage may become an issue.

Fish silage can be incorporated in fish diets. The digestibility of fish silage is high in fish. The availability of fish processing by-products is different in Ethiopia and in Kenya. In Ethiopia, freshwater fish by-products, mainly from tilapia filleting, are widely available but no marine fish by-products are found in the country. In Kenya, freshwater fish by-products from Nile perch processing are used for human consumption. Marine fish by-products from yellow fin tuna processing are currently converted into fish meals. Many identified potential partners in Ethiopia and in Kenya have expressed their interest to participate in the fish silage project.

8.2. Required research

Varies aspects will require further research. These are: (1) variety in chemical composition and nutritive value; (2) effects of replacement of imported feed protein sources by fish silage for poultry, pigs and ruminants; (3) effects of using fish silage as a protein supplement for low-quality, low-protein diets for ruminants; (4) effects of fish meal replacement by fish silage in most economically important farmed fish species; (5) handling and delivery method of fish silage in fish and livestock feed; (6) Bio-economic studies of fish silage substitution in fish and livestock diets.

Variety in chemical composition and nutritive value

To ensure that farmers receive a product of a rather constant quality, it is important that the day-to-day variation in chemical composition is small. To maintain a more or less constant quality, critical control points have to be defined and methods to monitor verifiable indicators have to be developed. It is important to determine the apparent digestibility of nutrients (crude proteins and amino acids) of different silage products.

Effects of replacement of local feed protein sources

This research is not only required to ensure that reliable arguments can be used to introduce fish silage into diets for livestock animals, but also to demonstrate to farmers that fish silage can replace traditionally used feed protein sources.

Effects of using fish silage as a protein supplement for low-quality, low-protein diets for ruminants

Studies are required to assess the economically feasibility of including fish silage in diets for ruminants. In this respect it has to be shown that fish silage is more beneficial than urea or other sources for ruminal-degradable crude protein.

Effects of fish meal replacement by fish silage in most economically important farmed fish species

This research is necessary to support the introduction of fish silage into diets of farmed fish, and to demonstrate to fish farmers that fish silage can replace expensive feed protein sources.

Handling and delivery method of fish silage in fish and livestock feed

Conventional methods of drying are too expensive and fish silage is usually manufactured and stored as liquid close to the point of use. Studies are needed to compare the quality of feeds combined into moist diets, or condensed or dried for use as fish and livestock feed ingredient.

Bio-economic studies of fish silage substitution in fish and livestock diets

Bio-economic data are necessary for up-scaling of application of fish silage in order to validate findings from laboratory and small-scale on-farm studies.

9. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

IMARES report C135/14
IMARES project code 4308401033

The scientific quality of this report has been peer reviewed by the colleague scientist and the head of the department of IMARES.

Approved: Dr. P.C. Goudswaard
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Annex 1. List of contacts of potential partners in Ethiopia and Kenya

I. Potential partners in Ethiopia

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