FERMENTATION CHARACTERISTICS, NUTRITIONAL VALUE AND PALATABILITY OF ENSILED SEAFOOD WASTES AND LOW QUALITY ROUGHAGES

by
Winston Anthony Samuels

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
in
Animal Science

APPROVED:

J. P. Fontenot, Chairman

V. G. Allen

H. J. Gerken, Jr.

J. A. Cherry

G. J. Flick

L. A. Swiger, Department Head

September, 1983
Blacksburg, Virginia

DEDICATION

In memory of my dear parents, Simeon and Margaret Samuels.

ACKNOWLEDGEMENTS

The author is deeply indebted to the National Seagrant Program without whose financial assistance this study would not have been possible.

The author wishes to express his sincere thanks to all individuals for their assistance and encouragement throughout this study and his entire graduate program.

To Dr. J. P. Fontenot, the author is deeply indebted for his thoughtful guidance, patience, understanding, suggestions and endless encouragement in conducting this study and for his invaluable assistance throughout his graduate program. Thanks to Dr. V. G. Allen for encouragement and thoughtfulness during the author's period of study.

To , the author is indebted for his technical assistance, patience, insight and invaluable encouragement. Thanks also to Drs. J. A. Cherry, G. J. Flick and L. A. Swiger for encouragement, helpful advice and criticism in the course of his program. To , thanks for critical review of this manuscript. Special appreciation is extended to for his kind assistance in the statistical analyses. The author also is indebted to the staff of the Forage Testing Laboratory for making the facilities available to conduct various analyses. To , thanks for assistance rendered in conducting mineral analyses.

Thanks to the various seafood processors in Hampton, Virginia,

who so willingly participated in making this venture a reality. To

and the staff of the Seafood Research and Extension Unit in Hampton, thanks for all assistance rendered.

To his fellow graduate students the author wishes to extend his sincere thanks for their manual assistance, input, encouragement and most of all, good humor. Special thanks to

and his staff at the Smithfield unit for encouragement and many hours of assistance.

Thanks and sincere appreciation is extended to

for her patience and extraordinary effort in typing this manuscript.

Lastly, the author is forever grateful to dearest for her assistance and understanding. She made it all possible, but more important, worthwhile. The helpful thinking and timely assistance of everyone enabled realization of goals otherwise unattainable.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

The total seafood catch was 28 million metric tons in the U.S.A. in 1960 (Borgstrom, 1961). In 1974, nationwide crab harvest exceeded 149,000 metric tons (NMFS, 1975). Large quantities of waste result from seafood processing. Solid wastes generated by seafood processing plants range from 30 to 85% of the landed catch. Only about 15% of the total weight of processed crabs and shrimps is used for human food. Waste approaches 50% from fish used for fileting or dressing. The disposal of these wastes presents problems due to odor, high water content and federal, state and local ordinances governing the disposal of wastes or by-products.

The manufacture of fish and crab meal has been an outlet for such wastes and the value of these meals as supplemental sources of protein is well documented. However, it is difficult for a small or medium sized seafood processor to economically process waste into meals. Also, an elaborate network would have to be established for collecting the raw by-product from various ports, and transporting it to a central processor. Due to the high cost of capitalization for small operations, the unit cost of fish and crab meal production usually cannot compete with the other protein meals. Other methods of processing are available but the process of ensiling is especially attractive due to low fossil fuel requirement.

Seafood wastes are generally high in moisture and low in water soluble carbohydrates. In order to achieve good fermentation, it would be desirable to increase the dry matter content. Additionally, a source

of fermentable carbohydrate or acid may be needed. Combining the seafood waste with materials containing appreciable water soluble carbohydrates would remove the need for acid addition and would also increase the dry matter content of the silage, thereby, rendering it more manageable.

Crop residues constitute vast underutilized sources of carbohydrates for use as animal feed. The potential use of crop residue, as animal feeds is worthy of consideration in view of the fact that ruminant animals are uniquely adapted to utilize the cellulose in high fiber materials. The ability of ruminants to digest fibers can be exploited to utilize such feedstuffs, especially ruminants on maintenance diets. Low digestibility and poor nutritive value have been the primary factors limiting greater feed utilization of crop residue in the past. Approximately 1 million tons of crop residues are available in Virginia, mostly in close proximity to the seafood processing industry. The ensiling of seafood wastes with crop residues would offer a practical way to utilizing two types of waste materials which are presently underutilized.

This research was undertaken to develop systems for processing of seafood wastes by ensiling to be used as feedstuffs for ruminants.

LITERATURE REVIEW

Principles of Ensilage Process

According to Barnett (1954) the objective in silage making is the achievement within the ensiled mass of an adequate concentration of lactic and other organic acids. These acids are produced as a result of the anaerobic fermentation brought about by the presence of micro-organisms within the ensiled mass. In order to make possible such a lactic acid fermentation, relatively large quantities of carbohydrates fermentable by lactic acid bacteria are required. The microorganisms metabolize the soluble carbohydrates, giving rise sequentially to the organic acids. The acids will reduce the pH to 4.5 or less at which point other forms of microbial activity are inhibited, resulting in the preservation of the material until it is fed.

Heath et al. (1973) reported that the ensiling process depends on three interrelated factors that govern the outcome of the process: 1) the composition of the plant material placed in the silo, 2) the amount of air allowed to enter the ensiled mass, and 3) the bacteria on the material. Wieringa et al. (1961) and Woolford (1972) reported that the ensiling process also depends on the temperature attained within the ensiled mass and that high temperature was associated with poor silage quality. Weise (1963) demonstrated that in laboratory silage kept at 40 C, coliform organisms remained active for a long time, however, the number of lactic acid bacteria in silage kept at 20 C was four times higher than in silage stored at 40 C. Several findings

have shown that the amount of butyric acid in silage increased with temperature (Zimmer, 1969; Ohyama, 1971; Woolford, 1972).

The ensiling process takes at least 21 d to complete (Barnett, 1954), however, if the proper pH is not achieved (i.e., the growth of lactic acid producing bacteria is suppressed), butyric acid producing bacteria (Clostridia sp) could attack both the remaining carbohydrates and the organic acids formed. This type of fermentation results in a foul smelling, slimy, unpalatable silage. The butyric acid producing bacteria may attack protein, converting it to volatile fatty acids and ammonia. Good quality silage is characterized by low ammonia nitrogen as percentage of total nitrogen; this figure should be less than about 12% and, furthermore, butyric acid must only occur in insignificant quantities (Nilsson and Rydin, 1965).

The ensiling process has advantages of helping mask odors or other factors that might reduce intake, and also of controlling or eliminating potential pathogens (McCaskey and Anthony, 1975; Harmon et al., 1975a).

A beneficial effect of the ensiling process is an increased solubility of nitrogen, resulting in greater utilization of nitrogen by ruminants (Goering and Waldo, 1974).

Seafood Waste

There are two main sources of seafood waste: 1) waste from finfish processing and 2) shellfish waste. Finfish processing waste consists of whole fish, fish offal, frames and heads. Shellfish waste is herein limited to the waste derived from the processing of crustacean species such as crabs, shrimp and crayfish and include

materials such as heads, shells, legs and viscera.

Fish Silage

Historical Aspects. The product from preserving and storing of wet fodder in a silo is called silage. The traditional use of the word has been in combination with green forage preserved either by acid addition or by the anaerobic production of lactic acid by bacteria. Noting the incorporation of materials other than green forage, McCullough (1978) defined silage as the feedstuff resulting from the anaerobic preservation of moist forage or other feedstuffs by the formation and/or addition of acids. Fish silage has been adopted for similar products of whole fish or parts of fish (Raa and Gilberg, 1982).

Fish silage is traditionally a liquid product made by the addition of acid to whole fish or to parts of fish (Tatterson and Windsor, 1974; Tatterson, 1982). Liquefaction proceeds by the action of enzymes in the fish (Sumner and James, 1977).

Silage production, either by acid addition or by fermentation was developed by Virtanen in the 1920's. He initiated the use of sulfuric acid and/or hydrochloric acid to preserve green fodder (AIV silage). Acid fish silage has been produced commercially for 30 yr in Denmark (Backhoff, 1976) and Poland (Sikorski et al., 1969). Raa and Gilberg (1982) reported that in Norway silage is produced commercially from fish guts and other waste products from the fishing industry.

In recent years there has been renewed interest in fish silage (Tatterson and Windsor, 1974; Disney et al., 1977) in both industrialized and developing countries (Sumner, 1976). This has mainly been because fish silage represents a means of utilizing waste fish in

circumstances where conventional fish meal production is inappropriate or not available (Raa and Gilberg, 1982). Such circumstances are characterized by scattered and irregular landing of fish, or when the quantities of fish are too small for viable operation of a fish meal plant (Disney et al., 1978). The production of liquid fish silage on an industrial scale is limited, however, because its high water content makes it uneconomical to transport the material for long distances (Backhoff, 1976).

Acid Preservation. The production of acid fish silage can be achieved by the addition of inorganic or organic acid. The principle involved in the production of such silages is that the native enzymes in the fish are spread throughout the fish mass by grinding and mixing (Tatterson and Windsor, 1974). Acid addition lowers the pH, resulting in a more rapid liquefaction, and also has a preserving effect on the product by limiting the growth of spoilage bacteria (Sumner and James, 1977; Tatterson, 1982).

Fish silage has been made by the addition of sulfuric acid (Freeman and Hoogland, 1956). Sulfuric acid can be replaced by hydrochloric (Wessels and Labuschange, 1974; Disney and Hoffman, 1976) or phosphoric acid (Jensen and Schmidtsdorff, 1977). Lisac (1961) considered in detail the use of various acid mixtures in varying quantities of the liquefaction and keeping quality of silage produced from Mediterranean sardine offal. Successful swine feeding trials were also performed. This work indicated that the cheapest acid suitable for such a raw material was a 6:1 mixture of sulfuric acid and formic acid.

The quantity of acid required to lower the pH sufficiently in a fish

homogenate depends on the concentration of protein and ash in the raw material (Raa and Gilberg, 1982). Edin (1940), working with acids used in AIV silage, suggested a formula based on pH, protein and ash measurements to calculate the amount of such acid required by minced raw material. The formula implied that roughly 9 liters of a 14 N inorganic acid were needed to preserve 100 kg of the most bony fish, whereas, 4 liters were sufficient for oily fish with very low ash and protein contents. Although mineral acids, such as hydrochloric and sulfuric are relatively inexpensive, there are disadvantages to their use. They are very corrosive (McDonald and Whittenbury, 1973) and before mineral acid silage can be fed to animals, it should be neutralized (Peterson, 1953; Tatterson and Windsor, 1974). However, Raa and Gilberg (1982) reported that the high salt level (2 to 5 kg/100 kg of silage) which results from neutralization was undesirable in animal nutrition and that the neutralization procedure was in itself so laborious that it is a major practical problem. As a result of such problems, considerable attention has been focused on the use of organic acids as silage additives.

Fish silage is produced in Denmark by the addition of 3% formic acid (Backhoff, 1976). Formic acid is more expensive than the common mineral acids, but it produces silages which are less acidic and which do not require neutralization before feeding, since preservation is achieved at a higher pH (Tatterson and Windsor, 1974). Also, the liquefaction process can be carried out within a pH range of 4.0 to 4.5 (Backhoff, 1976). The difference in price between inorganic and organic acids is partly counterbalanced by the higher efficacy of the organic acids. It has been recommended (Raa and Gilberg, 1982) that in order

to reduce the price of preservation, it may be best to use a mixture of inorganic and organic acids. The less expensive inorganic acid could be used to lower the pH sufficiently for the organic acid to become antimicrobial. Such experiments have been carried out mainly with formic in combination with sulfuric acid (Atkinson et al., 1974; Disney et al., 1978).

An important consideration in choosing the acid mixture is that, not only should the growth of spoilage bacteria be prevented, but also, that pathogenic bacteria, such as Salmonella and Clostridium botulinum, should not grow (Tatterson, 1982). Due to the antiseptic properties of formic acid, none of these organisms is likely to multiply below a pH of 4.5, the pH generally achieved when formic acid is added (Backhoff, 1976). In order to produce similar antibacterial actions as when formic acid is used, Edin (1940) reported that the production of fish silage using inorganic acids, require the pH of the final product to be around 2.0.

Fish silage preserved with inorganic acids or with formic acid at pH 3.5 to 4.0 is not completely protected against fungi (Gaiger, 1978). Kompiang et al. (1980) reported that the aflatoxin-producing fungus, Aspergillus flavus, was, for example, able to grow in the surface lipid of a fish silage made with the addition of 3% formic acid. Stable silages with a fresh acidic odor were always obtained when 3% propionic acid was added.

Working with fish silage in Norway, Strom et al. (1980), in a series of experiments with formic and propionic acids at concentrations varying from .05 to 2%, demonstrated conclusively that propionic acid at

concentration of .2% or more inhibited growth of Aspergillus flavus. Raa and Gilberg (1982) strongly recommended the use of propionic acid in order to prevent growth of potentially hazardous fungi.

Yeoh (1980) observed a drop in pH from 6.5 to 3.8, 4.4 and 4.9, respectively, when 2 and 3% formic acid and 3% propionic acid were added to minced whole fish. Microbial counts on the acid fish silage showed a decrease in the total viable counts and coliforms after addition of the acid. However, if insufficient acid was added, the counts rose again as spoilage developed.

Raa and Gilberg (1976) reported ensiling of fish viscera was achieved by adding .75% propionic acid and .75% formic acid. This silage, which had a pH of about 4.2 remained sterile for several mo at 27 C.

From the chemical analysis of fish viscera, Gilberg and Raa (1977) concluded that this raw material could be an important feed resource, depending on the development of a practical method for preservation of the viscera and a process for the production of a feedstuff. They ensiled a 2:1 mixture of fish waste and barley straw treated with .75% propionic acid and .75% formic acid. the pH of the product was 4.5 and the ensiled mixture remained stable for 1 yr.

Kompiang et al. (1980) reported that tropical "by-catch" fish had a high ash content and therefore more acid was needed for preservation. They recommended a 2.5% concentration of formic acid, or a mixture of formic and propionic acid as being the minimum concentration that would ensure preservation of fresh by-catch fish. Raa and Gilberg (1982) recommended the use of at least 3% of such acids in order to have a high safety margin. This represents a significant cost, and it is accordingly

important for the viability of the silage process to find the most economical combination of acids for such raw materials.

In the preparation of acid fish silage, it is common practice to mince the fish and mix it with the preservative acids. This may be a significant practical problem if the fish is fresh because the muscle components become rubber-like when exposed to acid (Raa and Gilberg, 1982). The mince, therefore, tends to form closed pockets where the acids do not enter quickly enough to prevent the growth of spoilage bacteria (Tatterson, 1982). This is not a major problem if the raw material is not fresh.

The living fish carries potential spoilage bacteria at the surface and in the digestive tract. The muscle tissues are usually sterile, but become invaded soon after death. It is, therefore, essential to chop the very fresh fish to expose its interior and exterior surfaces to the preservative acids (Raa and Gilberg, 1982). By-catch fish has been satisfactorily preserved by this method on Indonesian shrimp trawlers (Kompiang, 1980). With very small fish it is not necessary to mince the fish when preparing the silage. According to Gilberg and Raa (1979) addition of acid to whole or chopped small fish may even facilitate efficient extrusion of oil because skin dissolves while muscle contracts in acid.

Although some work has been done concerning production of acid fish silage, there is little known about the chemical changes taking place during the liquefaction and storage of the product. Since sufficient acid is present to halt bacterial growth, liquefaction is due almost entirely to autolysis in which proteolysis predominates (Tatterson, 1982).

The biochemistry of the process has not been studied in detail but it is likely to be influenced by the relative amounts of muscle, guts, kidney and other tissues in the ensiling mixture (Backhoff, 1976). Pelagic species such as herring and mackerel, especially with viscera present, autolyze more rapidly than white fish (Mackie, 1982). A silage of fish muscle autolyzes very slowly (Backhoff, 1976). This is because the level of active proteolytic enzymes is very low in muscle. It is not yet clear whether the muscle (Hjelmeland and Raa, 1980), contains protease inhibitors, besides trypsin inhibitors, which retard autolysis at acid pH, but available data do not indicate that such inhibitors exist.

The rate of autolysis of ensiled cod viscera was found to be highest at pH of around 4.0 (Raa and Gilberg, 1976). This was demonstrated by measuring the rate of tissue degradation in silages with differences in pH, but constant concentration of propionic acid. The rate of autolysis and the yield of soluble matter was much lower at pH 3.0 than 4.0. This may explain why a herring silage autolyzed better if formic acid was used alone rather than mixed with sulfuric or phosphoric acid, because the pH was 4.5 in the former case, but 3.1 in the latter (Jensen and Schmidtsdorff, 1977).

Raa and Gilberg (1982) conclusively stated that the rate of autolysis of acid fish silage was affected primarily by the pH and not by the type of acid used for preservation, and in order to obtain optimum solubilization, organic acids should be used. However, the use of organic acids may result in such oil having a higher acid content than oil from mineral acid silage. This was in part a contribution from the

organic acids which dissolve in the oil, as well as from fatty acids released by enzymes which are active at pH 4.5. This lipolytic activity can be reduced by heating the fresh silage to 45 to 50 C for a few minutes, a treatment which does not affect the proteolytic activity (Reece, 1980).

The stability of acid fish silage appears to be time and temperature dependent. Backhoff (1976) reported that the formation of non-protein nitrogen occurred mainly in the first day after the ensiling of cod and herring with 3% formic acid. He further reported that after storage for 40 d at 30 C about 30% of the tryptophan was lost. At lower storage temperatures the rate of degradation was significantly lower, particularly in the herring silage in which no reduction of tryptophan could be detected when stored at 5 C, and only 9% reduction at 15 C.

Tryptophan is stable at low pH when present in proteins, but degrades when free (Kompiang et al., 1980), which explains the marked effect of temperature on its stability (Backhoff, 1976). Whether enzymes are involved in the degradation of the free amino acid is not known, however, there are observations in favor of this suggestion. For example, tryptophan was shown to be stable in the heat-treated aqueous phase of a silage of cod or saithe viscera (Strom and Eggum, 1981). Overall, storage of liquefied acid fish silage for excessively long periods is not recommended because evidence clearly indicates that the destruction of tryptophan and the oxidation of lipids gradually occur. This leads to the development of rancid flavors and possibly even toxic substances (Mackie, 1982).

Fish silage may become a competitive process under conditions which

traditionally have been favorable for fish meal (Raa and Gilberg, 1982) due to a number of advantages:

1) "Acid-preserved fish silage does not putrefy, retaining a fresh acidic smell even after storage for weeks. As well, there are not the same environmental problems with silage as with fish meal manufacture. Although there are ways of reducing the odor and air pollution from fish meal factories, these are expensive, energy consuming, and require large quantities of washing water which either has to be purified or discharged as a polluting effluent.

2) Acid preserved fish silage is almost sterile and pathogens like Salmonella are efficiently killed in it. Fish meal has spread this pathogen worldwide.

3) The scale of production of fish silage can be varied at will without the economy of the process being much affected. The capital investment in equipment may be anything from a homemade drum with a chopper to a sophisticated plant designed for de-oiling large quantities of silage.

4) The energy requirements of silage production are very low compared with fish meal - a factor of increasing importance as oil prices increase."

Bacterial Fermentation. In silage making by purely biological processes, lactic acid bacteria produce large amounts of lactic acid from media containing sufficient quantities of fermentable carbohydrates (Nilsson and Rydin, 1963). The production of lactic acid decreases the pH and thereby renders the medium unsuitable for the growth of most other microorganisms. Growth of lactic acid bacteria is, therefore, a

way of preserving feed. The manufacture of butter and cheese, and the natural fermentation of green forage to a stable silage are well known examples of the beneficial use of lactic acid bacteria. The corresponding means of preserving fish by a purely biological sense as silage, is less well known (Raa and Gilberg, 1982) and has not been pursued into practice to any significant extent, in spite of very convincing results on the storage life and the nutritional value of this type of silage (Raa, 1965; James et al., 1977).

Fish is rich in protein and lipids but has a very low level of free sugars available for fermentation by bacteria (Raa and Gilberg, 1982). The most significant source of energy for the growth of bacteria in fish is the pool of free amino acids, which increases as proteolysis progresses during postmortem of the fish. A relatively high quantity of carbohydrate must therefore be added to the fish in order to achieve good preservation.

Nilsson and Rydin (1963) ensiled fresh herring with the addition of malt meal, oat meal or a mixture of both. Good fermentation was obtained in the malt-oat meal mixture. In a subsequent experiment, Nilsson and Rydin (1965) ensiled small Baltic herring at different temperatures with the addition of a 1:5 mixture of malt-barley meal. Fermentation temperatures of 20 to 28 C throughout yielded good silage, however, at 37 C the quality was poor.

Yeoh (1980) produced good quality fish silage in Malaysia by ensiling minced whole fish and a fermented rice product called "Ragi". No pathogens such as salmonella or staphylococcus were detected after ensiling and the mixture remained stable for more than 6 mo. Molasses

has been used successfully as a source of fermentable sugar to ensile fish waste (Raa, 1965; Durainaj et al., 1976; Kompiang et al., 1980). Fish silage was produced by Tibbetts et al. (1981) by mixing 60% ground fish with 30% shelled corn, 5% dried molasses and a 5% Lactobacillus acidophilus culture. After ensiling for 30 d, the silage was of high quality as estimated by appearance and a fresh fermented odor.

Lactic acid bacteria are present in very low numbers in fish when compared to potential spoilage bacteria (Shroder et al., 1980). In order to enhance the ensiling process and consequent preservation of the silage, it has been recommended that suitable bacterial cultures be added. However, when carbohydrate additives carry such bacteria as a natural microflora in sufficient numbers, then the use of bacterial cultures can be omitted (Nilsson and Rydin, 1963). Black (1955) reported that seaweed is self-ensiling and therefore might be a useful additive. Successful preservation has been achieved by favoring the growth of lactic acid bacteria which appeared to be naturally present in fish (Kompiang et al., 1980).

Fish preserved by lactic acid bacterial fermentation of added carbohydrate had an acceptable hygienic quality (Krishnaswany et al., 1965). It has been reported that coliforms, typhoid bacteria, staphylococci (Durairaj et al., 1976; James et al., 1977) and even spores of Clostridium botulinum (Wirahadikusu Mah, 1968) were destroyed in silage. However, if the silage is exposed to air the growth of yeast and fungi may occur (Durairaj et al., 1976). The antibacterial action is due both to low pH and also presumably to the presence of antibiotic substances produced by lactic acid bacteria (Olley et al., 1968; Ricks

et al., 1978). The production of such antibiotics may be induced by the presence of other bacteria (Shroder et al., 1980).

A major problem with fermented fish silage is that of high levels of ammonia production, especially during the first days of storage when the pH is decreasing. As much as 12% of the nitrogen was released as ammonia during 4 wk of storage of a fermented silage of Baltic herring at 28 C (Nilsson and Rydin, 1963). Corresponding figures with acid preserved silages were 3% (Gilberg and Raa, 1977) or 1.5 to 2% (Kompiang et al., 1980). Kompiang et al. (1980) also demonstrated this difference between fermented and acid silage in comparative studies with by-catch fish as raw material. They further reported that the release of ammonia must come from the breakdown of nonessential amino acids since the nutritional value of fermented silage was very good.

Nutritional Value of Fish Silage. Most feeding trials with acid preserved fish silage show that it was a good source of protein and that its nutritional value was comparable to that of fish meal when included in cereal based diets for livestock. Although beneficial effects of fish silage have been reported, some studies showed that silage was inferior to fish meal, especially in poultry diets (Norman et al., 1979).

Feed conversion efficiency and daily liveweight gain of pigs fed on a cereal diet supplemented with fish silage has been reported to be equal to that with fish meal (Cameron, 1962; Van Wyk et al., 1977; Rangkuti et al., 1980) and was shown to be significantly better than pigs on a soy protein based diet (Batterham and Gorman, 1980). Disney et al. (1978) reported that silage made from tuna offal by addition of

formic acid was slightly better than a fish meal based diet. No adverse effect on carcass quality was noted, although the fish lipid level in the silage diet was 1.1%, dry basis. These results are in agreement with earlier reports showing that pigs grew faster and consumed less feed per kg of growth when fed on a silage diet than on a diet enriched with the same quantity of milk protein (Hansen, 1959) or of soybean meal enriched with lysine (Hillyer et al., 1976). Claims of improved fertility in swine consuming fish silage has been reported (Lisac, 1961).

There are reports on the slightly inferior nutritional quality of fish silage as pig feed (Forge, 1976; Whittemore and Taylor, 1976). This has been observed when the inclusion rate of silage was as high as 25% of the dry matter (Whittemore and Taylor, 1976) but also at an inclusion rate of 5 to 10% of the dry matter of a barley based diet (Smith and Adamson, 1976), which is a realistic level for practical feed formulation.

Despite some slightly unfavorable feeding results with fish silage compared to fish meal, it seems safe to conclude that fish silage can be a high quality protein additive in pig diets. There are no published studies on the nutritional value of acid fish silage that has been stored for long periods of time. Rangkuti et al. (1980), however, reported that s silage of by-catch fish had a nutritional value that was equal to that of fish meal prepared from the same raw material in a fresh state after 14 d at tropical temperatures. Although feeding experiments with rats have revealed that storage for 60 d at 15 C had no adverse effect on the net protein utilization value of heated and a de-oiled silage of fish viscera (Strom and Eggum, 1981), studies are

needed to test whether buffer storage of fish silage for extended periods of time in containers should be a recommended practice.

A possible restriction to the use of fish silage in diets for bacon pigs may be the fishy off-flavor to the carcass. However, there are no indications that this is a more severe problem with fish silage than with fish meal having the same oil content (Raa and Gilberg, 1982). In fact, when low oil content raw material such as white fish offal is used there are no problems in utilizing the finished product to replace fish meal in the diet of pigs (Potter et al., 1980).

In order to avoid off-flavor of the carcass, it has been recommended that the level of fish oil in the final diet be no greater than 1% (Potter et al., 1980) and should be kept below .6% during the last days of the finishing feeding period (Barlow and Pike, 1977). It has also been recommended that when silage based diets are fed, conventional meals should be fed during the last few days; otherwise, the gut content acquires a fishy odor (Sumner, 1978) which may generate significant argument against fish silage in general. The addition of plant oil to the diet a few weeks before slaughter has been shown to reduce and even remove off-flavor caused by fish lipids (Opstvedt, 1971).

The commercial use of acid preserved silage in pig diets should involve control of the oil content, dry weight and protein. According to Potter et al. (1977), Strom and Eggum (1981) and Raa and Gilberg (1982) the most ideal way of standardizing acid preserved fish silage was by removing the oil after autolysis. This can be easily achieved by draining off the aqueous mid layer which is formed after autolyzing and standing of the silage. Such an aqueous phase has been shown to

replace skim milk in diets for pigs, and no carcass off-flavor resulted because of the low (.04%) oil content (Jensen, 1973).

The first feeding trials with acid preserved fish silage diets, by Edin (1940) yielded conclusive results that showed herring silage preserved with sulfuric acid was an excellent feed constituent in the diet of chickens. Growth rates and overall performance were the same as on diets composed of other protein sources. Moreover, the silage contributed sufficient vitamin D. In a later study, Hansen (1959) included neutralized fish silage at levels of 17 and 30% of the total protein in the diet of broilers and layers, respectively. At the high inclusion level the carcass had a fishy flavor, but the eggs were of normal good quality. According to Barlow and Pike (1977) fish oils can be included in the diet of layers without imparting an off-flavor to the eggs and there was no restriction of oil level in the diets of layers. The tendency of fish oils to taint broiler carcasses is probably much the same as for pigs, however, some variations do exist among the different strains of birds (Barlow and Pike, 1977).

Data on the nutritional value of silage of tropical fish are inconclusive. The nutritional value of silage of by-catch fish has been shown to be comparable to that of fish meal in diets for chickens (Poulter et al., 1980; Rattagool et al., 1980). However, slightly (Disney et al., 1978) and much lower value (Disney and Hoffman, 1978; Rattagool et al., 1980) have also been found, depending on the level of inclusion (Disney et al., 1978).

According to Raa and Gilberg (1982) factors such as the type of fish meal used in the control diets, the protein to lipid ratio,

freshness of the raw material, the duration of storing the silage prior to feeding, as well as the variety of the experimental birds, may have contributed to the apparent contradictory results that were obtained. It does seem to be well established, however, that very poor growth (25 to 60% of control) results when silage makes up more than 20% of the diet of broiler chickens (Kompiang et al., 1980). Feed consumption, feed conversion and general performance of the chickens were all negatively affected by acid preserved silage diets (Disney et al., 1978).

Several possible explanations have been given for such disappointing results. According to Raa and Gilberg (1982) the poor performance could be attributed to residual concentration of the preservative acids which imparted an acidic taste to the diets. However, Disney and Hoffman (1976), Kompiang et al. (1980) and Rattagool et al. (1980) reported that chickens preferred and grew faster on conventional broiler diets to which 1% formic acid or a 1% formic-propionic acid mixture (1:1) was added.

Disney and Hoffman (1978) examined whether partial spoilage of the raw material could account for the poor feeding values that were observed with broilers. They ensiled completely fresh fish, however, and reported that the nutritional value of the product was still poor, when compared to fish meal that was produced from the same raw material.

Chickens fed on acid preserved silage diets may acquire symptoms of thiamine deficiency (Disney et al., 1978; Rattagool et al., 1980). However, the nutritional value of a silage diet was not improved by boiling, to inactivate any thiaminase in the silage, prior to enriching

it with thiamine (Kompiang et al., 1980). Neither was the general performance of the chicks improved significantly by thiamine injection, thus giving further strong evidence against thiamine deficiency as the reason for poor growth (Ishihara et al., 1974).

Most amino acids with the exception of tryptophan and possibly histidine are stable in acid silage (Backhoff, 1976). These amino acids are unstable when free but stable when bound in proteins. Therefore, if the degree of autolysis is high, diets with a high inclusion level of silage may be deficient in these amino acids (Raa and Gilberg, 1982). Although a significant reduction in the level of tryptophan was detected after 21 d at 30 C of an acid silage, this reduction could not account for the significantly lower feed conversion efficiency of diets based on that silage compared to diets based on fish meal (Kompiang et al., 1980).

The silage based diets that were used in the feeding trials with chicken were made from dried mixtures of silage and feed meals (Disney and Hoffman, 1976; Disney et al., 1978; Kompiang et al., 1980). Kompiang et al. (1980) further reported that antioxidants were not added before the liquid silage was mixed with the meal and dried, but were included in the final diets. In such cases, therefore, the poor growth performance of the chickens might accordingly have been caused by oxidized lipids. This possibility seems quite valid since a good chicken feed was made from a fish silage that had been extracted with ether before it was mixed with corn and sun dried (Kompiang et al., 1980).

The apparent toxic effect of acid preserved silage diets may be

indirect, through decomposition of vitamin E and/or vitamin A by oxidized lipids. In agreement with this mechanism, the growth response of chickens fed on a silage-cassava diet was improved significantly with vitamin E supplementation. In another case, however, vitamin E supplementation had no significant effect (Kompiang et al., 1980) but it was not examined whether decomposition of the vitamin had occurred by the oxidized lipids already present in the silage/carbohydrate mixture when the feed was formulated.

Limited data are available on the nutritional value of fish silage to ruminants. Ferreiro et al. (1977) reported decreased feed intake in cattle from feeding a small amount of fish silage made by addition of 3.5% formic acid.

A mixture of 55% de-oiled and heated silage of viscera, 20% minced fish heads, 15% barley meal and 10% grass meal has been used in Norway for years in a practical feeding program and the results seem acceptable (Raa and Gilberg, 1982). This feed has, however, given a slightly lower milk yield than the commercial high protein meal when it was fed at a high rate to cows.

In contrast to acid preserved fish silage, feeding experiments with fermented fish silage have consistently shown that the nutritional quality was good, with the biological value of the protein similar to that of skimmed milk (Krishnaswany et al., 1965) or fish meal (Nilsson and Rydin, 1963; Kompiang et al., 1980).

Fish preserved by lactic acid fermentation have a better nutritional value for chickens than fish preserved by acid addition (Kompiang et al., 1980). It is likely that this better nutritional value is due

to protective action by the fermentation process on fish lipids. Since oxidation cannot occur under anaerobic conditions, as exists in a silo, then this seems to be a plausable explanation.

The peroxide value of oil in moist fermented silage has been shown to be very low (Wirhadikusumah, 1968). Even after drying of the silage the peroxide value was reported to be in the range of 4 to 12 (Wirhadikusumah, 1968) which is less than 1/10 of what has been found in a dried feed of fish preserved by acid addition (Disney et al., 1978).

Wirhadikusumah (1969) demonstrated that lactic acid bacteria could facilitate uptake and incorporation of calcium into the egg shell, and that feeding 40 g wet silage per hen per day did not impair taste nor flavor of the eggs. Broilers picked up off-taste flavor when fed the same quantity of silage; however, this problem was overcome by omitting silage from the diet 1 wk before slaughter.

Shellfish Waste

Large quantities of potentially valuable proteinaceous "waste" materials are discarded from shellfish processing plants. Although several applications for shellfish waste have been suggested (fertilizer; animal, fish and shellfish feed; chitin, chitosan and flavor additives), only a small percentage of the large quantities available are utilized. Studies with poultry, swine and cattle have generally reported that shellfish waste does have potential value as a feed supplement, especially for its protein content, if offered at low levels in combination with conventional feedstuffs (Bray et al., 1932; Parkhurst et al., 1944a,b; Kirk et al., 1967; Patton et al., 1975).

Nutritive Value. As with the physical characteristics of crustacea species, there is close similarity in the composition of shellfish wastes. All species possess an exoskeleton composed primarily of chitin, an acetylated glucosamine polymer, protein, which appears to be intimately associated with the chitin; and mineral matter, largely $CaCo_3$ (Peniston et al., 1969).

The general composition of shellfish waste meals has been reported to be 25 to 45% protein, 20 to 40% ash (high in Ca), 10 to 30% chitin and 2 to 10% ether extract (Watkins, 1976; Brundage et al., 1981; Watkins et al., 1982). Minor components of shellfish waste are phosphates and carotenoid pigments (Peniston et al., 1969; Wilkie, 1972).

Chitin always occurs in close association with other substances. In crustaceans, $CaCo_3$ serves as the cementing substance and accounts for some crustaceans meal being 18% Ca (Lovell et al., 1968). Fresh water crayfish meal was stated to be 14% chitin (Lovell et al., 1968), while salt water crayfish meal was reported as being 12.3% chitin (Black and Schwartz, 1950). The chitin content of crabmeal was reported to be 13% (Lubitz et al., 1943) while that of shrimpmeal was 7.6% (Brown, 1959).

Limited palatability and large quantities of chitinous material may pose serious limitations to the inclusion of crab meal in livestock diets (Brundage et al., 1981). Richards (1953) reported that the molecular structure of chitin was similar to that of cellulose, differing only in the substitution of an acetylamine group for the hydroxyl group on carbon 2 of the glucose unit. Campbel (1929) stated that the most likely empirical formula for chitin was $(C_{32}H_{54}O_{21}N_4)n$,

while Wigglesworth (1965) reported a formula of $(C_8H_{13}O_5N)n$. Examination of the chitin molecule would suggest that at least part of the chitinous material in shellfish waste may be subject to degradation by rumen microorganisms.

There is little information available concerning the feeding of chitinous products to ruminants. Chitin digestibility by young calves fed blue crab meal at 10 and 20% of the basal ingredients varied from 26 to 87% and averaged 66% (Patton et al., 1975). Inclusion of 10 or 20% crab meal did not affect body weight gain, feed intake or feed efficiency. Nitrogen digestion and retention were not altered when crab meal was included at 10% of the basal diet, but, nitrogen retention was reduced by substitution of 20% crab meal in the diet. Patton et al. (1975) further reported that the reduced nitrogen retention was associated with increased urine output. There was no difference in dry matter, fiber and Ca digestibilities between the basal and crab meal diets.

In another study, Patton and Chandler (1975) reported 36% digestibility for blue crab meal by in vivo nylon bag rumen fermentation techniques. Brundage et al. (1979) reported 75, 58 and 62% in vitro disappearance of dry matter, organic matter and nitrogen from Alaskan King and Tanner crab meals.

Brundage et al. (1981) concluded that crab meal could be a potential source of supplemental protein in concentrates for lactating cows. Supporting data by Patton et al. (1975) and Patton and Chandler (1975) led them to declare conclusively that the chitin molecule was a potential energy source and that crab meal could supply some of the crude protein

for ruminants whenever marginal diets were supplemented.

Most of the nutritional information that is available about shellfish waste is derived exclusively from monogastric research. A protein digestibility in crabmeal of 80% was observed in poultry by Mangold and Hock (1938). Schmalfuss and Werner (1936) reported that the protein availability of shell-free crab meal for chickens was 94% while Mangold and Damkobler (1938) found it to be 81%.

Parkhurst et al. (1943) reported that carb meal could satisfactorily replace fish meal in chick diets when the Ca to P ratio was adjusted. The high mineral content of shellfish meals may limit incorporation into feeds to 10% (Rutledge, 1971). At that level, the contribution from any protein in the meal was greatly reduced. Rutledge (1971) developed a method of milling and screening of meals as a means of doubling the protein content. This method reduced the Ca and chitin contents by 68 and 82, respectively, while at the same time leaving P only slightly altered.

Shrimp meal has long been used in diets by fish nutritionists for desired flesh coloration in trout and salmon. Feeding experiments have shown that carotenoids may be transferred from the feed to the flesh of trout and salmon (Gerhardsen, 1971; Meyers and Perkins, 1977). Saito and Regier (1970) fed a 29% shrimp meal diet to brook trout and reported superior coloring and flavor over fish fed a commercial diet. Spinelli et al. (1974) fed rainbow trout diets containing 10 and 25% red crab and reported high pigmentation after 2 mo.

Recently, shrimp and King crab processing by-products have been evaluated as feed supplements for mink (Watkins et al., 1982). These

wastes replaced approximately 10 and 20% of the protein in a 33% protein diet. Minks fed crustacean waste diets had lower final weights, weight gains and greater feed consumption than control groups. Watkins et al. (1982) further reported lower weight gains by males on high shrimp meal diet vs those on high sieved shrimp meal diet. They attributed this to the excess Ca intake on the high shrimp meal diet. Overall, general condition and pelt characteristics were not appreciably affected in any of the groups. From their study, Watkins et al. (1982) concluded that shellfish waste products could be used satisfactorily as protein supplements in mink diets. This could be done provided that the protein and energy concentrations of the diet were maintained at adequate levels and dietary Ca did not become excessive.

Studies of Ensiled Animal Waste

Poultry Waste

There are two main sources of poultry waste: 1) caged layer waste, also known as dried poultry waste (DPW) or dried poultry excreta (DPE), when fed in dry form, and 2) broiler litter. Caged layer waste is from caged laying hens and consists of excrement, broken eggs, egg shells, feathers and spilled feed. Broiler litter refers to the product consisting of excreta, spilled feed, feathers and bedding material.

Caged Layer Waste. Caged layer wastes are generally rich in crude protein, averaging 31% (Bhattacharya and Taylor, 1975; Samuels, 1980; Moriba, 1981). An important benefit from feeding caged layer wastes to ruminants is that additional supplementation of the diet with protein and minerals, especially Ca and P is not required since caged layer wastes are rich in these nutrients (Smith, 1974; Clark and Dethrow, 1975). In ruminants the availability of Ca and P in caged layer waste when used as the sole source of protein supplement has been found to be 92 and 70%, respectively (Bull and Reid, 1971).

Saylor and Long (1974) ensiled caged layer wastes (72% moisture) and ground orchardgrass hay (8.5% moisture) for 60 d in the following proportions: 100:0, 90:10, 80:20, 70:30, and 60:40. Ground shelled corn at a level of 5% was added to another group of identical treatments. Silage quality was poor in 100 and 90% caged layer waste mixtures. Mixtures containing 80, 70, and 60% caged layer waste had pH values of 7.1, 6.8 and 5.2. Corn grain added to the mixtures at ensiling had no effect on the ensiling parameters.

Samuels (1980), ensiled fresh caged layer waste with ground sugarcane bagasse for 42 d in the following proportions: 70:30, 60:40, 50:50, 40:60, 40:60 + H_2O, 30:70 and 30:70 + H_2O. The pH of the ensiled mixtures decreased to 5.2 and 4.7 for the 40:60 and 30:70 + H_2O mixtures. Lactic acid was highest for the 50:50, 40:60, and 30:70 + H_2O silage (8.2 to 8.7%). Total coliforms, fecal coliforms and proteus organisms were decreased or eliminated by ensiling. In a sheep metabolism trial, dry matter and crude protein digestibilities were highest for mixtures containing the highest level (60%) of waste. Dry

matter digestibility of caged layer waste, calculated by difference, was over 65% when ensiled with bagasse (Samuels, 1980) and over 70% when ensiled with corn stover (Moriba, 1981). Level of waste in the silages did not affect dry matter consumption by sheep.

Caged layer waste was ensiled satisfactorily by Arvat et al. (1978). Wethers were fed silages from waste from layers consuming a corn-soybean meal diet or a grain by-product diet to evaluate the nutritional value of both types of waste. The silage diets were prepared by adding 22.7% caged layer waste, 15.9% ground corn, 15.9% ground hay, .1% salt and 45.4% water. The ensiled mixtures appeared to be palatable. Feed consumption for silages from layers consuming a corn-soybean meal diet was lower than that of the control. Average daily gain was lower for both silages than control. No significant difference was found for the apparent digestibilities of nitrogen and energy among the diets. However, apparent digestibility of dry matter was lower for the caged layer waste silage, compared to the control.

Keys and Smith (1981b) combined 25 and 30% corn stover with 50 and 61% whole corn plant, respectively, and ensiled them with dry poultry excreta. The silages were fed ad libitum to different groups of yearling Holstein heifers for 140 d. Intake and performance were compared to cattle fed 88.4% whole corn plant silage supplemented with dried poultry excreta. Gains by animals fed whole corn plant diluted with 25% corn stover paralleled those of animals fed all corn silage diets.

Broiler Litter. According to Smith and Wheeler (1979) ensiling is the most economical method of processing broiler litter for feed. Accumulated broiler litter with water added to bring the moisture content within the range of 35 to 38% was ensiled for 42 d by Creger et al. (1973). The ensiled material was fed to heifer calves ad libitum for 120 d. The material was supplemented with a mixture of ground milo, dehydrated alfalfa meal, soybean meal, molasses and vitamins A and D. The heifers consumed an average of 5.4 kg of silage daily and had an average daily gain of 1.16 kg. Retail cuts from all animals were satisfactory in juiciness, tenderness and flavor.

The fermentation characteristics of corn forage, ensiled at two stages of maturity alone, with .5% urea, or with broiler litter comprising 15, 30, or 45% of the dry matter were compared (Harmon et al., 1975a). Addition of litter or urea to the corn forage at ensiling resulted in higher final pH values and greater concentrations of lactic and acetic acids than controls.

Harmon et al. (1975b) used the above treatments except the 45% litter, in studying digestibility, nitrogen utilization and palatability by sheep. Apparent digestibility of dry matter averaged 64.5% and was not different among treatments. Crude protein digestibility was increased by each level of litter addition. Increasing the level of litter from 15 to 30% of the silage dry matter decreased the efficiency of utilization of litter nitrogen. Dry matter intake was significantly higher for silages containing litter than for the control or the urea silage.

Broiler litter containing 19% moisture was ensiled with high

moisture corn grain containing 26% moisture in a 1:2 ratio (Caswell et al., 1977). Fermentation characteristics were not as good in the corn-litter mixture as for the corn ensiled alone. Intake trials with cattle revealed that there was a tendency for higher dry matter consumption of diets supplemented with broiler litter than those fed soybean meal-ensiled corn diet.

In another study Caswell et al. (1978) reported that in order to obtain maximum fermentation of broiler litter the moisture level should be at a minimum of 40%. Diets for wethers had 50% of the dietary nitrogen supplemented with heat processed litter, 22 or 40% moisture litter silage or soybean meal. Nitrogen retention was lower for the diet supplemented with processed litter, however, apparent digestibilities of the diets were not significantly different among the three diets supplemented with litter.

Cattle Waste. Anthony (1971) explored the feasibility of ensiling a mixture of cattle waste and grass hay. The mixture contained 57% cattle manure and 43% grass hay, and the ensiled mixture was termed "wastelage". The wastelage contained 12.4% crude protein, dry basis, and 51.4% dry matter. Rate of gain and feed efficiency of cattle fed a diet containing 40% wastelage and 60% corn were similar to those of cattle fed a conventionally formulated high concentrate diet.

Newton et al. (1977) ensiled 40 parts of cattle manure with 60 parts of a control high-concentrate diet. Digestibility studies were conducted with steers to compare dried and fermented waste diets. Digestibility values of the fermented waste revealed an improvement in dry matter and nitrogen digestibility, compared to the dried waste.

Feed efficiency values indicated that .77 kg of waste dry matter substituted for .39 kg of control diet dry matter. Average daily gains and feed efficiency favored the control diet, but differences were not significant.

A 60:40 ratio of cattle waste and chopped grass-legume hay was ensiled and fed to sheep and fattening cattle (Harpster et al., 1978). Diets fed were control, 50% wastelage and 50% high moisture corn, 100% wastelage, 100% corn silage, 60% wastelage and 40% high moisture corn and corn silage supplemented with soybean meal. Dry matter and organic matter digestibilities were significantly lower for the 100% wastelage diet. Nitrogen retention was lower for animals fed wastelage. Satisfactory performance was obtained with fattening cattle fed up to 50% wastelage, but feed efficiency was lower than for cattle fed a corn silage and high moisture corn based diet.

Vetter and Burroughs (1974) reported no differences in performance and intake among steers fed a diet consisting of 20 to 27% cattle waste ensiled with corn forage and corn grain compared to cattle fed a basal diet.

The inclusion of dairy waste fiber in the diet of lambs resulted in decreased intake and decreased dry matter and nitrogen digestibilities as the level of waste increased (Staples et al., 1981). Staples et al. (1981) concluded that dairy waste fiber could be ensiled successfully with various energy feedstuffs and could be utilized by lambs as 25% of the diet dry matter.

Treatment of ensiled cattle waste and roughage with NaOH increased dry matter and organic matter digestibilities, but depressed crude

protein digestibility (Lamm et al., 1979; Aines et al., 1982).

Cerola, a high fiber silage produced by fractionating feedlot manure, addition of 5% dry molasses and fermented for at least 3 wk was used in a digestion trial with lambs (Ward and Beede, 1973). The silage contained 11% crude protein. The health of the animals remained good throughout the trial.

Promising performance results have been obtained from ensiling cattle manure with straw or corn stover (McClure et al., 1973). These results indicate that steers could be maintained on a diet composed of fermented manure from cattle fed an all concentrate diet. The manure silage alone or with corn added resulted in daily gains, feed efficiency and dry matter consumption similar to those obtained with cattle fed corn silage plus corn added at 1% of body weight.

Cattle waste was used to reconstitute sorghum grain (Shake et al., 1977). Intake by heifers was drastically reduced when the grain to waste ratio was 1:1.

Cornman et al. (1981) studied the ensiling characteristics of different levels of cattle waste and rye straw and reported that total and fecal coliforms, salmonella, shigella and proteus organisms were destroyed in all the mixtures containing waste after 1 wk of ensiling. Lactic acid content tended to increase as level of waste increased, but pH values were similar for all silages.

Studying the fermentation characteristics of NaOH treated cattle-waste-rye straw silages, Aines et al. (1982) reported that NaOH treated silages had higher pH values, compared to untreated silages. Untreated silages exhibited desirable fermentation patterns as measured by pH,

lactic acid and water soluble carbohydrates. McClure et al. (1973) noted a significant drop in pH from 7.5 to 5 when waste from cattle fed high concentrate diets was ensiled with straw.

Swine Waste. The use of anaerobic fermentation as a method of intensifying animal performance when swine waste was refed was studied by Overhults et al. (1978). Pre-ensiled pH of the mixtures ranged from 6.2 to 6.6, while post-ensiled pH after 7 d ranged from 4.6 to 4.8. Performance studies were conducted with growing-finishing swine fed a basal diet, basal plus 20% fermented waste, dry basis, and basal plus 20% unfermented waste. The waste containing feeds were higher in ether extract and ash content than the basal diet. The unprocessed and fermented feeds containing swine waste were readily accepted. Average daily gains for manure-fed pigs were lower than for those receiving the basal. Feed efficiency was higher for pigs fed the fermented waste than those receiving the unfermented waste diet.

Berger et al. (1981a) studied the feasibility of ensiling swine waste with ground orchardgrass hay or with ground corn grain in the following ratios (wet basis): 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80. For mixtures of swine waste and orchardgrass hay fermentation, as measured by pH and lactic acid levels, was best for the 40:60 through the 60:40 mixtures. When used in a sheep metabolism trial, organic matter digestibility was not different for the 40:60 and 60:40 swine waste-orchardgrass hay silages than for orchardgrass hay fed alone (Berger et al., 1982b). Crude protein digestibility was lower for the waste containing diets than for the control. Nitrogen retention was negative for sheep fed the silages. In a subsequent

palatability trial with sheep, Berger et al. (1982b) reported that dry matter intake was comparable to that of orchardgrass hay. With swine, dry matter intake decreased as swine waste-orchardgrass hay silages were substituted for 25 to 50% of the basal diet (Berger et al., 1982b).

Yokoyama and Nummy (1976) ensiled whole corn plant (77%) with swine waste (23%) and reported a pH of 3.9 and lactic acid level of 8.3%, dry basis. No fecal odor was detected in the fermented material.

Animal wastes should be processed prior to feeding to enhance palatability and destroy potential pathogens (Fontenot et al., 1983). A number of processes have been used successfully. The processing of animal waste by ensiling is economical. In production trials, ruminants have performed satisfactorily on diets containing animal waste.

Nutritive Value of Low Quality Roughage

Low quality roughage represents a significant potential feed for ruminant animals. The term low quality roughage covers a wide range of roughages, from wood products to crop residues and poor hay. Many contradictory results have been published regarding the nutrient availability and feeding value of low quality roughages (Binger et al., 1961; Van Soest, 1969; Church and Santos, 1981). However, research indicates that chemical treatment and pelleting of low quality roughages improve animal performance (Dehority and Johnson, 1961; Rexen and Moller, 1974; Klopfenstein, 1978).

Chemical Composition

The chemical composition of low quality roughages varies considerably, being affected by variety, time of harvest and the

conditions under which they are grown (Barnes, 1973; Leask and Daynard, 1973). Low quality roughages are usually fibrous, often deficient in N, P, carotene and possibly some trace minerals (NAS, 1971). Binger et al. (1961) compared the composition of several crop residues with that of medium quality alfalfa hay. The most striking difference between the residues and alfalfa was the low protein content of the roughages. Low quality roughages have adequate amounts of hemicellulose and cellulose for energy production by rumen microorganisms, provided the carbohydrates are biologically available (Kohler et al., 1979).

High lignin content is usually associated with unavailability of carbohydrate in forages (Van Soest, 1969). In low quality roughages, lignin content varies from 5% in the straws to over 25% for peanut hulls. TDN is correlated inversely with lignin content. Rice straw has a relatively low TDN because the large amount of silica also interferes with carbohydrate digestion.

Various treatments have resulted in the modification of some components of low quality roughages, thus increasing digestibility (Colenbrander et al., 1971). Steam treatment resulted in the modification of the chemical composition of corn stover (Oji and Mowat, 1978). The treatment reduced the percent NDF from 73.1 to 54.1%, increased ADF from 44.5 to 50.3% and decreased hemicellulose from 28.6 to 3.8%. Pate (1979) compared the chemical composition of raw and steam pressure processed sugarcane bagasse. The most noticeable effect of processing was the large reduction in certain fiber components. Crude fiber was reduced from 43 to 34%, and NDF

from 83 to 51%. There was little change in ADF and cellulose. Values reported for total ash, Ca and P were 1.7, 2.1; .15, .42; .1 and .1%, respectively, for raw and processed bagasse.

Chemical treatments have been used successfully to alter the composition of low quality roughages resulting in increased digestibility and performance by cattle. Chemical treatment solubilizes some of the hemicellulose without changing the cellulose content (Klopfenstein et al., 1979). Lignin content is generally not reduced by chemical treatment (Ololade et al., 1970; Rexen and Thomsen, 1976). Therefore, the increase in extent of digestion is probably due to breaking of bonds between lignin and hemicellulose or cellulose without actual removal of lignin (Van Soest, 1975).

Several workers have shown that roughages from different plant species respond differently to chemical treatment (Chandra and Jackson, 1971; Koers et al., 1972; Rexen and Thomsen, 1976). Less hemicellulose is solubilized in wheat straw than in other residues (Lesoing, 1977).

Digestibility and Performance Studies

Fortification of poor quality roughages with liquid supplement to cattle resulted in improved performance but less than with good quality supplements containing natural proteins (Chico et al., 1972; Rush and Totusek, 1976). Although consumption of poor quality roughage may be increased by the feeding of urea-containing liquid supplement (Ernst et al., 1975), digestibility of organic matter has shown little if any, improvement but crude protein digestibility has generally been increased (Ernst et al., 1975; Jones et al., 1976). Church and Santos (1981) reported increased crude protein, dry matter and ADF

digestibilities with wheat straw supplemented with soybean meal or liquid supplement and fed to cattle.

Several chemical methods have been evaluated with the purpose of increasing low quality roughage digestibility (Klopfenstein, 1978; Sundstol et al., 1978; Horton and Steacy, 1979). The use of alkali and ammonia have shown the most promise. The ammonia method has some advantages over other alkali methods in that it increases both digestibility and crude protein content, does not require dehydration of the straw after treatment and can be carried out under farm conditions (Sundstol et al., 1983). However, digestibility of low quality roughage dry matter is not normally increased to the same extent as with other alkali treatments (Horton, 1978).

Treatment of wheat straw with ammonia improved digestibilities of dry matter, organic matter, crude protein and ADF by sheep (Herrera-Saldana et al., 1983). The inclusion of ammonia treated wheat straw at 65% of the diet of sheep resulted in dry matter digestibility of 56% compared to 50% for the control diet containing 65% untreated straw (Waiss et al., 1972).

Osuji and Archibald (1976) fed bagasse to sheep at levels of 21 to 27% of a diet supplemented with molasses. There were no significant differences in dry matter intake and in dry matter and energy digestibilities.

Keys and Smith (1981a) reported that intake of corn stover silage supplemented with ear corn by Holstein heifers was lower than corn silage. However, average daily gains and digestibility were similar.

Lamm et al. (1975) reported that mature gestating cows grazed on

corn stalk supplemented with various sources of nitrogen in the winter had similar performance when dry waste supplement was used compared to animals on liquid supplement free choice, but performance was lower than for soybean meal cube.

Garrett et al. (1976) fed cattle pelleted rice straw treated with NaOH. Feed intake was 41% greater than that for animals fed control, untreated straw. Daily gain was tripled by chemical treatment and feed-to-gain ratios were improved significantly. However, the treated straw had poorer efficiency than the alfalfa control. In another study Garrett et al. (1976) treated rice straw with ammonium hydroxide. Rate and efficiency of gain of cattle were both increased. However, the treated material was not equal to an alfalfa hay control.

Waller and Klopfenstein (1975) reported that lambs performed as well on corn cobs treated with ammonium hydroxide and mixed with sodium and calcium hydroxide as they did on a 4% NaOH treated cob. Performance was somewhat poorer than that obtained on cobs treated with a 3:1 ratio of sodium to calcium hydroxide. Klopfenstein (1979) reported that although ammonium hydroxide treatment was effective, it was not as effective as some treatments of Na and Ca.

Ammonium hydroxide treatment appeared to increase performance over calcium hydroxide treatment alone (Waller and Klopfenstein, 1975). Efficiency of gains by cattle produced by the mixture (ammonium and calcium hydroxides) was superior to that of 4% NaOH treated cobs. However, intake was somewhat lower with ammonium hydroxide treated cobs, probably because of free ammonia that remained in the cobs at feeding time. According to Klopfenstein (1979) the major advantage

of ammonium hydroxide is that the residual ammonia can be used as a source of supplemental non-protein N in the diet. Also, no mineral remains that might be detrimental to animals or to soil to which the animal excreta is added.

Unlike ammonium hydroxide, the use of mineral hydroxides to treat low quality roughages and their subsequent inclusion in the diet of ruminants can result in excess minerals, such as Na and eventually result in mineral imbalances (Jackson, 1977). This may necessitate other mineral additions (Arndt et al., 1980).

SEAFOOD WASTE 1.
FERMENTATION CHARACTERISTICS OF ENSILED SEAFOOD WASTES
AND LOW QUALITY ROUGHAGES

SUMMARY

Experiments were conducted to investigate the chemical composition of seafood waste and the physical and ensiling characteristics of seafood waste and low quality roughages. Crude protein for the fish, consisting of porgie (Stenotomus chrysops) heads and fileted flounder (flatfish species) and crab wastes was 60.4 and 44.1%, dry basis, respectively. Fish and crab processing wastes were ground and ensiled with corn stover or peanut hulls in proportions to give dry matter levels of 40, 50 and 60% alone and with 5% dry molasses or 1% formic acid in 3.8 liter cardboard containers double lined with polyethylene. The seafood wastes were also ensiled with wilted Johnsongrass (sorghum halepense) in 50:50 ratios, wet basis, with and without 5% dry molasses. All silages had desirable aromas except those with crab waste ensiled with crop residues at 40 and 50% dry matter. After ensiling average pH for mixtures with fish waste and crop residues was 6.5, compared to 8.0 for mixtures with crab waste. Addition of dry molasses decreased pH of the ensiled fish waste mixtures but had no effect on the crab waste mixtures. Lactic acid was higher ($P < .05$) for ensiled mixtures containing fish waste than for those containing crab waste. Substantial levels of acetic acid were present in the silages. Butyric acid levels were higher in silages containing crab waste and decreased with increased dry

matter levels. Desirable ensiling was observed for the mixture of fish waste and Johnsongrass, and ensiling was enhanced by addition of molasses. Coliforms and fecal coliforms were decreased or eliminated by ensiling. In subsequent small silo studies conducted to improve the fermentation characteristics of crab waste mixtures, only acetic acid resulted in a pH of 5 or less. Addition of a lactic acid culture (Lactobacillus plantarum) had no beneficial effect. Mixtures of finfish wastes and crab processing wastes were mixed with wheat straw and ensiled in 210 liter metal drums, double lined with polyethylene bags. Proportions of the fish and straw were 70:30 and 51:49, wet basis while that of the crab was 60:40 and 40:60. Dry molasses (5%) was included in all mixtures and acetic acid was added to the crab waste mixture to lower the initial pH to 4.5. All mixtures containing fish and straw showed a decrease in pH after ensiling. Lactic acid was higher for the 51:49 than for the 70:30 fish waste-straw mixture (3.4 vs 1.3%). No lactic acid was found in the ensiled mixtures containing crab waste.

(Key words: Seafood Waste, Low Quality Roughage, Additive, Ensiling.)

INTRODUCTION

Preservation of feedstuffs by ensiling is an accepted procedure. The ensiled product is preserved by the anaerobic production of acid by microorganisms. For some materials, the quality of ensiled material is improved by the addition of certain additives. Molasses has been shown to increase the dry matter and lactic acid contents and to reduce the pH and NH_3-N levels in silages (McDonald and Purves, 1956; Reaves and Brubaker, 1956; Ely, 1978). Waldo et al. (1971) and Wilkins et al. (1974) reported that the addition of formic acid as a silage additive prevented clostridial activity, and the content of NH_3-N was lower than that of silage made without adding the acid. Further effects of acid addition were a depression in fermentation acids and a rapid decrease in silage pH.

Ensiling of seafood processing wastes represent a potentially effective method of preserving these wastes. The ensiling process would also help alleviate the waste disposal and water pollution problems, as well as a method of recovering some of the potentially valuable nutrients in the wastes. Combining seafood wastes which contain high protein, water and fat and low carbohydrate, with low quality roughages which are low in moisture would result in mixtures with dry matter content suitable for ensiling.

Experiments were designed to investigate the physical and ensiling characteristics of seafood waste, to determine the optimum combinations of seafood waste and low quality roughages for production of acceptable

silages and to assess the value of additives in ensiling seafood waste.

EXPERIMENTAL PROCEDURES

Chemical Composition. Samples of porgie (Stenotomus chrysops) heads, residues from fileting flounder (flat fish species) and crab processing waste were collected from seafood processing plants in Hampton, Virginia, and ground through a Hobart laboratory meat grinder. Dry matter of the seafood wastes was determined by drying duplicate 200 g samples in a forced-draft oven at a maximum of 60 C for 48 h. These samples were allowed to air equilibrate, the duplicate dried samples were composited, ground to pass a 1 mm sieve and analyzed for dry matter and ash (AOAC, 1980). Kjeldahl N was determined on wet samples of seafood wastes (AOAC, 1980). Samples were wet ashed by the method of Sandel (1950) and analyzed for Mg and Ca by atomic absorption. Phosphorus was determined by the method of Fiske and Subbarow (1925). Water extracts of the seafood wastes were used for water soluble carbohydrate determination (Dubois et al., 1956, as adapted to corn plants by Johnson et al., 1966).

Small Silo Studies. Fish waste for this study was obtained from fileting monk fish (Squatina dumeril). The monk fish waste was processed by grinding in a meat grinder. The crab waste was obtained from a processing plant in which meat was hand picked from steamed blue crabs. The waste was ground in a high speed hammermill without a screen. Corn stover was ground in a tub grinder[1] through a 2 cm screen.

[1]Sperry-New Holland, New Holland, Pa.

The seafood wastes were mixed with corn stover (IFN 1-02-776) or peanut hulls alone and with the addition of 5% dry molasses (IFN 4-04-695) or 1% formic acid at proportions to give dry matter levels of 40, 50 and 60%. Thus, a 2 x 2 x 3 x 3 factorial arrangement of treatments was used. In addition, the two seafood wastes were ensiled with wilted Johnsongrass (Sorghum halepense), 50:50, wet basis, with and without 5% dry molasses. The mixtures were prepared by slowly adding the crop residues or grass to the seafood waste in a horizontal mixer and allowed to mix for 30 min. Six laboratory silos, each containing 2 kg and two initial mixture samples were prepared from each treatment mixture. Initial samples were subsampled aseptically for microbial tests and placed in .5 liter sterile jars and frozen until assays were conducted. Samples for dry matter determination were also taken. Ensiling mixtures were firmly packed into 3.8 liter cardboard containers double lined with polyethylene bags. Both bags were sealed individually, being careful to expel the air above the packed material before sealing. Silos were weighed before and after addition of the mixtures.

After a minimum of 42 d in an enclosed barn, one silo of each mixture was weighed, opened and observed for appearance and odor. The top 5 cm of ensiled material were removed prior to subsequent sampling. Samples were aseptically removed from the center of the ensiled mass. Water extracts of the initial and fermented mixtures were prepared for microbial analysis by homogenizing duplicate 25 g samples with 225 ml of sterile distilled water in sterile .5 liter jars in a Waring blender at full speed for 2 min. The homogenate was filtered through four layers of cheesecloth and the filtrate was immediately subjected

to quantitative tests for total coliforms (Anonymous, 1967) and fecal coliforms (Millipore, 1973) and qualitative measures of Salmonella, Shigella and Proteus (Lewis, 1964). The extracts of the initial and final mixtures were used for measurement of pH (electrometrically), volatile fatty acids (Erwin et al., 1961), lactic acid (Barker and Summerson, 1941, as modified by Pennington and Sutherland, 1956) and water soluble carbohydrates (Dubois et al., 1956, as adapted to corn plants by Johnson et al., 1966). Samples of crop residues were analyzed for dry matter, Kjeldahl N, soluble carbohydrate, ash, Ca, P and Mg by the same procedures used to determine the chemical composition of seafood wastes.

Studies were conducted to improve the fermentation of crab waste mixtures. Ground crab processing waste was ensiled with corn stover at a dry matter level of 50%. Propionic acid alone and a 1:1 mixture of propionic and sulfuric acids were added at levels of 2, 4 and 5% to mixtures prior to ensiling. Three laboratory silos, consisting of 2 liter cardboard containers double lined with polyethylene and two initial mixture samples, were prepared from each mixture. Another experiment was conducted with ground crab processing waste mixed with ground corn stover to achieve a dry matter level of 50%, with the addition of phosphoric, acetic, propionic and a 2:1 mixture of hydrochloric and sulfuric acids to bring the pH of the initial mixture to 4.5 or 5.5. A Lactobacillus plantarum culture was added to one-half of the silos at pH 4.5 and 5.5. Dry molasses was added at 5% to all treatments. For these studies, three 2 liter laboratory silos were prepared for each mixture.

Another study was conducted with crab waste and ground corn stover in proportions of 60:40 and 40:60, wet basis, ensiled in 3.8 liter laboratory cardboard containers double lined with polyethylene. Additives tested were acetic acid, lactic acid, 2:1 mixture of phosphoric and hydrochloric acids, ethanol, 2-bromoethane sulfonic acid (.1 g/kg) and Lactobacillus plantarum culture. The acids were added in amounts to give a pre-ensiling pH of 4.5. Dry molasses was added at 5% to all mixtures. Procedures for ensiling were similar to those previously outlined. Six silos each containing 2 kg and two initial mixture samples were prepared from each mixture.

Large Silo Study. Based on data from the small silo studies, this study was conducted to determine fermentation characteristics, the metabolism of nutrients and palatability of ensiled seafood waste and crop residue. Mixtures of finfish and crab processing wastes were ensiled with ground wheat straw in 210 liter metal drums double lined with .08 mm polyethylene bags. Dry molasses at 5% was included in all mixtures. The fish and straw were ensiled in combinations of 70:30 and 51:49, wet basis, while crab and straw were ensiled in combinations of 60:40 and 40:60, wet basis. The 70:30 fish and 40:60 crab mixtures were ensiled in proportions that would give a similar dry matter addition for each seafood waste. For the fish ensiled at 51:49 and the crab at 60:40 the levels of wastes were varied so that their dry matter would be approximately 60%. Acetic acid was added to the mixtures containing crab waste to lower the initial pH to 4.5. An average of 16% (v/w) glacial acetic acid was used.

The fish silages were prepared by first grinding the straw in a

commercial mobile mill and horizontal mixer through a 2 cm screen. Finfish waste that was previously ground in a meat grinder, and molasses were added to the straw and allowed to mix for 30 min. For crab waste silages, straw and crab waste were ground and mixed together. Molasses and acetic acid were gradually added to the crab-straw mixtures and allowed to mix for the same time as mixtures containing fish. For the straw ensiled with 5% dry molasses, sufficient water was added to achieve a dry matter level of 50%. After thorough mixing, the mixtures were augered into the drums. Samples were collected, composited, sub-sampled and frozen for analyses. All mixtures were packed firmly by trampling to remove excess air. An attempt was made to remove as much air above the ensiled mass as possible before each polyethylene bag was sealed.

The mixtures were ensiled for a minimum of 60 d in an open shed. When each silo was opened, the top 5 cm of ensiled material were removed. Samples were taken from several areas of the silo, sub-sampled and frozen for subsequent chemical analyses. Procedures used for determination of fermentation characteristics, dry matter, Kjeldahl N, Ca, Mg and P were the same as those used for the seafood wastes used in the small silo studies. Samples were analyzed for ether extract (AOAC, 1980), neutral detergent fiber (NDF) by the method of Van Soest and Wine (1967) acid detergent fiber (ADF) by the procedure of Van Soest (1963), lignin and cellulose (Van Soest and Wine, 1968). Sodium and K were determined by emission spectrophotometry utilizing a Perkin-Elmer 403 Atomic Absorption Spectrophotometer.

Statistical Analyses. Results of all experiments were analyzed by use of the general linear models (GLM) procedure of the Statistical Analysis System (SAS, 1979). For the first small silo experiment the results were analyzed as a 2 x 2 x 3 x 3 factorial arrangement, using the following orthogonal contrasts: 1) fish vs crab waste; 2) corn stover vs peanut hulls; 3) additives; 4) dry matter; 5) interactions. Linear and quadratic effects of increasing dry matter levels were tested by orthogonal polynomials. Differences among additives were tested by Duncan's (1955) Multiple Range Test. Results from the second small silo study were analyzed as a 2 x 3 factorial arrangement using the following orthogonal contrasts: 1) acid at 2% vs acid at 4 and 5%); 2) acid at 4% vs acid at 5%. The results of the third small silo study were analyzed as a 4 x 2 x 2 factorial arrangement of treatments using the following orthogonal contrasts: 1) pH 5.5 vs pH 4.5; 2) L. plantarum; 3) acid addition; 4) interactions. Differences among acids were tested by Duncan's (1955) Multiple Range Test. The following orthogonal contrasts were used for the last small silo experiment: 1) BES vs no BES; 2) additives; 3) L. plantarum; 4) interactions. Differences among additives were tested by Duncan's (1955) Multiple Range Test. For the large silo study the following comparisons were made: 1) crab vs fish waste; 2) level of fish waste; 3) level of crab waste; 4) straw vs seafood wastes.

RESULTS AND DISCUSSION

Chemical Composition. The dry matter of the fish waste was 26.4% while that of crab processing waste was 40.2 (table 1). Dry matter of the corn stover and peanut hulls was 91.2 and 91.7%, respectively. The crude protein for the fish waste was 60.4% while that for crab waste was 44.1%. Crude protein content was similar for corn stover and peanut hulls, averaging 7.2%. Water soluble carbohydrates were higher for crab than for fish waste (3.7 vs 2.0%, dry basis). Ash content was high in both seafood waste. The ash content of 34.5% for crab waste is similar to values previously reported for crab meal (Patton and Chandler, 1975). Calcium and P contents were high for all wastes, while Mg content was higher for the fish than for the crab waste. Respective values for water soluble carbohydrates were 4.7 and 8.6%, dry basis for corn stover and peanut hulls.

Small Silos. All silages containing fish waste had aromas indicative of good ensiling. The aroma of mixtures containing crab ensiled at 40 and 50% dry matter was extremely offensive. Putrefaction was detected in mixtures of crab waste and crop residues ensiled at 40% dry matter. Mold growth was observed in the fish ensiled with peanut hulls at 50 and 60% dry matter. When samples of mixtures containig crab waste were placed in the oven for dry matter determination, a pungent ammonia odor was detectable in surrounding areas.

Post-ensiled pH was lower ($P < .05$) for mixtures containing fish than for crab (table 2). In fact, pH increased during ensiling for

TABLE 1. CHEMICAL COMPOSITION OF SEAFOOD WASTES AND CROP RESIDUES

Item	Seafood wastes		Crop residues	
	Fish	Crab	Corn stover	Peanut hulls
	%	%	%	%
Dry matter	26.4	40.2	91.2	91.7
Composition of dry matter[a]				
Crude protein	60.4	44.1	7.1	7.2
Ash	28.0	34.5	7.4	4.6
Ca	7.3	14.2	.55	1.3
P	4.2	1.8	.09	.07
Mg	.23	.11	.12	.16
Water soluble carbohydrates	2.0	3.7	4.7	8.6

[a]Dry basis.

TABLE 2. EFFECT OF KIND OF SEAFOOD WASTE ON THE FERMENTATION CHARACTERISTICS OF SEAFOOD WASTES AND CROP RESIDUES, SMALL SILO STUDY[a]

Item	Seafood wastes		S.E.
	Fish	Crab	
pH	6.2 *	8.1	.04
Lactic acid, %, dry basis	3.0 *	.75	.05
Water soluble carbohydrates, %, dry basis			
Pre-ensiled	5.5	3.3	
Post-ensiled	1.4 *	.70	.03
Volatile fatty acid, %, dry basis			
Acetic	5.9	4.3	.43
Propionic	.68	.85	.06
Isobutyric	.33	.41	.02
Butyric	1.2 *	2.7	.07
Isovaleric	.43*	.70	.04
Valeric	.02*	.11	.01

[a]Averaged over crop residues, dry matter levels and additives.
*Differences between fish and crab wastes ($P < .05$).

the crab waste mixtures. Lactic acid levels were higher ($P < .05$) for ensiled mixtures containing fish. Water soluble carbohydrate disappearance was more pronounced in ensiled crab waste mixtures compared to mixtures with fish waste ($P < .05$). Acetic acid tended to be higher for mixtures containing fish than those containing crab waste (5.9 vs 4.3%). Butyric acid levels were higher ($P < .05$) in silages containing crab waste. Small quantities of isobutyric, isovaleric and valeric acids were present.

Kind of crop residue did not affect pH or levels of lactic acid (table 3). Water soluble carbohydrates after ensiling were similar for mixtures ensiled with peanut hulls and corn stover. Mixtures ensiled with corn stover had higher ($P < .05$) acetic acid than those ensiled with peanut hulls. Butyric acid levels were similar for both crop residues.

Significant waste by crop residue interactions were recorded for pH and lactic acid. Post-ensiled pH of the fish corn-stover mixtures was lower (5.97) than for the fish-peanut hulls mixtures (7.06) but the pH values of mixtures containing crab waste were similar (8.18 vs 8.06). Lactic acid showed similar trends but differences were not as large.

Post-ensiled pH of the mixtures was similar among dry matter levels (table 4). Lactic acid levels increased with dry matter level up to 50% dry matter (quadratic effect, $P < .05$). Water soluble carbohydrate level was lowest at 40% dry matter, indicating the highest disappearance, since initial levels were similar. Acetic acid was higher for mixtures ensiled at 40% dry matter than those ensiled at

TABLE 3. EFFECT OF KIND OF CROP RESIDUE ON FERMENTATION CHARACTERISTICS OF SEAFOOD WASTES AND CROP RESIDUES, SMALL SILO STUDY

Item	Crop residues		S.E.
	Corn stover	Peanut hulls	
pH[a]	7.0	7.2	.04
Lactic acid, %, dry basis[b]	1.8	1.9	.05
Water soluble carbohydrates, %, dry basis			
Pre-ensiled	3.4	5.3	
Post-ensiled	1.1	.99	.03
Volatile fatty acid, %, dry basis			
Acetic	6.2*	4.1	.43
Propionic	.82	.71	.06
Isobutyric	.44*	.31	.02
Butyric	2.1	1.8	.07
Isovaleric	.65*	.45	.04
Valeric	.08	.06	.01

[a]Averaged over seafood waste, dry matter levels and additives.
[b]Kind of waste x crop residue interaction ($P < .01$).
*Crop residues differ ($P < .05$).

TABLE 4. EFFECT OF DRY MATTER LEVEL ON FERMENTATION CHARACTERISTICS OF SEAFOOD WASTES AND CROP RESIDUES, SMALL SILO STUDY[a]

Item	Dry matter level			S.E.
	40	50	60	
pH	7.2	7.1	7.1	.04
Lactic acid, %, dry basis[bc]	1.3	2.2	2.1	.05
Water soluble carbohydrates, %, dry basis				
Pre-ensiled	4.5	4.0	4.6	
Post-ensiled[b]	.55	1.1	1.5	.03
Volatile fatty acid, %, dry basis				
Acetic[bc]	7.4	4.0	4.0	.43
Propionic[bc]	1.7	.46	.11	.06
Isobutyric[b]	.64	.31	.18	.02
Butyric[bc]	3.3	1.6	.88	.07
Isovaleric[b]	.92	.44	.29	.04
Valeric[b]	.12	.06	.02	.01

[a] Averaged over seafood waste, crop residues and additives.
[b] Linear effect ($P < .01$).
[c] Quadratic effect ($P < .05$).

50 and 60%, represented by a quadratic response ($P < .05$). Levels of propionic, butyric, isobutyric, isovaleric and valeric acids decreased linearly ($P < .01$) as dry matter level increased. Volatile fatty acid concentration decreased ($P < .01$) as the dry matter level increased in the mixtures. Barnett (1954) reported that moisture level is important during the ensiling process by permitting the packing of the ensiled mass to prevent additional fermentation.

The test for proteus organisms was positive in all mixtures. Following ensiling, total coliforms and fecal coliforms were low (table 5), and were in fact eliminated in some mixtures (appendix tables 1 and 2). The test for proteus organisms was negative. No salmonella and shigella were detected before or after ensiling, and had not been detected in the seafood waste.

Addition of dry molasses resulted in a decrease of pH to 5.6 ($P < .01$) and an increase in lactic acid to 5.5%, dry basis, for the ensiled fish waste mixture but had no effect on the crab waste mixtures (table 6). Waste by additive interaction was recorded ($P < .01$). Addition of formic acid did not decrease pH or increase lactic acid. In fact, formic acid addition resulted in increased post-ensiled pH of the fish waste-crop residue silage. Similar results were obtained by Tatterson and Windsor (1974) when 3% (v/w) of formic acid was added to white fish offal.

Substantial levels of acetic were present in the silages (table 7). Levels of all VFA except butyric and valeric were higher ($P < .05$) in fish waste mixtures ensiled without the addition of molasses and formic acid. Butyric acid was higher ($P < .05$) in mixtures ensiled with the

TABLE 5. EFFECT OF KIND OF SEAFOOD WASTE ON TOTAL AND FECAL COLIFORMS OF ENSILED SEAFOOD WASTES AND CROP RESIDUES, SMALL SILO STUDY[a]

Item	Seafood wastes	
	Fish	Crab
Total coliforms/g	250	4
Fecal coliforms/g	43	4

[a]Averaged over crop residues, dry matter levels and additives.

TABLE 6. EFFECT OF ADDITIVE ON ENSILING PARAMETERS[a] OF MIXTURES OF SEAFOOD WASTE AND CROP RESIDUES

Seafood waste	Additive	Dry matter	pH[bcd]	Lactic acid[bcdi]	H_2O soluble carbohydrate[i]		Coliforms/g	Fecal coliforms/g
					Pre[h]	Post[bcdh]		
		%		%	%	%		
Fish	None	42.10	6.51[e]	1.89[e]	4.79	1.16[e]	3	0
Fish	Molasses	46.00	5.64[f]	5.51[f]	7.88	1.01[e]	1045	8
Fish	Formic acid	42.40	6.72[g]	1.26[g]	3.66	2.05[f]	1519	43
Average		43.5	6.25	2.89	5.44	1.41	856	17
Crab	None	46.84	8.12[e]	.87[e]	2.26	.70[e]	834	1
Crab	Molasses	48.54	8.00[e]	.67[f]	5.11	.70[e]	222	0
Crab	Formic acid	46.60	8.02[e]	.70[f]	2.53	.70[e]	1	4
Average		47.3	8.04	.75	3.33	.70	352	2

[a]Averaged over dry matter levels and crop residues.
[b]Waste effect ($P < .01$).
[c]Additive effect ($P < .01$).
[d]Waste x additive interaction ($P < .01$).
[efg]Values within a waste and column with different superscripts are different ($P < .05$).
[h]Pre- and post-ensiled.
[i]Percent of dry matter.

TABLE 7. EFFECT OF ADDITIVE ON VFA[a] PRODUCTION OF SEAFOOD WASTES AND CROP RESIDUES

Seafood waste	Additive	Volatile fatty acids					
		Acetic[bc]	Propionic[bc]	Isobutyric[bc]	Butyric[bcd]	Isovaleric[bd]	Valeric[bd]
Fish	None	9.33[e]	1.35[e]	.59[e]	.98[e]	.62[e]	.05[e]
Fish	Molasses	3.89[f]	.54[f]	.16[f]	.91[e]	.20[f]	.01[e]
Fish	Formic acid	4.44[f]	.59[f]	.25[f]	1.73[f]	.50[g]	-
Average		5.89	.83	.33	1.21	.44	.03
Crab	None	4.64[f]	1.00[e]	.51[e]	2.43[e]	.94[e]	.07[e]
Crab	Molasses	4.37[f]	.69[f]	.34[f]	2.69[e]	.50[f]	.08[e]
Crab	Formic acid	3.98[f]	.85[f]	.40[f]	2.86[f]	.55[f]	.18[f]
Average		4.33	.85	.42	2.66	.66	.11

[a]Percent of dry matter, averaged over dry matter levels and crop residue.
[b]Additive effect ($P < .01$).
[c]Seafood x additive interaction ($P < .05$).
[d]Seafood effect ($P < .01$).
[efg]Values within a waste and column with different superscripts are different ($P < .05$).

addition of formic acid. The additives had minimal effects on VFA in crab waste silages. A waste by additive interaction existed for acetic, propionic, isobutyric and butyric acids ($P < .05$). The high levels of VFA and generally lower levels of lactic acid in the control silages indicate a VFA (mainly acetic) rather than lactic acid type of fermentation.

In the present experiment, post-ensiled mixtures containing fish waste had the highest counts of both total and fecal coliforms when formic acid was added. Yeoh (1980) reported coliform counts of 13 x 10^4 to 5.7 x 10^4 organisms/g for fish silage prepared with 2 or 3% formic acid. Beck (1978) found that formic acid had a pronounced inhibitory effect on the clostridia and the enterobacteriaceae; but the effect was strongly dependent on the concentration of the acid used. At minute concentrations, the growth of undesirable organisms was actually promoted by formic acid.

Good ensiling was observed in mixtures of fish waste and Johnsongrass but the mixtures with crab waste did not ensile satisfactorily (table 8). The pH of the ensiled mixture was 5.7 and lactic acid reached 3.5%, dry basis. The addition of molasses to mixtures containing fish waste resulted in a decrease in pH to 4.5 and increased lactic acid up to 7%, compared to mixtures without additive. The addition of molasses to mixtures containing crab waste did not affect pH or lactic acid. A highly significant interaction between seafood wastes and additive was obtained for pH and lactic acid. A drastic decline in water soluble carbohydrates followed the increase in lactic acid production in the ensiled fish waste mixtures.

TABLE 8. FERMENTATION CHARACTERISTICS OF ENSILED SEAFOOD WASTES[a] AND JOHNSONGRASS

Seafood waste	Additive	Dry matter (%)	pH[bcd]	Lactic acid[bcdh]	Soluble carbohydrate		Coliforms/g		Fecal coliforms/g	
					Pre[g]	Post[bcdgh]	Pre[g] X10[4]	Post[g] X10[1]	Pre[g] X10[4]	Post[g] X10[1]
Fish	None	23.1	5.67[e]	3.50[e]	5.0	.51[e]	3	0	280	0
Fish	Molasses	26.6	4.49[f]	7.04[f]	12.8	.16[f]	5	.06	270	0
Average		24.8	5.10	5.27	8.9	.34	4	.03	275	0
Crab	None	34.6	8.00	1.04	4.6	.49	27	365[e]	214[e]	.83
Crab	Molasses	36.5	7.96	1.05	7.8	.42	36	3187[f]	340[f]	0
Average		35.6	7.98	1.04	6.2	.46	32	1176	277	.41

[a] 1:1 mixture.
[b] Seafood effect ($P < .01$).
[c] Additive effect ($P < .01$).
[d] Seafood x additive interaction ($P < .01$).
[ef] Values within a waste and column with different superscripts are different ($P < .05$).
[g] Pre- and post-ensiled.
[h] Percent of dry matter.

Levels of acetic acid were similar for fish mixtures ensiled with and without molasses (table 9), but acetic acid was higher ($P < .05$) for crab mixtures ensiled alone than for mixtures ensiled with molasses. Regardless of additive, acetic acid levels were higher ($P < .01$) in mixtures containing fish, compared to mixtures containing crab waste. Butyric acid levels were higher ($P < .01$) in silages containing crab waste, averaging over 3%. Small quantities of propionic, isobutyric and isovaleric acids were present in the crab waste silages. After ensiling, coliform counts were higher in crab waste than fish waste silages. The coliforms were essentially eliminated in the fish waste silage and fecal coliforms were essentially eliminated in all mixtures after ensiling.

Dry matter disappearance was extremely low for all laboratory silos, ranging from 1.2 to 3.5%.

The results for crab waste silages clearly indicated that fermentation characteristics for such silages were not desirable. The pungent ammonia odor that was quite evident upon opening the silos and moreso when the samples were placed in the oven for dry matter determination, complexed with the putrefaction, low lactic acid production, drastic increases in pH and high butyric acid levels after ensiling seem to indicate that fermentation was of proteolytic/sacchrolytic clostridial type. McCullough (1978) reported that reduced lactic acid concentration in silages may be due to the presence of clostridial organisms which affect pH by using lactate as a substrate and replacing this stronger acid with the weaker acid butyrate. The growth of clostridia in silages is undesirable since they act against

TABLE 9. EFFECT OF ADDITIVE ON VFA PRODUCTION OF SEAFOOD WASTES AND JOHNSONGRASS

Seafood waste	Additive	Volatile fatty acids[a]				
		Acetic[b]	Propionic[b]	Isobutyric[c]	Butyric[b]	Isovaleric
Fish	None	10.1[d]	.62[d]	.14[d]	.04[d]	.14[d]
Fish	Molasses	9.9[d]	-	-	.14[e]	-
Average		10.0	.31	.07	.10	.07
Crab	None	6.0[d]	1.1[d]	.42[d]	3.0[d]	.51[d]
Crab	Molasses	4.6[e]	1.0[d]	.35[d]	3.1[d]	.32[e]
Average		5.3	1.1	.38	3.1	.42

[a]Percent of dry matter.
[b]Seafood effect ($P < .01$).
[c]Additive effect ($P < .01$).
[de]Values within a waste and column with different superscripts are different ($P < .05$).

preservation by destroying lactic acid, leading to a pH rise (McDonald, 1981). The clostridia reduce the nutritional value of the ensiled product by catabolism of amino acids, subsequently releasing ammonia.

Another possible explanation for the poor fermentation obtained with crab waste silages may be due to the metabolism of trimethylamine oxide which consequently is reduced to ammonia, other volatile bases (Strom et al., 1979), formate formation, NaOH and methane. These metabolites subsequently result in increased pH. Trimethylamine oxide is found in the muscle of marine animals and is associated with protein metabolism, osmoregulation and excretion (Okaichi et al., 1959; Budd, 1969). The presence of metabolites from trimethylamine oxide may have served as substrates for clostridial organisms. The reduction of these metabolites results in high levels of butyric acid, low lactate and a foul smelling silage brought about by the catabolism of amino acids. This condition is more prevalent in low dry matter silages (McDonald, 1981). The results from the crab mixture ensiled at 40% dry matter, clearly seem to support the preceeding, since improvement in odor and reduction in butyric acid levels did occur as the level of crab waste decreased in the mixtures. If clostridial organisms were responsible for the poor results obtained with crab waste mixtures, then altering the environment should discourage their growth.

In the intermediate experiments on improving ensiling of crab waste, most of the treatments had minimum or no effects. The pH values are given in appendix tables 3 to 6. A high level (5%) of a mixture of propionic and sulfuric acids was beneficial to ensile crab waste. However, the pH was reduced only to 6.81 (appendix table 3). Silages

made with propionic acid alone had a strong salty-ammonia odor and showed drastic increases in pH.

After ensiling crab waste-corn stover mixtures with various acid additives and L. plantarum culture, all mixtures were putrified and had a strong ammonia-like odor. There was an elevation in post-ensiled pH in all treatments, and addition of L. plantarum did not enhance fermentation. In fact, mixtures ensiled with L. plantarum showed the sharpest increase in post-ensiled pH. Whittenbury (1961) first defined criteria which a potential microorganism should satisfy for use in silage production. He suggested that such an organism must have a high growth rate and be able to compete with and dominate other organisms likely to occur in silage. Secondly, the organism must be acid-tolerant and produce a final pH of 4 quickly. The failure of L. plantarum in this experiment may be due to the failure to achieve a low initial pH. Also, the pH drop may have been relatively slow, consequently allowing clostridial activity in the early stages of fermentation before being inhibited. The presence of clostridia would suppress the explosive growth of L. plantarum, consequently resulting in increased pH. Rate of pH fall, therefore, is an important feature of preservation.

Addition of lactic acid and a mixture of phosphoric and hydrochloric acids in amounts to give a pre-ensiling pH of 4.5 resulted in post-ensiling pH of about 6.5 and 6.3, respectively. Silages made with ethanol addition had over 2% lactic acid after ensiling, but there was no change in pH. Byers et al. (1982) reported a 25% increase in lactic acid production and a 52% reduction in energy loss when ethanol was

added to corn silage. The response to ethanol in this study deserves further investigation. Lactic acid was highest ($P < .05$) in mixtures ensiled with lactic acid and showed a slight decrease after ensiling.

Post-ensiled levels of lactic acid increased up to 1.84% for the 60:40 mixture ensiled with phosphoric and hydrochloric acids. The only acid tested which resulted in a pH less than 5 was acetic acid (tables 10 and 11). Acetic acid inhibited lactic acid formation. Addition of 2-bromoethane sulfonic acid had no effect on odor, pH or lactic acid of the silages. Addition of L. plantarum culture had no effect on the fermentation parameters studied.

Large Silo Study

Composition and Ensiling Characteristics. The dry matter content of the fish waste was 26.4%, while that of the crab waste was 40.4% (table 12), similar to the seafood wastes used in the small silo study. Average dry matter for wheat straw was 91.3%. Crude protein content for the fish and crab processing wastes was 59.8 and 45.3%, dry basis, respectively. Crude protein for the straw was 5.5%, dry basis, which is slightly higher than previously reported (Herrera-Saldana et al., 1983). Ether extract was considerably higher in fish waste than crab waste (16.5 vs 4.3%), but ash content was higher in crab processing waste. The ether extract of fish waste is similar to the 16.3% reported by Raa and Gilberg (1976) for herring offal but higher than for fish meal (Sparre, 1965). Water soluble carbohydrates were 2.1, 3.6 and 3.3%, dry basis, for fish waste, crab waste and wheat straw, respectively. Calcium was high in both seafood wastes. Phosphorus content in both wastes was considerably less than the wastes used in the small

TABLE 10. EFFECT OF ADDITIVES ON pH AND LACTIC ACID OF ENSILED CRAB WASTE AND CORN STOVER[a]

Item	Additive						S.E.
	None	Acetic acid	Phosphoric + Hcl	Lactic acid	Ethanol	L. plantarum	
pH							
Pre-ensiled	7.46[b]	4.24[c]	4.82[d]	4.4[d]	7.5[b]	6.11[b]	
Post-ensiled	7.42[b]	4.75[c]	6.34[d]	6.60[d]	7.5[b]	7.36[b]	.21
Lactic acid, % dry basis							
Pre-ensiled	.43	.54	.72	6.25	.46	.10	
Post-ensiled	0	0	1.84[b]	5.68[c]	2.53[d]	.97[e]	.18

[a]60:40 wet basis.

[bcde]Means in the same row having different superscripts differ ($P < .05$).

TABLE 11. EFFECT OF ADDITIVES ON pH AND LACTIC ACID OF ENSILED CRAB WASTE AND CORN STOVER[a]

Item	None	Additive			S.E.
		Acetic acid	Phosphoric + Hcl	Lactic acid	
pH					
Pre-ensiled	6.81[b]	4.54[c]	5.58[d]	4.80[d]	
Post-ensiled	7.02[b]	5.14[c]	6.30[d]	6.34[d]	.26
Lactic acid					
Pre-ensiled	1.00[b]	.54[c]	.63[b]	3.76[d]	
Post-ensiled	.20[b]	.05[c]	.34[b]	3.46[d]	.21

[a]40:60 wet basis.
[bcd]Means in the same row with different superscripts differ.

TABLE 12. CHEMICAL COMPOSITION OF SEAFOOD WASTES AND STRAW USED IN LARGE SILO STUDY

Item	Fish waste	Crab waste	Straw
Dry matter, %	26.4	40.4	91.3
Composition of dry matter[a], %			
Crude protein	59.8	45.3	5.5
Ether extract	26.5	4.3	.45
Ash	28.1	33.4	5.2
Ca	7.5	12.7	.41
P	.71	.35	.08
Mg	.20	.70	.14
Na	.52	1.33	.26
K	1.10	.74	.12
NDF			80.1
ADF			52.6
Cellulose			39.1
Lignin			10.7
Water soluble carbohydrates	2.1	3.6	3.3

[a]Dry basis.

silo study. Magnesium and Na contents were higher for the crab, however, K content was higher for the fish than for the crab waste.

There was a tendency for mixtures containing fish ensiled at a high level (70:30) to have a slightly offensive odor. No surface or subsurface mold was observed. The texture of mixtures containing crab, especially the 60:40 mixture, was desirable and no offensive odor was detected.

Dry matter of the seafood waste-straw silages was within the range to produce good silage (table 13). Differences in composition of the fish and crab processing wastes are reflected in the chemical composition of the seafood silages. Since straw is decidedly deficient in crude protein, and feeding it often requires supplementing with a conventional protein meal, the increase in crude protein associated with seafood wastes addition could provide substantial savings in feed costs when straw diets are fed. As the level of seafood wastes in the silages decreased, there was a concomittant decrease in ether extract, ash and mineral contents. The increased mineral content with respect to seafood wastes addition is expected to supply essential minerals, especially Ca, P and Mg. Cell wall fractions in the silages reflect the level of straw included in the mixtures, increasing as the level of seafood wastes decreased.

All mixtures containing fish and straw showed a decrease in pH after ensiling (table 14). The pH of the 70:30 mixture was 6.3, compared to 5.4 for the 51:49 mixture ($P < .01$). Unlike previous studies, mixtures containing crab waste showed only a very slight increase in post-ensiled pH, indicating that sufficient acetic acid was added to

TABLE 13. CHEMICAL COMPOSITION OF ENSILED SEAFOOD WASTE AND STRAW, LARGE SILO STUDY

Item	Fish waste:straw[a]		Crab waste:straw[b]		Straw
	70:30	51:49	60:40	40:60	
Dry matter, %	45.2	58.4	61.5	66.9	53.1
Composition of dry matter[c]					
Crude protein	31.5	20.8	17.3	13.1	9.4
Ether extract	5.5	2.8	.32	.27	.44
NDF	55.2	66.2	49.8	67.2	79.4
ADF	37.9	44.3	35.1	46.5	53.9
Cellulose	26.6	32.6	26.0	34.1	39.1
Hemicellulose	17.3	21.9	14.7	33.1	25.5
Lignin	11.6	10.6	7.9	11.3	13.0
Ash	9.0	7.3	17.5	11.1	5.2
Ca	1.78	1.27	6.33	3.31	.41
P	.501	.381	.308	.226	.080
Mg	.160	.132	.415	.267	.138
Na	.450	.381	.637	.465	.263
K	.166	.141	.125	.123	.124

[a]Proportions of fish waste and straw, wet basis.
[b]Proportions of crab waste and straw, wet basis.
[c]Percent of dry matter.

TABLE 14. FERMENTATION CHARACTERISTICS OF THE SILAGES USED IN LARGE SILO STUDY

Item	Fish waste-straw 70:30[a]	Fish waste-straw 51:49[a]	Crab waste-straw 60:40[a]	Crab waste-straw 40:60[a]	Straw	S.E.
pH						
Pre-ensiled	7.56	7.23	4.63	4.58	6.86	
Post-ensiled[bcde]	6.26	5.24	4.91	4.61	4.28	.04
Lactic acid, %, dry basis						
Post-ensiled[bcde]	1.28	3.39	.11	0	3.61	.24
Water soluble carbohydrate, %, dry basis						
Pre-ensiled	2.60	3.10	3.46	3.08	3.28	
Post-ensiled[cde]	.54	.75	3.38	3.00	1.08	.11
Acetic acid, % of dry matter						
Pre-ensiling	0	0	9.95	14.63	0	
Post-ensiling[bcde]	5.55	1.30	8.68	13.81	.80	.43

[a]Proportion of waste and straw, wet basis.
[b]Mixtures containing fish waste differ ($P < .01$).
[c]Mixtures containing crab waste differ ($P < .01$).
[d]Fish waste different from crab waste ($P < .01$).
[e]Straw different from seafood silages ($P < .01$).

buffer the effect of the bases already present and produced.

Lactic acid was higher for the 51:49 than for the 70:30 fish waste-straw mixture ($P < .01$). Values were 3.4 and 1.3%, dry basis, respectively. Addition of acetic acid to mixtures containing crab apparently inhibited fermentation, since it decreased production of lactic acid, relative to the other silages. Water soluble carbohydrate disappearance was most dramatic in mixtures containing fish waste-straw. The decrease in water soluble carbohydrates for these treatments is indicative of fermentation of sugars in such silages. Levels of water soluble carbohydrates showed no appreciable disappearance in the 60:40 and 40:60 crab waste mixtures after ensiling.

Acetic acid was the only volatile fatty acid detected in the silages after ensiling. Higher levels of acetic acid were present in the 70:30 fish waste-straw mixture, compared to the 51:49 mixture ($P < .01$). This is probably a reflection of the higher lactic acid level present in the 51:49 mixture. Acetic acid contents of the 60:40 and 40:60 crab silages reflected acid treatments, with greater ($P < .01$) levels of acetic acid present in the 40:60 mixture than the 60:40 mixture. The lack of water soluble carbohydrates disappearance, coupled with the failure to produce lactic acid when acetic acid was added could cause speculation that acetic acid is more effective in minimizing energetically inefficient fermentation pathways and in conserving ensiled energy since the products of ermentation always result in considerable energy being lost.

The results from this study indicate that a suitable method of ensiling can be used effectively to process seafood waste and low

quality roughages. It is quite possible that a better fermentation pattern could have been obtained with crab waste mixtures had extremely large quantities of readily available carbohydrate and a mixed bacterial culture applied.

LITERATURE CITED

Anonymous. 1967. Standard Methods for the Examination of Dairy Products (12th Ed.). American Public Health Association, Inc., New York.

AOAC. 1980. Official Methods of Analysis (13th Ed.). Association of Official Analytical Chemists. Washington, D. C.

Barker, S. B. and W. H. Summerson. 1941. The colorimetric determination of lactic acid in biological material. J. Biol. Chem. 138:535.

Barnett, A. J. G. 1954. Silage Fermentation. Academic Press, New York.

Beck, T. L. 1978. The Microbiology of Silage Fermentation. In: M. E. McCullough (Ed.) Fermentation of Silage - A Review. pp 63-115. National Feed Ingredients Association, Des Moines, Iowa.

Budd, J. A. 1969. Metabolism of trimethylamine by a marine bacterium, Pseudomonas NCMB 1154. Marine Biol. 4:257.

Byers, F. M., R. D. Goodrich and J. C. Meiske. 1982. Influence of acetic acid, lactic acid and ethanol on the fermentation of corn silage. J. Anim. Sci. 54:640.

Dubois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebens and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11:1.

Ely, L. O. 1978. The use of added feedstuffs in silage production. In: M. E. McCullough (Ed.) Fermentation of Silage - A Review. p 233. National Feed Ingredients Association, Des Moines, Iowa.

Erwin, E. S., G. J. Mareo and E. M. Emory. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768.

Fiske, C. H. and Y. Subbarrow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375.

Herrea-Saldana, R., D. C. Church and R. O. Kellems. 1983. Effect of ammoniation treatment of wheat straw on in vitro and in vivo digestibility. J. Anim. Sci. 56:938.

Johnson, R. R., T. L. Balwari, L. H. Johnson, K. E. McClure and B. A. Dehority. 1966. Corn plant maturity. II. Effects on in vitro cellulose digestibility and soluble carbohydrate content. J. Anim. Sci. 25:617.

Lewis, K. H. 1964. Examination of Foods for Enteropathogenic and Indicator Bacteria. U.S. Dept. of Health, Education and Welfare, Washington, D. C.

McCullough, M. E. 1978. Fermentation of Silage - A Review. National Feed Ingredients Association, Des Moines, Iowa.

McDonald, P. 1981. The Biochemistry of Silage. John Wiley and Sons, England. pp 138-142.

McDonald, P. and D. Purves. 1956. Effects of the addition of molasses on the composition and digestibility of field silages. J. Sci. Food Agr. 7:189.

Millipore Corporation. 1973. Biological analysis of water and waste water. Catalog No. LAM 3028. Bedford, Mass.

Okaichi, T., M. Manabe and T. Hashimoto. 1959. Trimethylamine oxide in fish muscle. III. The origin of trimethylamine oxide in marine fish muscle. Bul. Jap. Soc. Sci. Fish. 25:No. 2. pp 136-140.

Oremland, R. S., L. M. Marsh and S. Polcin. 1982. Methane Production and Simultaneous Sulphate Reduction in Anoxic Salt Marsh Sediments. Nature 296:143.

Patton, R. S. and P. T. Chandler. 1975. In vivo digestibility evaluation of chitinous materials. J. Dairy Sci. 58:397.

Pennington, R. J. and T. M. Sutherland. 1956. Ketone-body production from various substrates by sheep rumen epithelium. Biochem. J. 63:353.

Raa, J. and A. Gilberg. 1976. Autolysis and proteolytic activity of cod viscera. J. Food Technol. 11:619.

Reaves, P. M. and R. E. Brubaker. 1956. Effects of various preservatives on seepage from high moisture silage. J. Dairy Sci. 39:939.

Sandel, E. B. 1950. Colorimetric determinations of traces of metals. Interscience Pub. Inc., New York. p 411.

SAS. 1979. SAS User's Guide. Statistical Analysis System Institute, Inc., Gary, N. C.

Sparre, T. 1965. Fish meal: Manufacture, Properties and Utilization. In G. Borgstrom (Ed.) Fish as Food. Vol. 3. p 431. Academic Press, New York.

Strom, A. R., J. A. Olafsen and H. Larsen. 1979. Trimethylamine oxide: A terminal electron acceptor in anaerobic respiration bacteria. J. Gen. Microbiol. 112:315.

Suyama, M. and T. Tokyhiro. 1954. Urea content and ammonium formation of the muscle of cartilagenous fishes. III. The distribution of urea and trimethylamine oxide in different parts of the body. Bul. Jap. Soc. Sci. Fish. 19:No. 10. pp 1003-1006.

Tatterson, I. N. and M. L. Windsor. 1974. Fish silage. J. Sci. Fd. Agr. 25:369.

Van Soest, P. J. 1963. The use of detergents in the analysis of fibrous feeds: II. A rapid method for determination of fiber and lignin. J. Assoc. Official Agr. Chem. 46:829.

Van Soest, P. J. and R. H. Uline. 1967. Use of detergents in the analysis of fibrous feeds. IV. The determination of plant cell wall constituents. J. Assoc. Official Anal. Chem.

Van Soest, P. J. and R. H. Uline. 1968. Determination of lignin and cellulose in acid detergent fiber with permanganate. J. Assoc. Official Anal. Chem. 51:78.

Waldo, D. R., J. E. Keys, Jr., L. W. Smith and C. H. Gordon. 1971. Effect of formic acid on recovery, intake, digestibility, and growth from unwilted silage. J. Dairy Sci. 54:77.

Wilkins, R. J., R. F. Wilson and J. E. Cook. 1974. Restriction of fermentation during ensiling, the nutritive value of silage made with the addition of formaldehyde. Proc. XII Int. Grassl. Cong. Section 6:674.

Whittenbury, R. 1961. An investigation of the lactic acid bacteria. PhD Dissertation. Univ. of Edinburgh, West Mains Road.

Yeoh, Q. L. 1980. The status of research on fish silage in Malaysia. In Fish Silage Production and Its Use. I.P.F.C.-FAO Fish Rep. No. 230. Rome.

SEAFOOD WASTE II. DIGESTIBILITY, NITROGEN AND MINERAL BALANCE AND PALATABILITY BY SHEEP OF ENSILED SEAFOOD WASTES AND STRAW

SUMMARY

Ensiled mixtures of seafood wastes and wheat straw were evaluated in digestion, nitrogen and mineral balance and palatability trials with sheep. Thirty-six crossbred wethers were fed a 1) basal diet (hay and concentrate) alone or a 1:1 ratio, dry basis, of basal and 2) ensiled fish waste and straw (70:30, 3) ensiled fish waste and straw (51:49), 4) ensiled crab waste and straw (60:40), 5) ensiled crab waste and straw (40:60) and 6) ensiled wheat straw (50% moisture). Dry matter digestibility was higher ($P < .01$) for the diet containing the 70:30 than for the diet containing 51:49 fish waste-straw silage. There was no difference in dry matter digestibility between the crab silages, however, organic matter digestibility was higher when the silage with the high level of crab waste was fed ($P < .01$). Crude protein digestibility was higher ($P < .01$) for diets containing ensiled fish waste, compared to diets containing ensiled crab waste. Fecal N excretion was not different among the seafood silage diets, but urinary N excretion was higher ($P < .01$) for sheep fed the fish waste silage diets than for those fed crab waste. Urinary N excretion was also higher ($P < .01$) for animals fed the 70:30 fish waste silage diet than for those fed the 51:49 silage diet. Nitrogen retention was positive for sheep receiving all diets. As percent of intake and absorbed, N retention was higher ($P < .01$) for animals fed the crab waste silage diets, compared to those receiving diets containing fish

waste silage. Blood urea N was higher ($P < .01$) for sheep fed diets containing fish silage compared to those fed crab silage. Absorption of P was higher ($P < .01$) among animals consuming the fish silage diets than for those receiving the crab silage. Retention of Mg and K was negative for sheep receiving all diets. Crude protein digestibility of the 70:30 and 51:49 fish waste and the 60:40 and 40:60 crab waste and straw silages, calculated by difference, was 84, 64, 55, 49 and 23%, respectively. Among the seafood silages, intake of dry matter was highest ($P < .01$) for sheep consuming the 60:40 crab waste silage diet and lowest ($P < .01$) for sheep fed the 70:30 fish waste silage diet.

(Key words: Seafood Wastes, Straw, Ensiling, Digestibility, Palatability, Sheep.)

INTRODUCTION

The disposal of the large quantities of wastes generated from seafood processing presents a major problem due to unfavorable odor, high moisture content and regulation concerning disposal of wastes or by-products. The production of meal would seem to be a logical use for such seafood waste, but the high costs of drying and processing are deterrents to profit from this procedure. Also, an elaborate network would have to be established for collecting the wastes from the usually small seafood processing plants.

The process of ensiling has been used to process animal excretory wastes (Fontenot et al., 1983). The change in pH and heat produced during ensiling are effective in destroying pathogens. Fish wastes have been ensiled alone for use as animal feed (Tatterson and Windsor, 1974; Backhoff, 1976). This process involves autolysis of the wastes in sealed containers. It appears that coliforms, typhoid bacteria, staphylococci and even spores of Clostridium botulinum are destroyed in fish silage (Wirahadikusumah, 1968; James et al., 1977).

The increasing production costs of high quality forages and pressure to use grains for human food has stimulated interest in the use of crop residues in ruminant diets. Wheat straw is one of the most commonly available crop residue throughout the world and is usually produced in geographic areas where beef cattle are also found (Acock et al., 1979). It is low in digestible energy, protein and minerals, but is high in dry matter. Since seafood wastes are rich in protein

and minerals but low in dry matter, ensiling of seafood wastes as part of a mixture with straw could make a desirable, economical and manageable product. Mixtures of the high moisture seafood wastes and the low moisture straw have been shown to produce acceptable silages (Experiment I).

This research was done to evaluate the nutritive value and voluntary intake by sheep of ensiled mixtures containing different proportions of fish and crab processing wastes and wheat straw.

EXPERIMENTAL PROCEDURE

Mixtures of finfish and crab processing wastes were ensiled with ground wheat straw in 210-liter metal drums double lined with double .08 mm polyethylene bags, with 5% dry molasses included in the mixtures. The fish and straw were ensiled in combinations of 70:30, and 51:49, wet basis, while crab and straw were ensiled in combinations of 60:40 and 40:60, wet basis. The proportions of seafood wastes were similar for the silages containing the lower and higher levels of waste. Acetic acid was added to the mixtures containing crab waste to lower the initial pH to 4.5. All mixtures were packed firmly to remove excess air. The bags were sealed with plastic-coated wire and stored upright in an open shed until initiation of sheep feeding studies. A complete description of the seafood wastes, straw and preparation of the silages is given elsewhere (Experiment 1).

Digestibility and Balance Trial

Thirty-six crossbred wether lambs (average weight, 34 kg) were used in a metabolism trial. Lambs were blocked according to breed type and body weight and randomly allotted to the following six treatments: 1) basal composed of 50% orchardgrass hay (IFN 1-03-427), 38.3% corn (IFN 4-02-931), 11.4% soybean meal (IFN 5-20-637), .3% limestone (IFN 6-02-632); 2) 50% basal and 50% of the 70:30 fish waste-straw silage; 3) 50% basal and 50% of the 51:49 fish waste-straw silage; 4) 50% basal and 50% of the 60:40 crab waste-straw silage; 5) 50% basal and 50% of the 40:60 crab waste-straw silage; 6) 50% basal and 50% ensiled

wheat straw, dry basis. All lambs were administered 2000 I.U. of vitamins A and D supplement I.M. prior to the start of the trial.

The sheep were placed in false bottom metabolism stalls similar to those of Briggs and Gallup (1949) permitting separate collection of urine and feces. A 2-d adaptation period to the stalls and a 5-d transition period to the experimental diets were followed by a 10-d preliminary and a 10-d period during which feces and urine were collected. The sheep were fed 780 g dry matter/d of each diet, plus 10 g iodized salt daily in equal portions during 2 h feeding periods at 12 h intervals. Two days before the start until 2 d prior to the end of the collection period, the diet components were sampled at each feeding. The silage samples were frozen daily in double-thickness plastic bags and composited at the end of the trial. Refusals were composited daily by animal and frozen. At the end of the collection period the refusals from each animal were weighed and subsampled.

Feces were collected once daily and dried for 24 h at a maximum of 60 C in a forced-draft oven. Fecal collections were composited daily by animal in metal cans with loose fitting lids and allowed to air equilibrate. At the end of the collection period the feces from each animal were weighed, mixed and subsampled. Procedures for collecting and handling the urine were similar to those described by Bhattacharya and Fontenot (1965).

Kjeldahl N was determined on wet samples of silage, basal, straw, urine and feces (AOAC, 1980). Dry matter of all material was determined by drying duplicate 200 g samples in a forced-draft oven at a maximum of 60 C for 48 h. These samples were allowed to air

equilibrate, composited, ground to pass a 1 mm sieve and analyzed for dry matter, ether extract, ash (AOAC, 1980), neutral detergent fiber (NDF) by the method of Van Soest and Wine (1967), acid detergent fiber (ADF) by the procedure of Van Soest (1963), lignin and cellulose (Van Soest and Wine, 1968). Feed and fecal samples were wet ashed by the method of Sandel (1950). Feed, fecal and urine samples were analyzed for Mg and Ca by atomic absorption and Na and K by emission spectrophotometry utilizing a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. Lanthanum oxide was included in dilutions for Mg and Ca analyses. Samples were analyzed for P by the method of Fiske and Subbarow (1925).

At the conclusion of the collection period rumen ingesta samples were taken via stomach tube 2 h after feeding. The rumen fluid was strained through four layers of cheesecloth and the pH of the strained fluid was determined electrometrically. Samples of the strained ruminal fluid were prepared for determination of ruminal ammonia nitrogen (Conway, 1958) and volatile fatty acids (Erwin et al., 1961). Blood samples were taken the same day by jugular puncture 6 h after feeding and analyzed for blood urea nitrogen (Coulombe and Favereau, 1963).

Palatability Trial. Thirty-six crossbred wether lambs with an average body weight of 29 kg were placed in six blocks of six animals by breed and weight, and allotted to the six diets that were fed during the metabolism trial. The lambs were kept in individual 1.2 m x 4 m stalls in a semi-enclosed barn. Water was provided ad libitum and lambs had access to iodized salt. The sheep were provided with fresh feed every 12 h at about 10% in excess of intake. The trial consisted

of a 12-d transition period during which the experimental diets were gradually introduced. A 10-d preliminary period preceded a 10-d measurement period. During the measurement period refusals were collected once daily, weighed, dried at 70 C in paper bags in a forced-draft oven and weighed. Diet components were sampled throughout the measurement period. The samples were frozen in double-thickness plastic bags after each feeding. At the end of the trial, diet components were composited by treatment, thoroughly mixed and a sample was removed for dry matter determination.

The sheep were weighed before the start and at the end of the palatability trial. The average value of the initial and final weights was used to determine metabolic size ($W_{kg}^{.75}$) on which dry matter intake was calculated.

Statistical Analyses. Data from the metabolism and palatability trials were analyzed using the GLM procedure of the Statistical Analysis System (SAS, 1979). Differences among treatments were tested using the following orthogonal contrasts: 1) basal vs silages; 2) 70:30 fish waste-straw silage vs 51:49 fish waste-straw silage; 3) 60:40 crab waste-straw silage vs 40:60 crab waste-straw silage; 4) fish waste vs crab waste-straw silage; 5) seafood wastes-straw silages vs ensiled straw.

RESULTS AND DISCUSSION

Chemical Composition. Dry matter of the basal diet was 89.8% and crude protein content averaged 12.4%, dry basis (table 15). The addition of seafood wastes to the straw at ensiling time resulted in increases in crude protein, ash, Ca, P, Mg and Na contents of the resulting silages. A more complete description and discussion of the chemical composition of the silages is presented elsewhere (Experiment 1).

Apparent digestibility. In no case was the effect of block significant throughout the trials. Dry matter and organic matter digestibilities were highest ($P < .01$) for the basal diet and lowest for the straw (table 16). Dry matter digestibility was higher ($P < .01$) for the diet with 70:30 fish waste and straw silage than for the diet with the 51:49 fish waste and straw silage. There was no difference in dry matter digestibility between the crab silages, however, dry matter digestibility tended to be higher for the diet containing the silage with the higher proportion of crab waste. Organic matter digestibility of the diet with the higher level of crab silage was higher than for the diet with the lower level ($P < .01$). The dry matter digestibility of the 60:40 crab waste-straw silage diet was similar to digestibility values reported by Patton et al. (1975) when 10 and 20% crab meal was added to the diet of young ruminating calves.

Crude protein digestibility was higher ($P < .01$) for diets con-

TABLE 15. CHEMICAL COMPOSITION OF BASAL AND SILAGES FED IN SHEEP METABOLISM AND PALATABILITY TRIALS

Item	Basal	Silages				
		Fish waste:straw		Crab waste:straw		
		70:30[a]	51:49[a]	60:40[b]	40:60[b]	Straw
Dry matter, %	89.8	45.2	58.4	61.5	66.9	53.1
Composition of dry matter[c]						
Crude protein	15.4	31.5	20.8	17.3	13.1	9.4
NDF	53.4	55.2	66.2	49.8	67.2	79.4
ADF	29.3	37.9	44.3	35.1	46.5	53.9
Cellulose	21.7	26.6	32.6	26.0	34.1	39.1
Hemicellulose	24.1	17.3	21.9	14.7	33.1	25.5
Lignin	6.8	11.6	10.6	7.9	11.3	13.0
Ether extract	2.3	5.5	2.8	.32	.27	.44
Ash	7.3	9.0	7.3	17.5	11.1	5.2
Ca	.72	1.78	1.27	6.33	3.31	.41
P	.184	.501	.381	.308	.226	.080
Mg	.261	.160	.132	.415	.267	.138
Na	.264	.450	.381	.637	.465	.263
K	.130	.166	.141	.125	.123	.124

[a]Proportions of fish waste and straw, wet basis.
[b]Proportions of crab waste and straw, wet basis.
[c]Percent of dry matter.

TABLE 16. APPARENT DIGESTIBILITY OF PROXIMATE COMPONENTS AND CELL WALL FRACTIONS BY SHEEP FED BASAL AND SEAFOOD WASTE-STRAW SILAGES

Item	Diets[a]						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Apparent digestibility, %							
Dry matter[bc]	74.1	62.6	58.6	60.7	58.9	48.6	.92
Organic matter[bcd]	75.4	65.5	60.5	65.4	61.6	49.3	.94
Crude protein[e]	69.5	76.5	66.6	62.3	59.3	44.5	3.39
Ether extract[b]	71.4	92.7	82.5	82.1	82.7	75.8	4.73
NDF[b]	71.8	56.5	53.2	56.0	55.9	44.2	1.31
ADF[b]	66.9	50.6	46.4	57.8	50.8	36.2	3.84
Cellulose[b]	42.1	59.6	52.4	58.7	55.2	43.1	3.14
Hemicellulose[b]	78.4	66.1	63.9	71.1	64.4	57.2	3.06

[a]Diets contained 50% basal and 50% silage, dry basis.
[b]Basal and silages differ ($P < .01$).
[c]Fish silages differ ($P < .01$).
[d]Crab silages differ ($P < .05$).
[e]Fish silages differ from crab silages ($P < .01$).

taining ensiled fish waste-straw compared to diets containing ensiled crab waste-straw. There was a tendency for crude protein digestibility to increase with level of seafood wastes in the mixtures. The lower crude protein digestibility for the diet with ensiled straw, compared to the other diets, is undoubtedly related to the lower crude protein content of this diet.

Apparent digestibility of ether extract was lower ($P < .01$) for the basal diet than for the seafood waste-straw silage diets. There was no difference in ether extract digestibility among the seafood diets, however, digestibility tended to be higher for diets containing the higher level of fish waste silage. These data support those of Lucas and Loosli (1944) who reported that ether extract digestibility was related to the level of fat in the diet.

Digestibility of the cell wall fractions except cellulose was higher ($P < .01$) for the basal than the seafood silage diets. Cellulose digestibility was lower ($P < .01$) for animals fed the basal diet. Digestibility of the cell wall fractions was lowest for straw containing diet and tended to increase with increasing levels of seafood waste in the diet. The higher protein content of the other diets compared to the diet with straw may explain part of the increased digestibility of fiber of these diets. Since it has been reported by Forbes and Garrigus (1943) that protein-rich feeds promote the microbiological breakdown of fiber. Armsby (1917) and Elett and Holdaway (1917) reported that in a low protein diet the digestibility of nutrients is lower than in a diet having a high protein content.

Nitrogen intakes were different ($P < .01$) among the diets (table

17). Since dry matter intake was the same among diets, the differences in N intakes were related to the N contents of the diets.

Fecal N excretion was not different among the seafood silage diets, but was higher for sheep fed the diet with ensiled straw. Urinary N excretion was higher ($P < .01$) for the fish waste silage diets than for the crab waste silage diets. Urinary N excretion was also higher ($P < .01$) for the diet containing 70:30 fish waste-straw silage, compared to the diet with the 51:49 fish waste-straw silage diet. Since animals on the 70:30 fish waste-straw silage diet were consuming the largest quantity of N, the increased urinary N loss may be associated with increases in N intake. Tagari et al. (1964) reported that at high N intake, it is utilized with lower efficiency, resulting in a high percentage of the ingested N appearing in the urine. This leveling effect is characteristic of many ordinary ruminant diets but can be modified by a number of factors affecting rumen ecology (Van Soest, 1982).

Nitrogen retention was positive for sheep receiving all diets. As percent of intake and absorbed, N retention was higher ($P < .01$) for animals fed the crab waste-straw silage, compared to those receiving diets containing fish waste-straw silage. If the requirement for N has been met, increasing dietary protein or N intake generally is balanced by increasing urinary loss (Van Soest, 1982). The carbon chains of some of the excess amino acids contained in the protein can be utilized as an energy source, however, this process results in an increased metabolic expense associated with the excretion of the excess N (Tyrell et al., 1970). In every case, N balance was in favor

TABLE 17. NITROGEN UTILIZATION OF SHEEP FED BASAL AND SEAFOOD WASTE-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Nitrogen intake, g/d[a,b,c,d]	20.4	28.5	23.0	21.1	18.4	15.9	.22
Nitrogen excretion, g/d							
Fecal	5.2	5.2	5.5	5.7	5.8	6.4	.17
Urinary[b,d]	12.2	20.9	15.2	10.9	8.7	8.0	1.22
Total[b,d]	17.4	26.1	20.8	16.7	14.5	14.4	1.52
Nitrogen retention							
Grams/d	3.0	2.4	2.3	4.4	3.9	1.5	1.31
Percent of intake[d]	14.6	8.2	9.7	20.7	21.3	9.2	5.43
Percent of absorbed[d]	19.8	9.7	12.5	27.9	30.6	13.8	7.45

[a]Basal and silages differ ($P < .01$).
[b]Fish silages differ ($P < .01$).
[c]Crab silages differ ($P < .01$).
[d]Fish silages differ from crab silages ($P < .05$).

of the crab waste silage diets. The superior N retention on diets containing crab waste silage, compared to diets containing fish waste silage may possibly be due to some undegraded dietary protein, in addition to microbial protein passing from the rumen to the abomasum. Substantial amounts of protein slightly soluble in rumen fluid are known to escape microbial degradation in the rumen and become available for digestion and absorption further down the tract, therefore, leading to a greater N retention (Hume, 1970).

Intakes of Ca were highest ($P < .01$) for animals fed the crab waste silage diets (table 18). Fecal excretion of Ca was higher ($P < .01$) for animals consuming the 60:40, compared to those fed the 40:60 crab waste-straw silage diet, reflecting differences in intake. However, the absolute amount of Ca absorbed tended to reflect Ca intakes except for animals fed the 70:30 fish waste silage diet. Calcium retention, expressed as grams/d or percent of intake, was not different among the seafood silage diets, but there was a trend towards higher Ca retention in animals fed crab waste silage diets, compared to those receiving diets containing fish waste silage.

Due to the dilution of the urine the P content was too low to be determined, and therefore retention could not be calculated. Intake of P was lower ($P < .01$) for animals receiving the crab silage diets than those receiving fish silage diets, reflecting differences in P content of the silages (table 19). Absorption of P, expressed as grams/d was higher ($P < .01$) for animals consuming the fish silage diets than those receiving the crab silage, related to differences in intake. Among animals receiving the fish waste silage diets, P absorption was

TABLE 18. CALCIUM BALANCE IN SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Intake, g/d[a,b,c,d]	5.6	9.5	7.8	27.4	15.8	4.4	.03
Excretion, g/d							
Fecal[a,c,d]	3.2	10.1	6.1	22.4	12.8	3.3	1.79
Urinary	.20	.35	.32	.19	.27	.20	.06
Total[a,b,c,d]	3.4	10.4	6.3	22.6	13.1	3.5	1.83
Absorption,g/d	2.4	- .54	1.7	5.1	3.0	1.1	1.79
Retention							
Grams/d	2.2	- .90	1.5	4.8	2.7	.90	1.79
Percent of intake	39.7	-8.4	17.8	17.9	17.1	21.0	17.26

[a]Basal and silages differ ($P < .01$).
[b]Fish silages differ ($P < .01$).
[c]Crab silages differ ($P < .01$).
[d]Fish silages differ from crab silages ($P < .01$).

TABLE 19. PHOSPHORUS ABSORPTION IN SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Intake, g/d[a,b,c,d]	1.44	2.54	2.18	1.92	1.60	1.01	.02
Excretion, g/d							
Fecal[a]	.54	.95	.97	.74	.99	.99	.11
Absorption							
Grams/d[b,c,d]	.90	1.59	1.21	1.17	.61	.02	.11
Percent of intake[c]	62.4	62.8	55.4	61.1	38.1	1.2	7.04

[a]Basal and silages differ ($P < .05$).
[b]Fish silages differ ($P < .01$).
[c]Crab silages differ ($P < .05$).
[d]Fish silages differ from crab silages ($P < .01$).

higher ($P < .01$) for those fed the 70:30 diet. Manston (1967) found that absorption of P increased when the dietary intake of the element increased. Absorption, expressed as a percent of intake was drastically depressed ($P < .01$) when animals were fed the 40:60, compared to those fed the 60:40 crab waste-straw silage diet, again a reflection of intake.

Fecal excretion of Mg was not significantly different among sheep fed the diets containing seafood silages, however, there was a trend towards increased fecal excretion of Mg as the level of crab waste increased (table 20). There was no difference in urinary excretion of Mg between sheep fed the basal and seafood silage diets. Urinary excretion of Mg was considerably higher than fecal excretion. In lactating beef cows it has been shown that urinary Mg was highly related to the amount of Mg fed (O'Kelley and Fontenot, 1969). Absorption of Mg was higher ($P < .05$) among animals fed the high level of crab silage compared to those receiving the low level, a reflection of intake. Retention of Mg was negative for sheep receiving all diets.

Fecal excretion of K showed a tendency towards decreased excretion as the level of both fish and crab increased and was highest for animals fed the straw diet (table 21). These data indicate better absorption from seafood wastes than straw.

Intakes of Na were higher ($P < .01$) for sheep fed the crab silage than for those fed fish silage diets (table 22). Kind of seafood fed affected ($P < .05$) the fecal excretion of Na, with animals consuming fish silage diets excreting more Na via the feces than those fed crab diets. This resulted in Na absorption being higher ($P < .01$) for animals receiving the crab silage diets. Na absorption was also higher

TABLE 20. MAGNESIUM BALANCE IN SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Intake, g/d[a,b,c]	1.02	1.50	1.52	2.64	2.10	1.54	.02
Excretion, g/d							
Fecal[a]	1.43	1.06	.94	1.60	1.52	1.09	.16
Urinary	3.91	4.12	4.32	4.39	3.79	3.11	.75
Total	5.34	5.18	5.26	5.99	5.31	4.20	.78
Absorption, g/d[a,b]	- .41	.44	.58	1.04	.58	.45	.16
Retention, g/d	-4.32	-3.68	-3.74	-3.36	-3.24	-2.65	.81

[a]Basal and silages differ ($P < .01$).
[b]Crab silages differ ($P < .05$).
[c]Fish silages differ from crab silages ($P < .01$).

TABLE 21. POTASSIUM BALANCE IN SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Intake, g/d[a]	1.01	1.12	1.06	1.00	.98	.91	.03
Excretion, g/d							
Fecal[a]	.70	1.18	1.48	.72	1.01	1.66	.18
Urinary	7.16	6.82	6.29	5.28	6.90	5.44	.64
Total	7.86	8.00	7.77	6.00	7.91	7.10	.58
Absorption, g/d	.31	- .06	- .42	.28	- .03	- .75	.20
Retention, g/d	-6.82	-6.90	-6.71	-5.00	-6.93	-6.20	.66

[a]Fish silages differ from crab silages ($P < .05$).

TABLE 22. SODIUM BALANCE IN SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets					
	Basal	Basal and ensiled mixtures, 1:1 dry basis				
		Fish waste:straw		Crab waste:straw		
		70:30	51:49	60:40	40:60	Straw	S.E.
Intake, g/d[abc]	5.85	6.36	6.30	7.32	6.63	5.80	.02
Excretion, g/d							
Fecal[abcd]	.81	1.44	2.02	1.12	1.57	2.85	.04
Urinary	3.48	3.70	2.62	3.22	3.71	2.47	.18
Total[b]	4.29	5.14	4.64	4.34	5.28	5.32	.22
Absorption, g/d[bcd]	5.05	4.93	4.28	6.20	5.07	2.95	.05
Retention, g/d[bc]	1.57	1.23	1.65	2.97	1.36	.48	.18

[a]Basal and silages differ ($P < .01$).
[b]Crab silages differ ($P < .01$).
[c]Fish silages differ from crab silages ($P < .05$).
[d]Fish silages differ ($P < .05$).

($P < .01$) in both high levels of seafood compared to the low levels. Both absorption and retention of Na were lowest among animals fed the straw diet. The lower absorption and retention of sheep fed the straw diet may possibly be related to the protein and (or) energy intake of this diet since Horrocks (1964b) reported data indicating an improvement in Na retention by steers when a low quality roughage was supplemented with a protein-grain pellet.

Ruminal fluid pH was lowest ($P < .01$) for sheep fed the basal diet compared to those receiving seafood silages (table 23). It is well established that animals receiving diets containing appreciable levels of concentrates are more likely to have lower ruminal pH due to a change in the fermentation pattern, than animals fed diets containing lower levels of concentrates. When compared to crab waste silage diets, sheep consuming the diets with fish waste silage had higher ($P < .01$) rumen pH, but the differences were small. No difference in rumen pH was recorded between sheep fed the different levels of crab waste silage, made with the addition of acetic acid. The rumen pH was higher ($P < .01$) for sheep fed the seafood silages even when acetic acid was added, compared to those receiving the basal diet, indicating that rumen fluid from sheep fed diets containing appreciable levels of protein had a high buffering capacity. This buffering capacity seems to be related to the release of ammonia in the rumen.

Although not different ($P < .05$), ruminal fluid ammonia levels tended to be higher for sheep fed the seafood waste silages, compared to those receiving the basal diet. There was also a trend for ruminal fluid ammonia levels to increase as the level of seafood increased in

TABLE 23. RUMINAL FLUID pH, AMMONIA NITROGEN, BLOOD UREA NITROGEN AND VOLATILE FATTY ACID CONCENTRATIONS OF SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

Item	Diets						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Ruminal fluid pH[a,b]	6.5	6.8	6.8	6.7	6.7	6.8	.06
Ruminal fluid NH_3-N, mg/dl	30.8	34.8	30.2	31.8	31.1	19.8	2.58
Blood urea-N, mg/dl[a,b,c]	14.5	28.1	24.8	14.7	15.0	14.5	.93
Volatile fatty acids							
Total, μM/ml[a,b,c]	109.0	90.8	72.8	89.5	90.1	86.0	1.55
Moles/100 moles							
Acetic[b]	64.8	59.9	63.4	76.2	76.7	67.8	2.38
Propionic[b]	19.6	25.3	22.6	14.2	16.0	23.5	1.58
Isobutyric[b]	1.0	1.9	1.6	.3	.1	.3	.18
Butyric[a]	12.2	8.1	8.2	8.1	6.8	7.2	.88
Isovaleric[b,d]	1.5	2.5	2.4	.8	.4	1.2	.13
Valeric[b]	.8	2.2	1.8	.4	0	0	.15
Acetic:propionic ratio[b]	3.4	2.4	2.6	6.7	5.5	2.9	.55

[a]Basal and silages differ ($P < .01$).
[b]Fish silages differ from crab silages ($P < .01$).
[c]Fish silages differ ($P < .05$).
[d]Crab silages differ ($P < .05$).

the mixtures. Studies of the effects of level of protein solubility on N metabolism in ruminants generally indicate that the degradation of protein in the rumen increases with protein solubility (Glimp et al., 1967; Nishimuta et al., 1973). This results in increased losses of feed N as ammonia, and possibly decreased quantities of feed protein reaching the lower gut (Wohlt et al., 1976). Orskov et al. (1971b), from their studies with fish meal, reported that on the basis of ammonia release, the solubility of fish meal was very low in the rumen compared to the small intestine. The high rate of ammonia release recorded in this study especially for the 70:30 fish-straw silage diet would seem to indicate that most of the protein in the fish silage was degraded in the rumen. Ruminal fluid ammonia was 19.8 mg/dl for sheep fed the straw diet.

Blood urea N was higher ($P < .01$) for sheep fed the 70:30 waste than those fed the 51:49 fish waste-straw silage diet. Blood urea N levels were also higher ($P < .01$) for sheep fed diets containing fish waste silage, compared to those fed diets containing crab silage. This is probably due to the lower N intake by sheep receiving the crab silage diets. Preston et al. (1961) found a high correlation between N intake and blood urea N. A strong relationship between blood urea and N retention can also be established especially for animals fed the 70:30 fish-straw silage diet, consuming an average of 28.5 g/d of N.

Total VFA, expressed as μm/ml was considerably higher ($P < .01$) in sheep fed the basal diet than those fed the seafood waste silage diet (table 23). This probably contributed to the lower ruminal pH recorded for these animals compared to animals consuming the silages. Total

VFA was higher ($P < .05$) for sheep fed the 70:30 than for those fed the 51:49 fish waste-straw silage diet. Since the 70:30 fish-straw silage diet had a higher level of protein than the 51:49 diet, it is possible that this excess protein was now being manifested in the form of VFA. Overfeeding of degradable protein beyond microbial requirements results in the metabolism of excess protein to VFA and ammonia (Van Soest, 1982).

When expressed as moles/100 moles, levels of acetic acid were higher ($P < .01$) for sheep receiving the crab waste silages than for those receiving fish waste silage diets. Levels of propionic acid and the branched chain VFA were higher ($P < .01$) for sheep fed fish waste silages than for those fed diets containing crab waste silage. Feeding the basal diet alone resulted in a higher ($P < .01$) butyric acid level, compared to sheep fed seafood diets. Chappell and Fontenot (1968) reported a tendency for total VFA concentration in the rumen to be higher when readily available carbohydrate sources were fed, and that this increase was primarily due to increased level of propionate and butyrate. In the present study, the acetic to propionic acid ratio was similar for sheep fed the crab waste silages, averaging 6.7 and 5.5 for the 60:40 and 40:60 diets, respectively. The acetate to propionate ratio was higher ($P < .01$) for sheep fed the crab silages than for those fed fish silages, a reflection of the acetic acid added directly to the crab mixtures. Acetic and propionic acids were the major VFA produced when the sheep were fed diets containing the ensiled straw.

Dry matter digestibility of the 70:30 fish waste-straw silage calculated by difference (Crampton and Harris, 1969) was higher ($P < .01$)

than for the 51:49 fish waste-straw silage (table 24). Although not significant, dry matter digestibility was also higher for the higher level of crab waste compared to the lower level. Crude protein digestibility increased as the level of seafood increased in each mixture and was highest ($P < .01$) for sheep fed the 70:30 fish waste-straw silage diet. The higher crude protein digestibility for these diets may be associated with the higher N intakes. Tagari et al. (1964) reported that there was a good linear response between N intake and apparent digestibility. Apparent digestibility of dry matter and crude protein for the straw silage was extremely low, averaging 23% in both cases. Depression in N digestibility parallels the amount of N bound to other components (Goering et al., 1972). Ether extract digestibility was high for all seafood silages. However, NDF, ADF, cellulose and hemicellulose digestibilities showed progressive decreases as the level of wheat straw increased. The decrease in the digestion coefficients as the level of straw increased is undoubtedly due to the lower digestion coefficients associated with the straw. The highest digestion coefficients for the ensiled straw were for ether extract, cellulose and hemicellulose. If the digestion coefficients of the seafood wastes were calculated by difference, they would be in excess of 100%.

Expressed as g/d, dry matter intake was higher ($P < .01$) for sheep consuming the basal diet than those fed the silages (table 25). Intake was higher ($P < .01$) for sheep fed the crab waste-straw silage, compared to the fish waste-straw silage. Intake of dry matter was higher ($P < .01$) for sheep consuming the 60:40 than the 40:60 crab-straw silage diet. Addition of acetic acid to mixtures containing crab did not seem to

TABLE 24. APPARENT DIGESTIBILITY[a] OF SEAFOOD WASTES-STRAW SILAGES BY SHEEP

Component	Fish waste:straw 70:30 silage	Fish waste:straw 51:49 silage	Crab waste:straw 60:40 silage	Crab waste:straw 40:60 silage	Straw silage	S.E.
Dry matter[bc]	51.0	42.8	47.3	43.7	23.0	2.19
Crude protein[bcd]	83.6	63.8	55.0	49.2	23.3	3.41
Ether extract	113.8	100.6	92.8	96.8	80.0	9.42
NDF	41.2	34.2	40.0	39.8	16.9	2.75
ADF	36.5	28.4	44.7	34.3	10.4	6.11
Cellulose	76.8	62.6	73.5	68.3	44.0	5.57
Hemicellulose	53.8	49.4	61.1	50.3	36.1	4.96

[a]Calculated by difference, using value for ensiled plus basal and basal diet.
[b]Fish waste silages differ ($P < .01$).
[c]Seafood silages differ from straw silage ($P < .01$).
[d]Fish silages differ from crab silages ($P < .01$).

TABLE 25. DRY MATTER INTAKE OF SHEEP FED BASAL AND SEAFOOD WASTES-STRAW SILAGES

	Diets[a]						
		Basal and ensiled mixtures, 1:1 dry basis					
		Fish waste:straw		Crab waste:straw			
	Basal	70:30	51:49	60:40	40:60	Straw	S.E.
Grams per day[b,c,d,e]	1217	708	924	1194	923	1023	69.5
Grams per $W_{kg}^{.75}$[b,c,d,e]	52.3	30.1	38.8	46.6	39.0	41.6	2.37

[a] Contains 50% basal and 50% silage, dry basis.
[b] Basal and silages differ ($P < .01$).
[c] Fish silages differ from crab silages ($P < .01$).
[d] Fish silages differ ($P < .05$).
[e] Crab silages differ ($P < .05$).

cause a problem. Animals that were fed diets containing crab, especially the 60:40 diet consumed their feed readily. The possibility of using acetic acid as a silage additive has been dismissed by many researchers because its presence in silage in high concentrations has been associated with poor animal performance resulting from low voluntary dry matter intakes (Wilkins et al., 1971; Brown and Radcliffe, 1972). The evidence is conflicting as to whether these are associative or casual relationships (Hillman et al., 1958; Osbourn and Wilkins, 1967). However, recent studies by Deswysen (as cited by McDonald, 1981) have shown that acetate by itself induces only a very small reduction in the voluntary dry matter intake of silage by sheep. Therefore, any effect of high acetic acid levels in silage on animal performance is likely to arise from factors associated with the acetic acid production and not with the acid itself. The present data would appear to support this conclusion. Dry matter intake was lower ($P < .01$) for sheep fed the 70:30 fish-straw compared to the 51:49 silage diet. The reduced consumption of the 70:30 diet may be due to the high protein content of the diet. Garrett (1970) and Tyrell et al. (1970) not only observed a decreased feed intake when high protein diets were fed to cattle but also reported that on such diets the animals required more feed to maintain energy equilibrium. Dry matter intake was high for sheep fed the wheat straw supplemented diet.

Conversion of intake in g/d to grams per unit of metabolic size resulted in the same response, with dry matter intake higher ($P < .01$) for animals fed the crab than fish waste silage.

LITERATURE CITED

Acock, C. W., J. K. Ward, I. G. Rush and T. J. Klopfenstein. 1979. Wheat straw and sodium hydroxide treatment in beef cow rations. J. Anim. Sci. 49:354.

Armsby, A. P. 1917. Influence of the degree of fatness of cattle upon their utilization of feed. J. Agr. Res. 11:451.

AOAC. 1980. Official Methods of Analysis (13th Ed.). Association of Official Analytical Chemists. Washington, D. C.

Backhoff, H. P. 1976. Some chemical changes in fish silage. J. Fd. Tech. 11:353.

Briggs, H. M. and W. D. Gallup. 1949. Metabolism stalls for wethers and steers. J. Anim. Sci. 8:479.

Brown, D. C. and J. C. Radcliffe. 1972. Relationship between intake of silage and its chemical composition and in vitro digestibility. Australian J. Agr. Res. 23:25.

Chappell, G. L. M. and J. P. Fontenot. 1968. Effect of level of readily-available carbohydrates in purified sheep rations on cellulose digestibility and nitrogen utilization. J. Anim. Sci. 27:1709.

Conway, E. J. 1958. Micro-diffusion Analysis and Volumetric (4th Ed.). The McMillian Co., New York.

Coulombe, J. J. and L. Faureau. 1963. A new semi-micro method for colorimetric determination of urea. Clin. Chem. 9:102.

Crampton, E. W. and L. E. Harris. 1969. Applied Animal Nutrition (2nd Ed.). W. H. Freeman and Co., San Francisco, Calif.

Deswysen, A. 1980. Ph.D. Dissertation. Univ. of LouVain. As cited by McDonald. 1981.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11:1.

Elett, W. B. and C. W. Holdaway. 1917. The effects of high protein and high energy rations in feeding dairy cows. Virginia Agr. Exp. Sta. Tech. Bul. 12.

Erwin, E. S., G. J. Marco and E. M. Emory. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768.

Fiske, C. H. and Y. Subbarow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375.

Fontenot, J. P., L. W. Smith and A. L. Sutton. 1983. Alternative utilization of animal wastes. J. Anim. Sci. 57(Suppl 2):221.

Forbes, R. M. and W. P. Garrigus. 1948. Application of the lignin ratio technique to the determination of the nutrient intake of grazing animals. J. Anim. Sci. 7:373.

Garrett, W. N. 1970. Energy utilization of high protein diets. J. Anim. Sci. 31:242.

Glimp, H. A., M. K. Karr, C. O. Little, P. G. Woolfolk, G. E. Mitchell, Jr., and L. W. Hudson. 1967. Effect of reducing soybean protein solubility by dry heat on the protein utilization of young lambs. J. Anim. Sci. 26:858.

Goering, H. K., C. H. Gordon, R. W. Hemken, D. R. Waldo, P. J. Van Soest and L. W. Smith. 1972. Analytical estimates of nitrogen digestibility in heat damaged forages. J. Dairy Sci. 55:1275.

Hillman, D., C. A. Lassiter, C. F. Huffman and C. W. Duncan. 1958. Effect of all-hay vs all-silage rations on dry matter intake of lactating dairy cows: Moisture and pH as factors affecting appetite. J. Dairy Sci. 41:720.

Horrocks, D. 1964b. Sodium and potassium balances and growth on high and low sodium diets. II. The feeding of protein-rich concentrates in addition to sodium. J. Agr. Sci. 63:373.

Hume, I. D. 1970. Synthesis of microbial protein in the rumen. III. The effect of dietary protein. Australian J. Agr. Res. 21:305.

James, M. A., K. M. Iyer and M. R. Nair. 1977. Comparative study of fish ensilage prepared by microbial fermentation and formic acid ensilage. In: Proc. Conf. Handling Process. Mark. Trop. Fish. p 273. Tropical Products Institute, London.

Lewis, D. 195 Blood urea concentrations in relation to protein utilization in the ruminant. J. Agr. Sci. 48:438.

Lucas, H. L. and J. V. Loosli. 1944. The effect of fat upon the digestion of nutrients by dairy cows. J. Anim. Sci. 3:3.

Manston, R. 1967. The influence of dietary calcium and phosphorus concentration on their absorption in the cow. J. Agr. Sci. 68: 263.

McDonald, P. 1981. The Biochemistry of Silage. John Wiley and Sons, England. p 145.

Nishimuta, J. F., D. G. Ely and J. A. Boling. 1973. Nitrogen metabolism in lambs fed soybean meal treated with heat, formalin and tannic acid. J. Nutr. 103:49.

O'Kelley, R. E. and J. P. Fontenot. 1969. Effects of feeding different magnesium levels of drylot-fed lactating beef cows. J. Anim. Sci. 29:959.

Orskov, E. R., C. Fraser and I. McDonald. 1971b. Digestion of concentrates in sheep. II. The effect of urea or fish-meal supplementation of barley diets on the apparent digestion of protein, fat, starch and ash in the rumen, the small intestine and the large intestine, and calculation of volatile fatty acid production. Brit. J. Nutr. 25:243.

Osbourn, D. F. and R. F. Wilkins. 1967. Animal nutrition and conservation. Rep. Grassld. Res. Inst., Hunley. p 42.

Patton, R. S. and P. T. Chandler. 1975. In vivo digestibility of chitinous materials. J. Dairy Sci. 58:397.

Patton, R. S., P. T. Chandler and O. G. Gonzalez. 1975. Nutritive value of crab meal for young ruminating calves. J. Dairy Sci. 58: 404.

Preston, R. L., L. H. Brewer and W. H. Pfander. 1961. Blood urea and rumen ammonia in sheep as affected by level and source of carbohydrate and protein. J. Anim. Sci. 20:947 (Abstr.).

Sandel, E. B. 1950. Colorimetric Determinations of Traces of Metals. Interscience Pub. Inc., New York. p 411.

SAS. 1979. SAS User's Guide. Statistical Analysis System Institute, Inc., Cary, NC.

Tatterson, I. N. and M. L. Windsor. 1974. Fish silage. J. Sci. Fd. Agr. 25:369.

Tagari, H., Y. Dror, I. Ascarelli and A. Bondi. 1964. The influence of levels of protein and starch in rations of sheep on the utilization of protein. Brit. J. Nutr. 18:333.

Tyrrell, H. F., P. W. Moe and W. P. Flatt. 1970. Influence of excess protein intake on energy metabolism of the dairy cow. European Assoc. Anim. Prod. 13:69.

Van Soest, P. J. 1963. The use of detergents in the analysis of fibrous feeds: II. A rapid method for determination of fiber and lignin. J. Assoc. Official Agr. Chem. 46:829.

Van Soest, P. J. and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. The determination of plant cell wall constituents. J. Assoc. Official Anal. Chem. 50:50.

Van Soest, P. J. and R. H. Wine. 1968. Determination of lignin and cellulose in acid detergent fiber with permanganate. J. Assoc. Official Anal. Chem. 51:780.

Van Soest, P. J. 1982. Metabolic Functions - Nitrogen Metabolism: Nutritional Ecology of the Ruminant. O & B Books, Inc., Corvallis, Oregon.

Wilkins, R. J., K. J. Hutcheson, R. F. Wilson and C. E. Harris. 1971. The voluntary intake of silage by sheep. J. Agr. Sci. (Camb) 77:531.

Winahadikusumah, S. 1968. Preventing clostridium botulinum type E poisoning and fat rancidity by silage fermentation. Lantbr. Hogsk. Annlr. 34:551.

Wohlt, J. E., C. J. Sniffen, W. H. Hoover, L. L. Johnson and C. K. Walker. 1976. Nitrogen metabolism in wethers as affected by dietary protein solubility and amino acid profile. J. Anim. Sci. 42:1280.

GENERAL DISCUSSION

Presently, large resources of protein and essential minerals from waste from seafood processing plants and accidental catches in excess of local processing capacities are being discarded and there is no immediate possibility to utilize these nutrients as human food. These wastes could obviously be channeled into meal production by using fossil fuel. The production of dry meals would most definitely ameliorate the disposal and environmental pollution problems associated with the waste. Dried meals store well, but often suffer significant nitrogen loss in the drying process. Dried crab meal is extremely dusty, however, this can be overcome by pelleting.

Faced with these alternatives, other methods of processing seafood waste need to be developed. As investigated in this thesis, one solution to this problem is processing by ensiling. The high cost of fuel will place this process in a favored position over processes such as dry meal production which require large energy inputs. An especially attractive feature of ensiling seafood waste is that obnoxious odor is reduced or completely eliminated. Production of silage by bacterial fermentation is an excellent method of feed preservation. Bacteria certainly have a great potential in improving the quality of seafood products by contributing to preservation. Furthermore, the fermentation characteristics and feeding value of ensiled seafood waste is of scientific interest. Fish and crab processing wastes are high in moisture, protein and minerals but low in water soluble carbohydrates

which are valuable for ensiling. Therefore, the ensiling of seafood waste would require combination with materials having high dry matter content.

Over 400 million metric tons of crop residues are produced each year in the U.S. (Larson, 1979). These residues are characterized by having high dry matter and cell wall contents. Crop residues are used primarily for beef production in the U.S. and Canada. The use of these residues fall into two general categories: 1) in gestation rations where the requirements of the cow are only slightly above maintenance and residues can often meet this need; and 2) in rations for growing calves or lactating beef cows where a higher quality forage is needed. The ensiling of seafood waste with crop residues, not only renders the product more manageable but also results in the production of a material containing appreciable levels of crude protein, minerals, ether extract and cellulose. Applying additives to improve the fermentation and preservation of ensiled seafood waste and crop residue also have merit. Hence, these factors were investigated.

The fermentation parameters as measured by pH, lactic acid and volatile fatty acid production, destruction of potential pathogens, soluble carbohydrate disappearance and odor, were better for fish waste mixtures than for mixtures with crab waste. Formic acid addition did not enhance fermentation, however, the addition of molasses resulted in significant increases in the fermentation parameters of the fish waste silage. The results not only indicate that bacterial fermentation rather than acid addition can be used to process fish waste successfully, but that fish waste can also be ensiled in much higher quantities than

previously thought, providing a source of fermentable carbohydrate such as molasses is available and the dry matter level is increased.

Unlike fish waste, the ensiling of crab processing waste by bacterial fermentation was not feasible in this study. Crab waste silages ensiled at 40% dry matter, were putrified, and very offensive in odor, especially silages ensiled with the addition of formic acid. Also, there was a tendency for the weight of these silages to increase slightly rather than decrease after ensiling. Effluent was also quite evident from these silage. Clostridial organisms grow actively in wet conditions (Nilson, 1956). Generally, undesirable bacteria can operate at a lower pH in wetter materials (Cranshaw, 1977). Therefore, the wetter the silage the less inhibitory a given concentration of organic acids and hydrogen ions to clostridial growth. The effluent may be associated with the presence of clostridial organisms. It is also noteworthy, that from a standpoint of initial pH, formic acid silages had the lowest pH but experienced a dramatic increase in pH after ensiling. The results indicated that crab silage ensiled at an estimated dry matter of 40% had an ideal wet environment for clostridial growth, since putrefaction decreased and odor improved as dry matter level increased up to 60%.

The reduction of trimethylamine oxide to trimethylamine gives rise to the characteristic off-flavor of marine animals in the early stage of decay (Beatty and Gibbons, 1937; Tarr, 1954). The level of trimethylamine varies with geographic area, season, size and parts of the marine animals (Suyama and Takuhiro, 1954). Oremland (1982) reported that the level of trimethylamine was relatively high in salt marsh sediments

which are the areas that crabs inhabit. The concentration of trimethylamine is greater in fish than in crab (Ronald and Jakobsen, 1947). The question may, therefore, be asked, if most of the foregoing is true, why were the fermentation characteristics more desirable with mixtures containing fish than with crab? In this research, only the heads, bones, viscera and fins were used from fish while pieces of meat were still contained on the crab. Also, the marshy areas where crabs feed would quite likely result in higher trimethylamine concentration in their bodies at a particular time compared to fish. The anaerobic condition in the silo could possibly have led to a faster reduction of trimethylamine oxide to the volatile bases and consequently contribute to the very offensive odor that was prevalent especially in crab silages ensiled at 40 and 50% dry matter.

Since the exoskeleton of crabs is composed chiefly of $CaCo_3$ and chitin, an acetylated glucosamine, it is quite possible that under anaerobic conditions these two major components along with NaOH act as strong buffers to counteract the effect of any lactic acid production that would likely occur and also result in marked pH increases.

If the growth of clostridia were responsible for the poor fermentation in crab silages, then their growth can be discouraged. Firstly, the optimum pH for their growth is 7 to 7.4, and they cannot tolerate acid conditions (Pelczar and Reid, 1972). If sufficient amount of lactic acid is produced to lower the pH to a critical level, their growth is inhibited. Secondly, the addition of beneficial bacterial cultures, such as L. plantarum, to the ensiled mass at pH low enough

to encourage their growth and result in high lactic acid production, would definitely make the environment less favorable for the clostridia to compete. The reduction of trimethylamine oxide occurs readily at pH 6 (Large, 1971). Therefore, acid addition would most likely restrict the growth of clostridia and at the same time inhibit or even lessen the reduction of trimethylamine oxide to its volatile bases and also lessen the buffering effect of $CaCo_3$ and NaOH.

The addition of several inorganic and organic acids or a culture of L. plantarum to mixtures of crab silages did not result in improved fermentation. Acetic acid was the only acid tested that resulted in the production of a very stable silage. During ensiling marked changes in buffering capacity take place and result in an increase in the amount of acid required to lower the pH, over that required before ensilage (Playne and McDonald, 1966). The change can be explained, to a large extent, by the action of bacteria on the organic acids. According to Whittenbury et al. (1967) even under the best possible bacteriological conditions, i.e., microflora dominated by a homolactic population of lactic acid bacteria, these changes still occur.

It is quite possible that the results obtained with L. plantarum would have been more favorable if it were added as part of a mixed culture. Whittenbury et al. (1967) reported that a mixed culture of Streptococcus faecalis and L. plantarum was very effective in lowering silage pH. Although Streptococcus faecalis is not acid tolerant, it reduces the pH rapidly to a level at which lactobacillus growth is favored and the final fall in pH is accomplished by lactobacilli naturally present on the ensiled mass. By adding an inoculum of L.

plantarum as well, the last part of the acidification can be controlled. An inoculum of L. plantarum by itself has not proven to be ideal, as initially it does not grow rapidly to dominate the anaerobic flora and ensure economy of sugar in fermentation (Whittenbury et al., 1967). The addition of high levels of soluble carbohydrate and a mixed bacterial culture as aids to the ensiling of crab wastes constitute an important basis for further research and development.

The importance and the understanding of the versatility of ruminants in the human food chain is constantly increasing, and its ultimate usefulness is limited only by the imagination of the investigators involved. For example, it has long been established that acid preserved fish silage cannot be used as part of the ruminant diet and that bacterial fermented fish silage should only constitute a very small fraction of such diets. According to Brundage et al. (1981) crab meal was unpalatable to lactating dairy cows even at low levels and this limited palatability could pose serious limitations to the use of crab meal in livestock rations. The mineral content of fish silage and crab meal has also limited their use in the diet of ruminants for fear of large increases in urine volume. Their use has, therefore, been restricted to the diets of pigs and poultry.

The ruminant is quite capable of converting numerous waste products into valuable meat protein. However, this can only be accomplished by thoroughly understanding the mechanisms involved.

Digestion and palatability data from this investigation did indicate that bacterial fermented fish silage and acid preserved crab silage can be included in the diet of ruminants, both as a protein and

mineral supplement without causing any deleterious effect. Digestion coefficients, and nitrogen and mineral balance data indicate conclusively that both fish and crab silage have potential for widespread future use in ruminant's diet. The dry matter intake data from the sheep palatability study show that addition of acetic acid to silages does not necessarily result in depression of intake. This depression of intake may at least in part have been overcome by feeding the acid silage as part of a basal mixture.

Ensiling seafood waste and crop residues appear attractive. Not only does it require less energy than processes using fossil fuel, but it is practical and demonstrated successful process. Fermentations have thus stood the test of time as useful processes in production of silage. They not only conserve the nutrient values of the feed ensiled, in some cases they result in biochemical changes that enhance the nutrient content. Conversion of seafood waste into silage may be a feasible way of salvaging these resources.

BIBLIOGRAPHY

Acock, C. W., J. K. Ward, I. G. Rush and T. J. Klopfenstein. 1979. Wheat straw and sodium hydroxide treatment in beef cow rations. J. Anim. Sci. 49:354.

Aines, G. E., W. D. Lamm, K. E. Webb, Jr., and J. P. Fontenot. 1982. Effects of diet, dry matter level and sodium hydroxide treatment on the ensiling characteristics and utilization by lambs of cattle waste-rye straw mixtures. J. Anim. Sci. 54:504.

Anonymous. 1967. Standard Methods for the Examination of Dairy Products (12th Ed.). American Public Health Association, Inc., New York.

AOAC. 1980. Official Methods of Analysis (13th Ed.). Association of Official Analytical Chemists. Washington, D. C.

Anthony, W. B. 1971. Cattle manure as feed for cattle. Proc. Int. Symp. on Livestock Wastes. A.S.A.E. Publ. Proc. 271-293.

Armsby, A. P. 1917. Influence of the degree of fatness of cattle upon their utilization of feed. J. Agr. Res. 110:451.

Arndt, D. L., C. R. Richardson, R. C. Albin and L. B. Sherrod. 1980. Digestibility of chemically treated cotton plant by-product and effect on mineral balance, urine volume and pH. J. Anim. Sci. 51:215.

Arvat, V. R., R. J. Lipsey and J. M. Vandepopulieri. 1978. Digestibility of ensiled caged layer waste by ruminants. Amer. Soc. Anim. Sci. 460 (Abstr.).

Atkinson, A., E. Lamprecht and D. Misplon. 1974. Acid alkali preservation of fish meal. In 28th Annu. Rep. of the Dif. Fishing Ind. Res. Inst. Cape Town. p 44.

Backhoff, H. P. 1976. Some chemical changes in fish silage. J. Fd. Tech. 11:353.

Barker, S. B. and W. H. Summerson. 1941. The colorimetric determination of lactic acid in biological material. J. Biol. Chem. 138:535.

Barlow, S. M. and I. H. Pike. 1977. The role of fat in fish meal in pig and poultry nutrition. Tech. Bull. Int. Assoc. Fish Meal Manuf. U.K. 4:38.

Barnes, A. C. 1973. Process By-products. The Sugarcane (2nd Ed.). Halstead Press, New York. p 446.

Barnett, A. J. G. 1954. Silage Fermentation. Academic Press, New York.

Batterham, E. S. and T. B. Gorman. 1980. Fish silage for growing pigs. In Proc. Rec. Adv. Anim. Nutr., University of New England, Armidate, Aust. p 111.

Beatty, S. A. and N. E. Gibbons. 1937. The measurement of spoilage in fish. J. Biol. Bd. Can. 3:70.

Beck, T. L. 1978. The Microbiology of Silage Fermentation. In: M. E. McCullough (Ed.) Fermentation of Silage - A Review. pp 63-115. National Feed Ingredients Association, Des Moines, Iowa.

Berger, J. C. A., J. P. Fontenot, E. T. Kornegay and K. E. Webb, Jr. 1981. Feeding swine waste. II. Nitrogen utilization, digestibility and palatability of ensiled swine waste and orchardgrass hay or corn grain fed to sheep. J. Anim. Sci. 52:1404.

Berger, J. C. A., J. P. Fontenot, E. T. Kornegay and K. E. Webb, Jr. 1981. Feeding swine waste. I. Fermentation characteristics of swine waste ensiled with ground hay or ground corn grain. J. Anim. Sci. 52:1388.

Bhattacharya, A. N. and J. P. Fontenot. 1965. Utilization of different levels of poultry litter nitrogen by sheep. J. Anim. Sci. 24:1174.

Bhattacharya, A. N. and J. C. Taylor. 1975. Recycling animal waste as a feedstuff: A review. J. Anim. Sci. 41:1438.

Binger, H. P., C. R. Thompson and G. O. Kohler. 1961. Tech. Bul. No. 1235. Washington, D. C. USDA-ARS U.S. Govt. Printing Off. p 1.

Black, M. M. and H. M. Schwartz. 1950. The estimation of chitin and chitin nitrogen in crawfish waste and derived products. Anal. 75:185.

Black, W. A. P. 1955. The preservation of seaweed by ensiling and bactericides. J. Sci. Food Agric. 6:14.

Borgstrom, G. 1962. Nutrition, Sanitation and Utilization. In Fish as Food. Academic Press, New York.

Bray, C. I., J. B. Francioni and E. M. Gregory. 1932. Protein supplements and pastures for swine. Louisiana Agr. Exp. Sta. Bull. No. 228.

Briggs, H. M. and W. D. Gallup. 1949. Metabolism stalls for wethers and steers. J. Anim. Sci. 8:479.

Brown, R. L. 1959. Protein analysis of shrimp-waste meal. Comm. Fisheries Rev. 21(2a):6.

Brown, D. C. and J. C. Radcliffe. 1972. Relationship between intake of silage and its chemical composition and in vitro digestibility. Australian J. Agr. Res. 23:25.

Brundage, A. L., F. M. Husby, V. L. Burton and J. L. Franklin. 1979. Dry matter and nitrogen solubility of Alaska marine waste. J. Dairy Sci. 62 (Suppl 1):135 (Abstr.).

Brundage, A. L., F. M. Husby, G. L. Beardsley and V. L. Burton. 1981. King crab meal in concentrates for lactating cows. J. Dairy Sci. 64:433.

Bull, L. S. and J. T. Reid. 1971. Nutritive value of chicken manure for cattle. Proc. Int. Symp. on Livestock Wastes. A.S.A.E. Pub. Proc. 271:297.

Budd, J. A. 1969. Metabolism of trimethylamine by a marine bacterium, Pseudomanas NCMB 1154. Marine Biol. 4:257.

Byers, F. M., R. D. Goodrich and J. C. Meiske. 1982. Influence of acetic acid, lactic acid and ethanol on the fermentation of corn silage. J. Anim. Sci. 54:640.

Cameron, C. D. 1962. Acid fish offal silage as a source of protein in growing and finishing rations for bacon pigs. Can. J. Anim. Sci. 42:41.

Campbell, F. L. 1929. The detection and estimation of insect chitin. Ann. Ent. Soc. Amer. 22:401.

Caswell, L. F., K. E. Webb, Jr., and J. P. Fontenot. 1977. Fermentation, nitrogen utilization, digestibility and palatability of broiler litter ensiled with high moisture corn grain. J. Anim. Sci. 44:803.

Caswell, L. F., J. P. Fontenot and K. E. Webb, Jr. 1978. Fermentation and utilization of broiler litter ensiled at different moisture levels. J. Anim. Sci. 46:54?

Chandra, S. and M. G. Jackson. 1971. A study of various chemical treatments to remove lignin from coarse roughages and increase their digestibility. J. Agr. Sci. 77:11.

Chappell, G. L. M. and J. P. Fontenot. 1968. Effect of level of readily-available carbohydrates in purified sheep rations on cellulose digestibility and nitrogen utilization. J. Anim. Sci. 27:1709.

Chico, C. F., T. A. Shultz, Elena Shultz, A. A. Carnevale and C. B. Ammerman. 1972. Molasses-urea for restricted forage fed steers in the tropics. J. Anim. Sci. 35:859.

Church, D. C. and A. Santos. 1981. Effect of graded levels of soybean meal and of a nonprotein nitrogen-molasses supplement on consumption and digestibility of wheat straw. J. Anim. Sci. 53:1609.

Clark, J. L. and M. R. Dethrow. 1975. Dried poultry waste as a supplemental nitrogen source for cattle. Poul. Sci. 54:1747 (Abstr.).

Colenbrander, V. F., L. D. Muller, J. A. Wassou and M. D. Cunningham. 1971. Effects of added urea and ammonium polyphosphate to corn stover silage on animal performance. J. Anim. Sci. 33:1091.

Conway, E. J. 1958. Micro-diffusion Analysis and Volumetric (4th Ed.). The McMillian Co., New York.

Cornman, A. W., W. D. Lamm, K. E. Webb, Jr., and J. P. Fontenot. 1981. Ensiling cattle waste with rye straw as a diet supplement for ruminants. J. Anim. Sci. 52:1233.

Coulombe, J. J. and L. Favreau. 1963. A new semi-micro method for colorimetric determination of urea. Clin. Chem. 9:102.

Crampton, E. W. and L. E. Harris. 1969. Applied Animal Nutrition (2nd Ed.). W. H. Freeman and Co., San Francisco, Calif.

Cranshaw, R. 1977. An approach to the evaluation of silage additives. ADAS Quart. Rev. 24:1.

Creger, C. R., F. A. Gardner and F. M. Farr. 1973. Broiler litter silage for fattening beef animals. Feedstuffs 45(3):25.

Dehority, B. A. and R. R. Johnson. 1961. Effect of particle size upon the "in vitro" cellulosic digestibility of forages by rumen bacteria. J. Dairy Sci. 44:2242.

Deswysen, A. 1980. Ph.D. Dissertation. Univ. of LouVain. As cited by McDonald. 1981.

Disney, J. G., I. N. Tatterson and J. Alley. 1977. Recent developments in fish silage. Proc. Conf. Handl. Process. Mark. Trop. Fish. pp 231-240. London: Tropical Products Institute.

Disney, J. G., A. Hoffman, J. Olley, I. J. Clucas, A. Barranco and B. J. Francis. 1978. Development of a fish silage/carbohydrate animal feed for use in the tropics. Trop. Sci. 20:129.

Dubois, M., K. A. Gilles, J. K. Hamilton, P. A. Rebers and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28:350.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11:1.

Durairaj, S., T. Santhanaraj, K. M. Sultan and K. A. Rajah Dorai. 1976. Utilization of trash fish. Fish ensilage - some aspects of processing and storage. 1. In Proc. Symp. Fish Process. Inc. Central Food Tech. Res. Int. Mysore, India. 81.

Edin, H. 1940. Undersokningar angaande importavstengnin-gens aggviteproblem. Nord. Jordbr. Torsk. 22:142. As quoted from Raa and Gilberg, 1982.

Elett, W. B. and C. W. Holdaway. 1917. The effects of high protein and high energy rations in feeding dairy cows. Virginia Agr. Exp. Sta. Tech. Bull. 12.

Ely, L. O. 1978. The use of added feedstuffs in silage production. In M. E. McCullough (Ed.) Fermentation of Silage - A Review. p 233. National Feed Ingredients Association, Des Moines, Iowa.

Ernst, A. J., J. F. Limpus and P. K. O'Rourke. 1975. Effects of supplements of molasses and urea on intake and digestibility of native pasture hay by steers. Australian J. Exp. Agr. Anim. Husb. 15:451.

Erwin, E. S., G. J. Marco and E. M. Emory. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768.

Ferreino, H. M., T. M. Sutherland and A. Wilson. 1977. Effect of nitrogen source on rumen fermentation in diets based on sugar-cane. Trop. Anim. Prod. 2(3):319-322. In Chem. Abstr. 1978 (89):106327.

Fiske, C. H. and Y. Subbarrow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375.

Fontenot, J. P., L. W. Smith and A. L. Sutton. 1983. Alternative utilization of animal wastes. J. Anim. Sci. 57 (Suppl 2):221.

Forbes, R. M. and W. P. Garrigus. 1948. Application of the lignin ratio technique to the determination of the nutrient intake of grazing animals. J. Anim. Sci. 7:373.

Freeman, H. C. and P. L. Hoogland. 1956. Processing of cod and haddock viscera. 1. Laboratory experiments. J. Fish. Res. Bd. Can. 13(6):869.

Gaiger, P. J. 1978. Fish silage trials in Hong Kong. In Proc. I.P.F.C. 18(3):527.

Garrett, W. N. 1970. Energy utilization of high protein diets. J. Anim. Sci. 31:242.

Garrett, W. N., H. G. Walker, G. O. Kohler and M. R. Hart. 1976. Feedlot response of beef steers to diets containing NaOH or NH_3 treated rice straw. In 15th California Feeders Day Proc. Univ. of California, Davis. pp 39-47.

Gerhardsen, G. M. 1971. Norwegian rearing of pondfish. The Norwegian School Econ. Business Admin. Inst. Fish Econ. p 55.

Gilberg, A. and J. Raa. 1977. Properties of a propionic acid/formic acid preserved silage of cod viscera. J. Sci. Food Agric. 28:647.

Gilberg, A. and J. Raa. 1979. Solubility and enzymatic solubilization of muscle and skin of capelin (Mallotus villosus) at different pH and temperature. Comp. Biochem. Physiol. 63B:309.

Glimp, H. A., M. K. Karr, C. O. Little, P. G. Woolfolk, G. E. Mitchell, Jr., and L. W. Hudson. 1967. Effect of reducing soybean protein solubility by dry heat on the protein utilization of young lambs. J. Anim. Sci. 26:858.

Goering, H. K., C. H. Gordon, R. W. Hemken, D. R. Walso, P. J. Van Soest and L. W. Smith. 1972. Analytical estimates of nitrogen digestibility in heat damaged forages. J. Dairy Sci. 55:1275.

Goering, H. K. and D. R. Waldo. 1974. Processing effects on protein utilization by ruminants. Proc. Cornell Nutr. Conf. p 25.

Hansen, P. 1959. Ensilering of fisk og Fiskeaffald. Meaddr. Fisk Minist. Fors. Lab. Denmark. p 26.

Harmon, B. W., J. P. Fontenot and K. E. Webb, Jr. 1975a. Ensiled broiler litter and corn forage. 1. Fermentation characteristics. J. Anim. Sci. 40:144.

Harmon, B. W., J. P. Fontenot and K. E. Webb, Jr. 1975b. Ensiled broiler litter and corn forage. II. Digestibility, nitrogen utilization and palatability by sheep. J. Anim. Sci. 40:156.

Harpster, H. W., T. A. Long and L. L. Wilson. 1978. Comparative value of ensiled cattle waste for lambs and growing-finishing cattle. J. Anim. Sci. 46:238.

Heath, M. E., D. S. Metcalfe and R. F. Barnes. 1973. Forages: The Science of Grassland Agriculture (3rd Ed.). The Iowa State Univ. Press, Ames.

Herrea-Saldana, R., D. C. Church and R. O. Kellems. 1983. Effect of ammoniation treatment of wheat straw on in vitro and in vivo digestibility. J. Anim. Sci. 56:938.

Hillman, D., C. A. Lassiter, C. F. Huffman and C. W. Duncan. 1958. Effect of all-hay vs all-silage rations on dry matter intake of lactating dairy cows: Moisture and pH as factors affecting appetite. J. Dairy Sci. 41:720.

Hillyer, G. M., D. G. Peers, R. Morrison, D. A. Parry and M. P. Woods. 1976. Evaluation for on farm use of de-oiled herring silage as a protein feed for growing pigs. In Proc. Torry Res. Stn. Symp. Fish Silage Torry Research Station, Aberdeen.

Hjelmeland, K. and J. Raa. 1980. Fish tissue degradation by trypsin type enzymes. In Advances in Fish Science and Technology J. J. Connell Ed. Fishing News Books. Farnham, Surray, England. p 456.

Horrocks. D. 1964b. Sodium and potassium balances and growth on high and low sodium diets. II. The feeding of protein-rich concentrates in addition to sodium. J. Agr. Sci. 63:373.

Horton, G. M. J. 1978. The intake and digestibility of ammoniated cereal straw by cattle. Can. J. Anim. Sci. 58:471.

Horton, G. M. J. and G. M. Steacy. 1979. Effect of anhydrous ammonia treatment on the intake and digestibility of cereal straw by steers. J. Anim. Sci. 48:1239.

Hume, I. D. 1970. Synthesis of microbial protein in the rumen. III. The effect of dietary protein. Australian J. Agr. Res. 21:305.

Ishihara, T., H. Kinari and M. Tasuda. 1974. Studies on thiaminase 1 in marine fish. III. Vitamin B_1 deficiency disease of chicken caused by inclusion of anchovy in diet. Bull. Jpn. Soc. Fish. 40(3):309.

Jackson, M. G. 1977. Review article: The alkali treatment of straws. Anim. Feed Sci. Technol. 2:105.

James, M. A., K. M. Iyer and M. R. Nair. 1977. Comparative study of fish ensilage prepared by microbial fermentation and formic acid ensilage. In Proc. Conf. Hardling Process. Mark. Trop. Fish. Tropical Products Institute London. p 273.

Jensen, J. 1973. Fish hydrolysate and fish silage. Final report to Danida on the work carried out on "FIsh hydrolysate" and "fish silage" in the period of May 1972 to April 1973. p 22. Fiskerministeries Forsogslaboratorium, Copenhagen.

Jensen, J. and W. Schmidtsdorff. 1977. Fish silage, low fat and soluble fish protein products. In Proc. I. A. F. M. M. Symp. Prod. Use Fish Meal. Szczecin, Poland.

Johnson, R. R., T. L. Balwari, L. H. Johnson, K. E. McClure and B. A. Dehority. 1966. Corn plant maturity. II. Effects on in vitro cellulose digestibility and soluble carbohydrate content. J. Anim. Sci. 25:617.

Jones, S. R., W. B. Anthony and J. P. Cunningham. 1976. Urea and protein liquid supplements for steers. Proc. Western Sec. ASAS 27:284.

Keys, J. E. and L. W. Smith. 1981a. Effect of poultry excreta and ground ear corn on growth, intake and digestion of corn stover silage diets by yearling dairy hefiers. J. Dairy Sci. 61:141.

Keys, J. E. and L. W. Smith. 1981b. Effect of dried poultry excreta on growth intake and digestion of corn stover silage diets by yearling dairy heifers. J. Dairy Sci. 64:211.

Kirk, W. G., R. L. Shirley, J. F. Easley and F. M. Peacock. 1967. Composition and feed value of shrimp meal. Quart. J. Florida Acad. Sci. 30:51.

Klopfenstein, T. 1978. Chemical treatment of crop residues. J. Anim. Sci. 46:841.

Klopfenstein, T., L. Berger and J. Paterson. 1979. Performance of animals fed crop residues. Fed. Proc. 38:1939.

Koers, W., M. Prokop and T. J. Klopfenstein. 1972. Sodium hydroxide treatment of crop residues. J. Anim. Sci. 35:1131 (Abstr.).

Kohler, G. O., H. G. Walker and D. D. Kuzmicky. 1979. Processing and use of crop residues including alfalfa press cake. Fed. Proc. 38:1934.

Kompiang, I. P., A. Darwanto, and R. Anifudin. 1980. Nutritional value of fish silage. In Proc. I.P.F.C. Workshop Fish Silage. FAO Fish Rep. No. 230. p 44.

Kompiang, I. P., Yushadi, and D. C. Creswell. 1980. Microbial fish silage: Chemical composition, fermentation characteristics and nutritional value. In Proc. I.P.F.C. Workshop Fish Silage. FAO Fish Rep. No. 230. p 38.

Krishnaswamy, M. A., S. B. Kadkol and G. D. Revankar. 1965. Nutritional evaluation of an ensiled product from fish. Can. J. Biochem. 43:1879.

Lamm, D., L. E. Jones, D. C. Clanton and J. K. Ulard. 1975. Dehydrated poultry waste as a nitrogen source for cattle. J. Anim. Sci. 41:409 (Abstr.).

Lamm, W. D., K. E. Webb, Jr., and J. P. Fontenot. 1979. Ensiling characteristics, digestibility and feeding value of ensiled cattle waste and ground hay with and without sodium hydroxide. J. Anim. Sci. 48:104.

Large, P. J. 1971. Non-oxidative demethylation of trimethylamine N-oxide by pseudomonas aminovorans. Febs Letters 18(2):297.

Larson, W. E. 1979. Crop residues: Energy production or erosion control. J. Soil and Water Cons. 34:74.

Leask, W. C. and F. B. Daynard. 1973. Dry matter yield, in vitro digestibility, percent protein and moisture of corn stover following grain maturity. Can. J. Plant Sci. 53:515.

Lesoing, G. W. 1977. Chemical treatment of wheat straw. M.S. Thesis. Univ. of Nebraska, Lincoln.

Lewis, D. 1957. Blood urea concentrations in relation to protein utilization in the ruminant. J. Agr. Sci. 48:438.

Lewis, K. H. 1964. Examination of foods for enteropathogenic and indicator bacteria. U.S. Dept. of Health, Education and Welfare, Washington, D.C.

Lisac, H. 1961. The liquid ensilage of Mediterranean sardines for animal feeding. Proc. G.F.C.M. 6:111.

Lovell, R. T., J. R. Lafleur and F. H. Hoskins. 1968. Nutritional value of freshwater crayfish waste meal. J. Agric. Food Chem. 16:204.

Lubitz, J. A., C. R. Tellers and R. T. Parkhurst. 1943. Crabmeal in poultry rations. 1. Poul. Sci. 22:307.

Lucas, H. L. and J. V. Loosli. 1944. The effect of fat upon the digestion of nutrients by dairy cows. J. Anim. Sci. 3:3.

Mackie, I. M. 1982. General review of fish protein hydrolysates. In Animal Feed Science and Technology 7:113-124. Elsevier Scientific Publishing Co.

Mangold, E. and A. Hock. 1938. Wallhandkrabbenschrotes bei huhnern. Arch. fur Gefluglkunde 12:97.

Mangold, E. and H. Damkohler. 1938. Wallhandkrabbenschrot als. Eiwelssfutter fur das Gefluged. II. Archiv. fur Geflugelkunde. 12:104.

Manston, R. 1967. The influence of dietary calcium and phosphorus concentration on their absorption in the cow. J. Agr. Sci. 68: 263.

McCaskey, T. A. and W. B. Anthony. 1975. Health aspects of feeding animal waste conserved in silage. Proc. 3rd Int. Symp. on Livestock Wastes. ASAE. Pub. Proc. 275-230.

McClure, K. E., R. L. Preston and E. W. Klosterman. 1973. Digestibility and palatability of fermented cattle manure fed to cattle. J. Anim. Sci. 37:350.

McCullough, M. E. 1978. Fermentation of silage - A review. National Feed Ingredients Association, Des Moines, Iowa.

McDonald, P. and R. Whittenbury. 1973. Ensilage. In The Chemistry and Biochemistry of Herbage. G. W. Butler and R. W. Bailey (Ed.) Academic Press, New York. Vol. 3.

McDonald, P. 1981. The Biochemistry of Silage. John Wiley and Sons, England. pp 138-142.

McDonald, P. and D. Purves. 1956. Effects of the addition of molasses on the composition and digestibility of field silages. J. Sci. Food Agr. 7:189.

Meyers, S. P. and B. F. Perkins. 1977. Recovery and applications of by-products from Louisiana shellfish industries. In Proc. 2nd Annual Trop. Subtrop. Fish. Tech. Conf. Texas A&M Univ.

Millipore Corporation. 1973. Biological analysis of water and waste water. Catalog No. LAM 3028. Bedford, Mass.

Moriba, J. N. 1981. Digestibility and palatability of caged layer waste and corn stover ensiled alone and with molasses. M.S. Thesis. VPI&SU, Blacksburg.

NAS. 1971. Atlas of nutritional data on United States and Canadian feeds. National Academy of Sciences, Washington, D.C.

Newton, G. L., P. R. Utley, R. J. Ritter and W. C. McCormick. 1977. Performance of beef cattle fed wastelage and digestibility of wastelage and dried waste diets. J. Anim. Sci. 44:447.

Nilson, P. E. 1956. Some characteristics of the silage microflora. Arch. F. Mikrobiol. 24:396.

Nilsson, R. and C. Rydin. 1963. Fermentation as a means of preserving organic materials. Acta. Chem. Scand. 17(1):174.

Nilsson, R. and C. Rydin. 1965. A new method of ensiling foodstuffs and feedstuffs of vegetable and animal origin. Enzymologia 29: 126.

Nishimuta, J. F., D. G. Ely and J. A. Boling. 1973. Nitrogen metabolism in lambs fed soybean meal treated with heat, formalin and tannic acid. J. Nutr. 103:49.

NMFS. 1975. Fisheries of the United States. 1974. Current Fisheries Statistics No. 6700. Marine Fish. Service, U.S. Dept. of Commerce, Washington, D.C.

Norman, G. A., D. Silverside, D. A. Hector and S. Francis. 1979. The acid treatment of animal by-products. Trop. Sci. 21(4):221.

Ohyama, Y. 1971. Problems in silage fermentation. Jap. J. Zootech. Sci. 42:301.

Oji, U. I. and D. N. Morvatt. 1978. Nutritive value of steam-treated corn stover. Can. J. Anim. Sci. 58:177.

Okaichi, T., M. Manabe and T. Hashimoto. 1959. Trimethylamine oxide in fish muscle. III. The origin of trimethylamine oxide in marine fish muscle. Bull. Jap. Soc. Sci. Fish. 25:No. 2. pp 136-140.

O'Kelley, R. E. and J. P. Fontenot. 1969. Effects of feeding different magnesium levels of drylot-fed lactating beef cows. J. Anim. Sci. 29:959.

Olley, J., J. E. Ford and A. P. Williams. 1968. Nutritional value of fish visceral meals. J. Sci. Food Agric. 19:282.

Ololade, B. G., D. N. Morvat and J. E. Winch. 1970. Effects of processing methods on the in vitro digestibility of sodium hydroxide treated roughages. Can. J. Anim. Sci. 50:657.

Opstvedt, J. 1971. Fish taint in eggs and poultry meat. In Proc. Nutr. Conf. Feed Manuf. No. 5. H. Swan and D. Lewis eds. Churchill Livingstone, London. p 70.

Oremland, R. S., L. M. Marsh and S. Polcin. 1982. Methane production and simultaneous sulphate reduction in anoxic salt marsh sediments. Nature 296:143.

Orskov, E. R., C. Fraser and I. McDonald. 1971b. Digestion of concentrates in sheep. II. The effect of urea or fish-meal supplementation of barley diets on the apparent digestion of protein, fat, starch and ash in the rumen, the small intestine and the large intestine, and calculation of volatile fatty acid production. Brit. J. Nutr. 25:243.

Osbourn, D. F. and R. F. Wilkins. 1967. Animal nutrition and conservation. Rep. Grassld. Res. Inst., Hurley. p 42.

Osuji, P. O. and K. A. E. Archibald. 1976. The nutritive value of some Caribbean feedstuffs. Proc. 1st Int. Symp. on Feed Consumption, Animal Nutrient Requirements, and Computerization of DIets, Utah State Univ. pp 86-97.

Overhults, D. G., I. J. Ross, G. L. Cromwell, J. L. Taraba. 1978. Recycling swine waste in a growing finishing ration. A.S.A.E. No. 78-4007. Utah State Univ. Logan.

Parkhurst, R. T., M. S. Gutowska and C. R. Fellers. 1944a. Crab meal in poultry rations. III. Laying and breeding rations. Poul. Sci. 23:118.

Parkhurst, R. T., M. S. Gutowska, J. A. Lubritz and C. R. Fellers. 1944b. Crab meal in poultry rations. II. Chick and broiler rations. Poul. Sci. 23:58.

Pate, F. M. 1979. Improving the nutritive value of sugarcane bagasse with steam-pressure treatment. Fla. Beef Cattle Res. Rep. Inst. Food Agr. Sci. Univ. of Fla. pp 46-50.

Patton, R. S. and P. T. Chandler. 1975. In vivo digestibility evaluation of chitinous materials. J. Dairy Sci. 58:397.

Patton, R. S., P. T. Chandler and O. G. Gonzalez. 1975. Nutritive value of crab meal for young ruminating calves. J. Dairy Sci. 58:404.

Pelczar, M. J., Jr., and R. E. Reid. 1972. Microbiology (3rd Ed.). McGraw Hill Book Co., New York.

Peniston, Q. P., E. L. Johnson, C. N. Turrill and M. L. Hayes. 1969. A new process for recovery of by-products from shellfish waste. In Proc. 24th Industrial Waste Conf. Part I. Purdue Univ. Lafayette, Indiana. p 403.

Pennington, R. J. and T. M. Sutherland. 1956. Ketone-body production from various substrates by sheep rumen epithelium. Biochem. J. 63:353.

Peterson, H. 1953. Acid preservation of fish and fish offal. F.A.O. Fish. Bull. 6(1):18.

Playne, M. J. and P. McDonald. 1966. The buffering constituents of herbage and of silage. J. Sci. Fd. Agr. 17:264.

Potter, D., I. Tatterson and J. Wignall. 1980. Preliminary studies of two techniques for the removal of oil from fish silage using commercial equipment. In Advances in Fish Science and Tech. J. J. Connell ed. Fishing News Books, Farnham, England. p 338.

Poulter, R. G., K. M. Jaymardena, P. Ganegoda and K. M. P. Ranaweera. 1980. Studies on fish silage in Sri Lanka. A summary. In Proc. I.P.F.C. Workshop Fish Silage. FAO Fish. Rep. No. 230:64.

Preston, R. L., L. H. Brewer and W. H. Pfander. 1961. Blood urea and rumen ammonia in sheep as affected by level and source of carbohydrate and protein. J. Anim. Sci. 20:947 (Abstr.).

Raa, J. and A. Gilberg. 1976. Autolysis and proteolytic activity of cod viscera. J. Fd. Technol. 11:619.

Raa, J. and A. Gilberg. 1982. Fish Silage: A Review. In Critical Reviews in Food Science and Nutrition. CRC Press. Vol. 16. pp 382-419.

Rankgkuti, M., L. Batubara and M. Angus. 1980. Fish silage for pig production. In Proc. I.P.F.C. Workshop Fish Silage F.A.O. Res. Rep. No. 230:70.

Rattagool, P. P., S. Swachathamwongratana and N. Wongchinda. 1980. Fish Silage in Thailand: Further Trials on Broiler Chicken. In Proc. I.P.F.C. Workshop Fish Silage F.A.O. Fish. Rep. No. 230. p 59.

Rattagool, P. P., N. Wongchinda and S. Swachathamwongratana. 1980. Studies on the nutritive value of fish silage for broiler chickens. In Proc. I.P.F.C. Workshop Fish Silage. F.A.O. Fish. Rep. No. 230. p 48.

Reaves, P. M. and R. E. Brubaker. 1956. Effects of various preservatives on seepage from high moisture silage. J. Dairy Sci. 39:939.

Reece, P. 1980. Control and reduction of free fatty acid concentration of free fatty acid concentration in oil recovered from fish silage prepared from sprat. J. Sci. Food Agric. 31:147.

Rexen, F. and M. Moller. 1974. Use of chemical methods to improve the nutritonal value of straw crops. Feedstuffs 46(8):46.

Rexen, R. and K. V. Thomsen. 1976. The effect of digestibility of a new technique for alkali treatment of straw. Anim. Feed Sci. Technol. 1:73.

Richards, A. G. 1953. Chemical and physical properties of cuticle chitin, and its derivatives. K. D. Roeder, ed. Insect Physiology. John Wiley and Sons, Inc., New York, N.Y.

Ricks, E., B. Ridling, G. A. Iacobucci an D. V. Myers. 1978. Approaches to analyze and optimize protein hydrolysates. Proc. Fed. Biochem. Soc. 44(A3):119.

Roa, P. D. 1965. Ensilage of fish by microbial fermentation. Fish News Int. 4(3):283.

Ronald, O. A. and F. Jakobsen. 1947. Trimethylamine oxide in marine products. J. Soc. Chem. Ind. 66. No. 5. pp 160-166.

Rush, I. G. and R. Totusek. 1976. Supplemental value of feed grade biuret and urea-molasses for cows on dry winter grass. J. Anim. Sci. 42:497.

Rutledge, J. E. 1971. Decalcification of crustacean meals. J. Agric. Food Chem. 19:236.

Samuels, W. A. 1980. Fermentation, utilization and palatability of ensiled caged layer waste and sugarcane bagasse. M.S. Thesis. VPI&SU. Blacksburg.

Saito, A. and L. W. Regier. 1970. Determinations of total carotenoid pigments in trout and salmon flesh. Halifax, Nova Scotia, News Serv. Circ. No. 36. p 2.

Sandel, E. B. 1950. Colorimetric determinations of traces of metals. Interscience Pub. Inc., New York. p 411.

SAS. 1979. SAS User's Guide. Statistical Analysis System Institute, Inc., Gary, N.C.

Saylor, W. W. and T. A. Long. 1974. Laboratory evaluation of ensiled poultry waste. J. Anim. Sci. 39:139 (Abstr.).

Schmalfuss, H. and H. Werner. 1936. Ueber die vermentbarhilit der Wollhandkrable, Eriocheir sinensis. Die Landwirtschafti. Vers-Stationen 125:341.

Schneider, B. H. and W. P. Flatt. 1975. Factors affecting digestibility: The evaluation of feed through digestibility experiments. The Univ. of Georgia Press, Athens.

Schroder, K., E. Clausen, A. M. Sandberg and J. Raa. 1980. Pshchotrophic lactobacillus planterum from fish and its ability to produce antibiotic substances. In Advances in Fish Science and Technology. J. J. Connell ed. Fishing News Books, Farnham, Surrey, England. p 480.

Shake, L. J., B. W. Pinkerton, C. E. Donnell, J. K. Riggs and R. E. Lichtennealner. 1977. Utilization of cattle excrement for growth and maintenance of beef cattle. J. Anim. Sci. 45:166.

Sikonski, Z. E., E. Dunajski and S. Kobylinski. 1969. The reduction of fish in Poland. F.A.O. Fish Tech. Pap. No. 69. p 17. Rome: Food Agric. Organ.

Smith, L. W. 1974. Dehydrated poultry excreta as a crude protein supplement for ruminants. World Anim. Rev. 11:16.

Smith, L. W. and W. E. Wheeler. 1979. Nutritional and economic value of animal excreta. J. Anim. Sci. 48:144.

Sparre, T. 1965. Fish meal: Manufacture, properties and utilization. In G. Borgstrom (Ed.) Fish as Food. Vol. 3. p 431. Academic Press, New York.

Spinelli, J., L. Lehman and D. Wieg. 1974. Composition, processing, and utilization of red crab (Pleuroncodes plancpes) as an aquacultural feed ingredient. J. Fisheries Res. Board Can. 31:1025.

Staples, C. R., G. F. Fahey, Jr., R. B. Rindsig and L. L. Berger. 1981. Evaluation of dairy waste fiber as a roughage source for ruminants. J. Dairy Sci. 64:662.

Strom, A. R., J. A. Olafsen and H. Larsen. 1979. Trimethylamine oxide: A terminal electrom acceptor in anaerobic respiration bacteria. J. Gen. Microbiol. 112:315.

Strom, T., A. Gilberg, B. Stormo and J. Raa. 1980. Fish silage: Why not use propionic and formic acid? In Advances in Fish Science and Technology. J. J. Connell ed. Fishing News Books Ltd., Farnham.

Strom, T. and B. O. Eggum. 1981. Nutritional value of fish viscera silage. J. Sci. Food Agric. 32:115.

Sumner, J. 1976. A feasibility study of fish silage production in the Indo Pacific Fisheries Council Region. FAO/IPFC Jt. Rep., No. FT/76/4. Rome: Food Agric. Organ.

Sumner, J. and D. James. 1977. Silage production in tropical and subtropical fisheries. Proc. Second Annual Trop. and Subtrop. Fisheries Technological Conference of the Americas. Texas A&M Univ. p 99.

Sumner, J. 1978. Performance of pigs fed on diets containing fish silage: Evaluation in the commercial situation. In Proc. I.P.F.C. 18(3):554.

Sundstol, F., E. Coxworth and D. N. Mowat. 1978. Improving the nutritive value of wheat straw and other low quality roughages by treatment with ammonia. World Anim. Prod. 26:13.

Suyama, M. and T. Tokyhiro. 1954. Urea content and ammonium formation of the muscle of cartilagenous fishes. III. The distribution of urea and trimethylamine oxide in different parts of the body. Bul. Jap. Soc. Sci. Fish. 19. No. 10. pp 1003-1006.

Tagari, H., Y. Dror, I. Ascarelli and A. Bondi. 1964. The influence of levels of protein and starch in rations of sheep on the utilization of protein. Brit. J. Nutr. 18:333.

Tarr, H. L. 1954. Microbiological deterioration of fish post mortem, its detection and control. Bacteriol. Rev. 18:1.

Tatterson, I. 1982. Fish Silage - Preparation, Properties and Uses. Animal Feed Science and Technology 7:153. Elsevier Scientific Publishing Co.

Tatterson, I. N. and M. L. Windsor. 1974. Fish silage. J. Sci. Fd. Agr. 25:369.

Tibbetts, G. W., R. W. Seerley, H. C. McCampbell and S. A. Vezey. 1981. An evaluation of an ensiled waste fish product in swine diets. J. Anim. Sci. 52:93.

Tyrrell, H. F., P. W. Moe and W. P. Flatt. 1970. Influence of excess protein intake on energy metabolism of the dairy cow. European Assoc. Anim. Proc. 13:69.

Van Soest, P. J. 1963. The use of detergents in the analysis of fibrous feeds: II. A rapid method for determination of fiber and lignin. J. Assoc. Official Agr. Chem. 46:829.

Van Soest, P. J. and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. The determination of plant cell wall constituents. J. Assoc. Official Anal. Chem.

Van Soest, P. J. and R. H. Wine. 1968. Determination of lignin and cellulose in acid detergent fiber with permanganate. J. Assoc. Official Anal. Chem. 51:78.

Van Soest, P. J. 1969. Composition, maturity and nutritive value for forages. In R. F. Gould (Ed.) Celluloses and Their Applications. Amer. Chem. Soc. Washington D.C. pp 262-277.

Van Soest, P. J. 1975. Physiochemical aspects of fibre digestion. In I. W. McDonald and A. C. I. Warner (Ed.) Digestion and Metabolism in the Ruminant. pp 351-365. Univ. of New England Publishing Unit, Australia.

Van Soest, P. J. 1982. Metabolic Functions - Nitrogen Metabolism: Nutritional Ecology of the Ruminant. O & B Books, Inc., Corvallis, Oregon.

Van Wyk, G. N., F. Franck, B. J. Potgieter, J. P. Wessels and A. Atkinson. 1977. Utilization of fish silage. A study of its intake by porkers. Agroanimalia. 9:13.

Vetter, R. L. and W. Burroughs. 1974. Nutritive value of cattle excreta silage. J. Anim. Sci. 39:1003 (Abstr.).

Walso, D. R., J. E. Keys, Jr., L. W. Smith and C. H. Gordon. 1971. Effect of formic acid on recovery, intake, digestibility, and growth from unwilted silage. J. Dairy Sci. 54:77.

Waiss, A. C., Jr., J. Guggol, G. O. Kohler, H. G. Walker, Jr., and W. N. Garrett. 1972. Improving digestibility of straws for ruminant feed by aqueous ammonia. J. Anim. Sci. 35:109.

Waller, J. C. and T. Klopfenstein. 1975. Hydroxides for treating crop residues. J. Anim. Sci. 41:424 (Abstr.).

Ward, G. M. and D. K. Beede. 1973. Digestibility of processed feedlot manure. Feedstuffs 45(28):25.

Ward, G. M., D. E. Johnson and E. W. Kienholz. 1975. Nutritional properties of feedlot manure fractionated by Oreco Process. Proc. 3rd Int. Symp. on Livestock Wastes, ASAE Pub. Proc. 275: 208.

Watkins, B. E. 1976. Evaluation of shrimp and crab processing waste as a feed supplement for mink (Mustela vison). M.S. Thesis. Oregon State Univ., Corvallis.

Watkins, B. E., J. Adair and J. E. Oldfield. 1982. Evaluation of shrimp and king crab processing by products as feed supplements for mink. J. Anim. Sci. 55:578.

Weise, F. 1963. Beitrage zur grundlagenforschung in der garfutterbereitung. II. Das bakteriologische bild einer grassilage. Lanbauforsch. Volkenrode 13:111. As cited by McCullough. 1978.

Wessels, J. P. and S. Labuscharge. 1974. Preservation of fish with acid. In 28th Annu. Rep. Dir. Fishing Industry Res. Inst., Cape Town, 1974. 48.

Whittenbury, R. 1961. An investigation of the lactic acid bacteria. Ph.D. Dissertation. Univ. of Edinburgh, West Mains Road.

Whittenbury, R., P. McDonald and D. G. Bryan-Jones. 1967. A short review of some biochemical and microbiological aspects of ensilage. J. Sci. Fd. Agr. 18:441.

Wieringa, G. W., S. Schukking, D. Kapelle and S. de Haan. 1961. Influence of heating on silage fermentation and quality. Netherlands J. Agr. Sci. 9:210.

Wigglesworth, V. B. 1965. The principles of insect physiology. Methuen and Co. Ltd. London, England.

Wilkie, D. W. 1972. The carotenoid pigmentation of pleuroncodes planipes stimpon (crustacea:decapoda galatheidae). Comp. Biochem. Physiol. 42B:731.

Wilkins, R. J., K. J. Hutcheson, R. F. Wilson and C. E. Harris. 1971. The voluntary intake of silage by sheep. J. Agr. Sci. (Camb): 77:531.

Wilkins, R. J., R. F. Wilson and J. E. Cook. 1974. Restriction of fermentation during ensiling, the nutritive value of silage made with the addition of formaldehyde. Proc. XII Int. Grassl. Cong. Section 6:674.

Wirahadikusumah, S. 1968. Preventing clostridium botulinum type E poisoning and fat rancidity by silage fermentation. Lantbr. Hogsk. Annlr. 34:551.

Wirahadikusumah, S. 1969. The effect of fish silage on the quality of hen eggs and meat of broilers. Lontbr. Hogsk. Annlr. 35: 823.

Wohlt, J. E., C. J. Sniffen, W. H. Hoover, L. L. Johnson and C. K. Walker. 1976. Nitrogen metabolism in wethers as affected by dietary protein solubility and amino acid profile. J. Anim. Sci. 42:1280.

Woolford, M. K. 1972. Some aspects of the microbiology and biochemistry of silage making. Herb. Abstr. 42:105.

Yeoh, Q. L. 1980. The status of research on fish silage in Malaysia. In Fish Silage Production and Its Use. I.P.F.C.-FAO Fish Rep. No. 230. Rome.

Yokoyama, M. T. and R. W. Nummy, Jr. 1976. Inclusion of livestock feces into corn silage. J. Anim. Sci. 43:211 (Abstr.).

Zimmer, E. 1969. Biochemical principles of ensiling. Proc. 3rd Congr. Europ. Grassld. Fed. 113.

APPENDIX

TABLE 1. FERMENTATION CHARACTERISTICS OF MIXTURES OF FISH WASTE AND CROP RESIDUES AT DIFFERENT DRY MATTER LEVELS

Estimated dry matter	Crop residue		Percent fish waste	Additive	Dry matter %	H_2O soluble carbohydrate		pH		Lactic acid[abcdf]	Coliforms		Fecal coliforms	
	Kind	Percent				Pre[ef]	Post[adef]	Pre[e]	Post[abcde]		Pre[e] X10^4	Post[e] X10^1	Pre[e] X10^4	Post[e] X10^1
40	Corn stover	22.8	77.2	None	32.1	4.63	.77	6.33	6.45	1.83	7	0	276	0
40	Corn stover	21.7	73.3	Molasses	31.6	7.65	.10	7.50	5.24	2.86	16	0	270	0
40	Corn stover	22.8	77.2	Formic acid	34.2	4.54	1.07	4.49	7.47	.91	8	0	130	0
50	Corn stover	37.8	62.2	None	46.2	2.66	1.56	6.28	5.79	2.48	16	0	343	0
50	Corn stover	36.1	58.8	Molasses	49.1	5.85	1.32	6.51	5.15	5.43	43	0	370	0
50	Corn stover	37.8	62.2	Formic acid	43.6	3.64	1.31	4.25	6.70	1.50	20	0	283	0
60	Corn stover	52.8	47.2	None	52.4	3.18	1.87	6.70	5.67	2.78	10	0	350	0
60	Corn stover	50.0	45.0	Molasses	61.0	6.83	1.42	6.48	4.97	5.94	8	0	270	0
60	Corn stover	52.8	47.2	Formic acid	56.6	3.53	3.14	4.43	6.42	1.00	0	1.5	0	0
40	Peanut hulls	22.5	77.5	None	34.0	5.01	.68	6.14	6.39	.84	66	.4	330	0
40	Peanut hulls	21.7	73.3	Molasses	36.7	7.84	1.00	6.03	6.15	3.48	7	8.8	340	1
40	Peanut hulls	22.5	77.5	Formic acid	34.4	4.84	.87	6.56	7.05	.43	0	3.2	0	0
50	Peanut hulls	37.8	62.2	None	46.0	5.66	1.18	6.04	7.47	1.46	20	4.3	140	0
50	Peanut hulls	36.1	58.8	Molasses	45.8	8.33	1.00	7.53	5.61	7.84	141	0	203	0
50	Peanut hulls	37.8	77.5	Formic acid	44.4	5.43	1.25	4.48	5.94	2.73	0	2	0	0
60	Peanut hulls	37.8	47.2	None	58.1	5.31	.90	5.94	7.31	1.97	16	10	203	0
60	Peanut hulls	50.0	45.0	Molasses	59.4	8.26	1.20	6.85	5.35	8.03	14	15.3	323	16
60	Peanut hulls	37.8	47.2	Formic acid	57.8	5.15	4.68	4.48	6.72	1.00	0	85	0	0

[a] Significant linear effect ($P < .01$).
[b] Significant quadratic effect ($P < .01$).
[c] Fish waste x crop residue interaction ($P < .01$).
[d] Fish waste x dry matter interaction ($P < .05$).
[e] Pre- and post-ensiled.
[f] Percent of dry matter.

TABLE 2. FERMENTATION CHARACTERISTICS OF MIXTURES OF CRAB WASTE AND CROP RESIDUES AT DIFFERENT DRY MATTER LEVELS

Estimated dry matter	Crop residue		Percent crab waste	Additive	Dry matter	H_2O soluble carbohydrate		pH		Lactic acid[abcdf]	Coliforms		Fecal coliforms	
	Kind	Percent			%	Pre[ef]	Post[adef]	Pre[e]	Post[abcdf]		Pre[e] X10^4	Post[e] X10^1	Pre[e] X10^4	Post[e] X10^1
40	Corn stover	1.9	98.1	None	37.7	3.46	.30	7.35	8.19	.72	10	8.3	310	0
40	Corn stover	1.0	94.0	Molasses	42.0	4.86	.45	7.02	8.07	.77	4	0	375	0
40	Corn stover	1.9	98.1	Formic acid	39.6	3.37	.32	7.01	8.08	.26	8	0	380	0
50	Corn stover	17.9	82.1	None	49.4	3.14	1.26	6.96	8.24	1.50	15	0	120	0
50	Corn stover	16.9	78.0	Molasses	52.1	3.96	.91	6.88	8.07	1.00	10	0	263	0
50	Corn stover	17.9	82.1	Formic acid	49.8	2.45	1.10	6.78	8.15	1.10	20	0	243	0
60	Corn stover	37.8	62.2	None	59.0	2.86	1.02	6.74	8.11	1.10	39	18	260	0
60	Corn stover	36.8	58.1	Molasses	58.3	3.52	.24	6.87	7.89	.24	3	34.5	190	0
60	Corn stover	37.8	62.2	Formic acid	60.2	2.43	1.04	6.54	8.03	1.03	6	11.6	290	0
40	Peanut hulls	1.9	98.1	None	44.3	2.42	.35	6.51	7.95	.62	12	0	216	0
40	Peanut hulls	1.0	94.2	Molasses	38.1	3.10	.45	7.02	8.06	.78	8	17	250	0
40	Peanut hulls	1.9	98.1	Formic acid	41.8	2.04	.72	6.56	7.73	.68	6	0	350	0
50	Peanut hulls	17.8	82.2	None	49.2	2.81	.54	6.08	8.11	.55	1	0	160	0
50	Peanut hulls	16.8	78.1	Molasses	41.6	3.22	.63	5.82	7.91	.55	4	1.8	189	0
50	Peanut hulls	17.8	82.2	Formic acid	49.9	2.32	.67	6.57	8.01	.60	10	0	360	0
60	Peanut hulls	37.5	62.5	None	59.6	2.48	.71	6.51	8.11	.70	40	16.7	245	20
60	Peanut hulls	36.5	58.4	Molasses	61.6	3.61	.97	6.91	7.98	.70	28	1.2	143	0
60	Peanut hulls	37.5	62.5	Formic acid	58.9	2.21	.58	6.27	8.12	.54	1	11.6	180	0

[a] Significant linear effect ($P < .01$).
[b] Significant quadratic effect ($P < .01$).
[c] Crab waste x crop residue interaction ($P < .01$).
[d] Crab waste x dry matter interaction ($P < .01$).
[e] Pre- and post-ensiled.
[f] Percent of dry matter.

TABLE 3. EFFECT OF VARIOUS PERCENTAGES OF PROPIONIC AND SULFURIC ACIDS ON pH OF CRAB WASTE-CORN STOVER MIXTURES[a]

Acids	Level (%)	Pre-ensiled pH	Post-ensiled[b] pH
Propionic acid	2	6.30	7.68
	4	5.61	7.45
	5	4.98	7.41
Propionic + sulfuric acids	2	6.10	7.71
	4	5.42	7.55
	5	4.86	6.81

[a]Ensiled at 50% dry matter.
[b]Difference between levels of acid ($P < .01$).

TABLE 4. EFFECT OF VARIOUS ACID ADDITION AND LACTOBACILLUS PLANTARUM CULTURE ON pH OF CRAB WASTE-CORN STOVER MIXTURES[a]

Acids	L. plantarum	Estimated pH	Pre-ensiled pH	Post-ensiled[bcd] pH
None	-		7.61	8.15
	+		7.63	8.66
Phosphoric acid	-	5.5	5.62	8.21
	+		5.58	8.34
Phosphoric acid	-	4.5	5.50	7.82
	+		5.50	8.34
Acetic acid	-	5.5	5.25	7.92
	+		6.28	7.98
Acetic acid	-	4.5	5.16	7.95
	+		5.28	7.98
Hydrochloric & sulfuric acids	-	5.5	6.25	8.16
	+		6.78	8.04
Hydrochloric & sulfuric acids	-	4.5	5.36	8.08
	+		5.45	8.14
Propionic acid	-	5.5	5.65	7.95
	+		5.63	7.98
Propionic acid	-	4.5	5.18	7.36
	+		5.04	7.48

[a]Ensiled at 50% dry matter.
[b]Difference between none and acids ($P < .01$).
[c]Difference between acids at pH 5.5 and 4.5 ($P < .05$).
[d]Difference among acids ($P < .01$).
(-) indicates no culture was added.

TABLE 5. EFFECT OF ADDITIVES ON pH AND LACTIC ACID OF ENSILED CRAB WASTE AND CORN STOVER (60:40)

Additive	BES[b]	pH		Lactic acid[e]	
		Pre-ensiled	Post-ensiled[a]	Pre-ensiled	Post-ensiled[a]
				%	%
None	+	7.59	7.23	.43	.00
	-	7.32	7.60	.44	.00
Acetic[c]	+	4.17	4.77	.61	.00
	-	4.31	4.73	.47	.00
Phosphoric[c] + HCl[c]	+	4.97	6.27	.85	1.30
	-	4.66	6.41	.59	2.37
Lactic acid[c]	+	4.33	6.55	5.24	4.81
	-	4.47	6.62	7.26	6.54
Ethanol	+	7.32	7.37	.37	2.61
	-	7.73	7.58	.54	2.44
L. plantarum[d] -	+	5.00	7.27	.16	.64
	-	6.32	7.20	.19	.26
+	+	5.85	7.35	.18	1.11
	-	6.37	7.32	.00	.83

[a]Difference between no additive and additive ($P < .01$).
[b]2-bromoethane sulfonic acid.
[c]Ensiled at pH 4.5.
[d]Ensiled at pH 5.5.
[e]Dry basis.

TABLE 6. EFFECT OF ADDITIVES ON pH AND LACTIC ACID OF ENSILED CRAB WASTE AND CORN STOVER (40:60)

Additive	BES[b]	pH		Lactic acid, %[d]	
		Pre-ensiled	Post-ensiled[a]	Pre-ensiled	Post-ensiled[a]
None	+	6.85	7.00	.91	.03
	-	6.77	7.03	1.08	.35
Acetic[c]	+	4.56	5.18	.45	.10
	-	4.51	5.11	.62	0
Phosphoric[c] + HCl[c]	+	5.50	6.22	.66	.32
	-	5.65	6.36	.60	.35
Lactic acid[c]	+	4.75	6.35	3.81	3.80
	-	4.85	6.33	3.70	3.11

[a]Difference between no additive and acids ($P < .01$).
[b]2-bromoethane sulfonic acid.
[c]Ensiled at pH 4.5.
[d]Dry basis.

The vita has been removed from the scanned document

FERMENTATION CHARACTERISTICS, NUTRITIONAL VALUE AND PALATABILITY OF ENSILED SEAFOOD WASTES AND LOW QUALITY ROUGHAGES

by

Winston Anthony Samuels

(ABSTRACT)

Fish and crab processing wastes were ground and ensiled with corn stover or peanut hulls alone and with 5% dry molasses or 1% formic acid in 3.8 liter cardboard containers double lined with polyethylene. The wastes and roughages were ensiled in proportion to give dry matter levels of 40, 50 and 60%. The seafood wastes were also ensiled with wilted Johnsongrass with and without molasses. After ensiling, average pH for mixtures with fish waste was 6.5, compared to 8.0 for mixtures with crab waste. Addition of dry molasses resulted in a decrease ($P < .01$) of pH to 5.6 for the ensiled fish mixture but had no effect on the crab waste mixtures. Lactic acid was higher ($P < .01$) for ensiled mixtures containing fish waste than for those containing crab waste. Substantial levels of acetic acid were present in the silages. Butyric acid levels were higher in silages containing crab waste and decreased linearly ($P < .01$) with increased dry matter levels. Desirable ensiling was observed for the mixture of fish waste and Johnsongrass. Coliforms and fecal coliforms were decreased or eliminated by ensiling. In a large silo study, mixtures of finfish and crab processing wastes were mixed with wheat straw and ensiled in 210 liter metal drums, double lined with polyethylene bags. Proportions of the fish and straw

were 70:30 and 51:49, wet basis, while that of the crab was 60:40 and 40:60. Acetic acid was added to the crab waste mixtures to lower the initial pH to 4.5. After ensiling all mixtures containing fish and straw showed a decrease in pH. Addition of acetic acid to mixtures containing crab waste inhibited fermentation, but resulted in a very stable product. In a sheep digestion trial, dry matter digestibility was higher ($P < .01$) for the 70:30 diet than for the 51:49 fish diet. There was no difference in dry matter digestibility between the crab silages. Crude protein digestibility was higher ($P < .01$) for diets containing ensiled fish, compared to diets containing ensiled crab. Nitrogen retention was positive for sheep receiving all diets. Nitrogen retention was higher ($P < .01$) for animals fed the crab silage diets, compared to those receiving diets containing fish silage. There was a trend for P absorption to be higher in animals fed crab silage. In the sheep palatability trial, intake of dry matter was higher ($P < .01$) for sheep consuming the crab silage diet and lowest ($P < .01$) for sheep fed the 70:30 fish silage diet.