EXTRUSION-COOKING OF FOOD
Seminar held at SIK - The Swedish Food Institute, Gothenburg, Sweden on January 21, 1981.

Arranged by:
SIK - The Swedish Food Institute
The Nordic Co-Operative Organisation for Applied Research
The Swedish Nutrition Foundation

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ISBN 91-7290-095-4
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Programme</td>
<td>2</td>
</tr>
<tr>
<td>Christiane Mercier, Effect of extrusion-cooking on the physical and biochemical characteristics of cereals and starchy products.</td>
<td>3</td>
</tr>
<tr>
<td>N.-G. Asp and I. Björck, Influence of extrusion-cooking on the nutritional value.</td>
<td>8</td>
</tr>
<tr>
<td>Yngve Andersson, Sensory properties of extruded foods</td>
<td>11</td>
</tr>
<tr>
<td>Pekka Linko, Enzymatic hydrolysis of starch in an extruder.</td>
<td>16</td>
</tr>
<tr>
<td>Peter Gry, Extrusion of fish/starch mixtures.</td>
<td>18</td>
</tr>
<tr>
<td>Lena Jonsson et al., Extrusion of high fiber products.</td>
<td>20</td>
</tr>
<tr>
<td>Hans Jungvid et al., Water turnover in cats fed differently processed dry diets.</td>
<td>29</td>
</tr>
<tr>
<td>Judson M. Harper, Historical developments and future trends in extrusion cooking.</td>
<td>48</td>
</tr>
<tr>
<td>Sampo Haarasilta, Future trends in extrusion-cooking Scandinavia.</td>
<td>53</td>
</tr>
</tbody>
</table>
PROGRAMME

09.00-09.10 Introduction

09.10-09.40 Process technique
The technology of extrusion-cooking from an engineering point of view

09.40-10.00 COFFEE

10.00-10.45 Product properties
Chemical modifications of starch and protein during extrusion

10.45-11.10 Influence of extrusion-cooking on the nutritive value

11.10-11.40 Functional properties of extruded products

11.40-12.00 Discussions

12.00-13.15 LUNCH

13.15-13.30 Extrusion-cooking in practice
Enzymatic hydrolysis of starch in an extruder

13.30-13.45 Extrusion of fish protein/starch mixtures

13.45-14.00 Extrusion of high-fiber cereal products

14.00-14.15 Extrusion of soy proteins

14.15-14.30

14.30-14.50 Water turn-over in carnivores fed on different processed dry diets

14.50-15.05 COFFEE

15.05-15.50 Historical developments and future trends in extrusion-cooking

15.50-16.05 Future trends in extrusion-cooking in Scandinavia

16.05-16.45 Discussion

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Lars-Göran Sjöberg, AB Semper, Sweden

Judson Harper, Colorado State University, Colorado, USA

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EFFECT OF EXTRUSION-COOKING ON THE PHYSICAL AND BIOCHEMICAL CHARACTERISTICS OF CEREALS AND STARCHY PRODUCTS

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Extrusion-cooking, a high temperature short time (HTST) process, is increasingly used to produce and to modify animal feed as well as human food. In both cases, the shape, texture, density, palatability and the energy value of the end-products are different. Extrusion must lead to a feed with a maximum metabolizable energy whereas a human food, representing only part of the total consumer daily food, does not require the same high energy value.

The various staple foods, such as pasta products, snacks, cookies, confectionary, baking and baby-instant foods, beverages... are generally prepared from cereal (maize, wheat, rice...) potato and manioc tubers and legume seeds (soya, broad bean, pea) either alone or in combination.

Therefore, in order to promote new products with nutritional value, organoleptic and functional properties equivalent or even higher than conventional food, the effect of extrusion parameters on the main nutrients of raw materials and on the characteristics of the end-products are largely studied.

Our research projects, since 1971, have contributed to develop the twin-screw french extruder Creusot-Loire for foods. Work has been carried out with a BC 45 Creusot-Loire mainly on cereals [wheat flour and corn semolina; wheat, maize (waxy, normal, amylo V, amylo VII) and rice starches] and tuber starches (potato and manioc).

Raw materials have been extruded at different barrel temperatures (50-250°C), with a moisture content before extrusion varying between 10.5 to 28.5 %.

The effect of extrusion has been studied particularly on the carbohydrate fraction and mainly on starch.

The physicochemical characteristics of the end-products are expressed as expansion, breaking strength, water absorption, water solubility and final cooked paste viscosity.
The modification of the physical structure of starch is followed by X-ray diffraction and the ultrastructure with a scanning microscope.

The modification of the chemical structure of starch is demonstrated by using an enzymic sequential method (pullulanase, β-amylase and amyloglucosidase).

The in vitro digestibility of the extruded product is measured by a Bacillus subtilis α-amylase test and compared to an in vitro artificial rumen technique and in vivo experiments on rats.

Our studies show that the physical characteristics of the end-products depend mainly upon the temperature of extrusion, the screw design, the die geometry and the moisture of raw materials (ref. 1, 4, 12, 13, 14).

The modification of the physical and chemical structure of starch granule depends upon the botanical origin, the ratio amylose/amylopectin, the addition of agents (fatty acids, monoglycerides, emulsifier, triglycerides, phosphatide, ...).

Extrusion-cooking solubilizes starch to a certain extend by destroying the organized structure of the granule. When amylose and lipids are present in the granule, as is the case with cereal starches, extrusion and solubilization are accompanied by the formation of a new structure. This structure has been observed by X-ray diffraction studies, to be similar to the V-amylose structure and to be caused by complex formation between the amylose and the lipid fraction of starch, probably as a helical form of six and/or seven glucose residues per turn. This structure does not appear on the extrusion either of potato starch, free from lipids, or of waxy- maize starch, free from amylose. Complex formation of the amylose fraction of potato starch extruded with oleic acid confirms the previous hypothesis. This amylose-lipid complex reduces the solubility and the stickiness of the end-product and increases the low temperature stability, which leads to modified starch having competitive properties with chemically modified starch (ref. 2, 4, 7, 8, 11, 14).

With a high extrusion temperature (180-200°C) the behaviour of potato starch differs from that of cereal starches. Whereas cereal starch is solubilized without any formation of maltodextrins, linear oligosaccharides have been observed on the extrusion of potato starch. The enzyme study of the oligosaccharides fraction and the residual extruded starch, by the successive actions of the debranching enzyme, pullulanase, and of β-amylase, has led to an explanation of the effect of extrusion. The amylose fraction of potato starch has been split into linear oligomers, whereas the amylpectin fraction is as in the native starch. The fact that such linear oligomers are not produced during extrusion of cereal starches under the same conditions, can be explained by the lack of availability of amylose because of its complex formation with lipids (ref. 6, 8, 14, 15).

In case of legume seeds, whereas extrusion-cooking inactivates completely the trypsin inhibitors, α-galactosides, responsible of flatulence and glucosides (vicine
and convicine) responsible of favism are still present even extruded as an high temperature as 200°C.

As far as the nutritional properties of extruded starchy products are concerned, the complexed amylase fraction has been shown to be resistant to α-amylase and could be responsible for the lower in vitro digestibility of extruded maize starch containing 52 and 61% amylase, in comparison with the digestibility of extruded waxy and normal maize starches. However, the texture of the extruded product is also involved in their digestibility. According to the extrusion temperature, the physical aspect of extruded cereal starch varies from a spaghetti-like to an expanded product, and the ability of the enzyme to degrade starch depends upon the dispersion of the product.

Observed by the in vitro artificial rumen technique, extrusion of maize starch improved the rate of ammonium utilization, which is faster and more intensive than with native starches. When the susceptibility to α-amylase of starch reaches 70 to 80%, urea utilization is at its maximum (ref. 5).

However, the in vivo digestibility, by growing rats, of extruded maize semolina, has been shown to be similar to the one of native semolina. No significant differences have been observed between the apparent digestibilities of dry matter, energy and nitrogen of the two diets. With potato starch, to the contrary, extrusion leads to the complete digestibility, as the other technological treatments (ref. 3). Therefore,

- for animal nutrition, twin-screw extrusion-cooking damages too much starch and does not improve significantly the apparent digestibilities of the diet to become competitive with the less costly treatments used for animal production (ref. 3, 5, 10). However, for pets and fish, extrusion allows to produce feed with required characteristics such as expansion and floating ability (ref. 12, 13);

- for human nutrition, twin-screw extrusion-cooking, by solubilizing starches, lead to a highly digestible product. The effect of complexation with fatty acid on cereal starch is important on the palatability of the end-product and could be responsible for a lower digestibility (ref. 9, 14). Conversely, the absence of such complexation by extruding lipid-free starch allows to prepare a linear oligosaccharides mixture without any enzymic or chemical additives, and directly available for dietetic and instant baby foods (ref. 15).

Cereal grains, being an important source of vitamins, investigations have been carried out on the retention of certain water-soluble (C, B-group) and insoluble (A) vitamins during extrusion. Retention of vitamin A varies from 50 to 90% and depends upon their source such as alcohol, acetate or palmitate vitamin A. Loss of 35% of vitamin C has been observed during extrusion of a corn / soy bean / nut mixture. Temperature, time and shear rate are important factors on the destruction of B-group vitamins.

In general, it appears that extrusion-cooking as an HTST process, results in relatively small vitamins losses (ref. 14).

1b. ACTION CONCERTEE DGST (Délegation Générale à la Recherche Scientifique et Technique, Paris) 1978. Obtention de produits alimentaires nouveaux à base de manioc, no 77-7-0432. Ed. GREBAUT J., DELGER P. and de la GUERIVIERE J.F.,

1c. ACTION CONCERTEE DGST (Délegation Générale à la Recherche Scientifique et Technique, Paris) 1979. Voies d'obtention de produits diététiques et de régime à base de céréales, no 74-7-0774. Ed. GREBAUT J., DELGER P., ALBERG M., MERCIER C. and CHARBONNIERE R.


3. VERMOREL, M. 1974. Influence du traitement d'extrusion sur la digestibilité de la semoule de maïs et de la féculle de pomme de terre sur le rat en croissance. Rapport INRA.


INFLUENCE OF EXTRUSION COOKING ON THE NUTRITIONAL VALUE *

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Summary of presentation at the Nordforsk-SIK-SNF seminar on Extrusion-Cooking, Göteborg, January 21, 1981.

High-shear cooking extruders, that are generally used for processing of human foods, have been classified as HTST (high temperature/short-time devices). The effect of HTST treatment on the nutritional value has been investigated especially regarding milk. Generally, a good retention of nutrients has been reported compared with alternative heating processes. In extrusion cooking, time-temperature conditions are comparable to other HTST processes, but some unique features are present in that the material is subjected to extremely high pressure and severe shearing forces. Furthermore, the heating is performed at intermediate water activity, implying optimal conditions for the Maillard reaction to occur.

* The investigation is financed by The National Swedish Board for Technical Development.
Since extrusion cooking is now more and more used for processing basic foods, i.e. weaning foods in developing countries, gruels, breakfast cereals and bread, a thorough documentation of its effect on the nutritional value is essential.

In cereal-based products, lysine is the limiting and also the most reactive amino acid. The very few and limited investigations performed indicate little available lysine loss during extrusion. Studies of PER (protein efficiency ratio) in rats also indicate that protein nutritional value can be well preserved in extrusion cooking.

Relatively good retention of vitamins has also been reported. Some studies, however, indicate that increased shear forces associated with higher screw speeds may be detrimental to B-vitamin retention.

Starch has been reported to become partially fragmented and solubilized and more rapidly hydrolysed by amylase in vitro. The effect of extrusion on in vivo hydrolysis and intestinal uptake of starch has not been studied so far.

Dietary fibre in extruded products has also not yet been investigated. Dietary fibre-like material might be formed if some protein or starch becomes undigestible. The prominent expansion during extrusion might also change the physiological properties of the dietary fibre.

Within a joint study organized by the Nordic Cooperative Organization for Applied Research we are investigating nutritional properties of extruded materials. Wheat starch, wheat flour and whole grain wheat flour have been studied so far. The materials are processed under strictly controlled conditions by Dr J. Olkku, Technical Research Centre of Finland (VTT), Food Research Laboratory. The equipment used is a Creusot-Loire twin screw extruder type BC 45.
The following parameters are studied:

- Gas-chromatographic assay of amino acids
- Protein nutritional value assayed with nitrogen balance technique in young rats
- In vitro starch hydrolysis with salivary amylase
- In vivo absorption of starch in young rats
- Enzymatic gravimetric assay of dietary fibre monomers
- Dietary fibre balance in young rats

In vivo protein digestibility decreased about 5% in the extruded whole grain flour but was not changed in the wheat flour. The biological value decreased 10-25% and was well correlated with lysine assayed after acid hydrolysis. In addition to mass temperature the feeding rate and screw speed seemed important for the lysine retention.

The in vitro starch hydrolysis with salivary amylase was very rapid in all extruded materials, compared with raw samples, or samples gelatinized by boiling.

In vivo intestinal uptake of starch has so far been investigated only with wheat starch. Preliminary results indicate a somewhat more rapid uptake of the extruded material, but plasma glucose and insulin responses were similar.

Enzymatic dietary fibre assay indicated an increased fraction of undigestible starch in extruded whole grain wheat flour. Gas-chromatographic assay verified an increased content of glucose-based fibre. Dietary fibre balance in rats showed that the undigestible starch was degraded completely by intestinal bacteria.
SENSORY PROPERTIES OF EXTRUDED FOODS

Yngve Andersson
SIK - The Swedish Food Institute

When food materials are processed in a cooker-extruder they are subjected to high temperatures and pressures combined with action of shearing forces. As a result of this treatment the material undergoes chemical and physical modifications. For instance, the chemical composition can be changed by gelatinization and break-down of starch, denaturation of proteins and complex formation between carbohydrates and protein. Besides, a structure formation is achieved. Of course, such changes also will influence the appearance, the taste, and the texture of the extruded products.

The desired sensory characteristics of extruded foods are related to how they are intended to be used. In snacks, "biscuits" and "crispbreads" - where the extruded material constitute a complete food item - the sensory properties are extremely important for the consumer acceptance. In fact, in the advertisements the manufacturers in many cases stress that the consumers when trying their products get a specific taste, texture, or "sensation".

For extruded materials that are intended to be mixed with other components it is the sensory characteristics of the complete food that are most important. Examples are extruded carbohydrate-rich semi-manufactured products for gruels, porridges, beverages, and textured vegetable proteins.

I will take textured soy proteins as an example. They can increase the chewability of meat patties, which can be considered as positive. On the other hand if too much is incorporated in a recipe the typically "beany" soy flavour occurs, which is negatively. The incorporation level must be optimized with consideration to the sensory properties.

The sensory properties of extruded products can be influenced in the following ways:
1. By selection of raw materials.
2. By changing the processing conditions
3. By treatment of the extruded food by i.e. drying, frying etc.

It is obvious that the selection of raw materials is very important for the sensory properties of the extruded product. We will later during this day hear about how combinations of fish proteins and cereal fibers, respectively, and starchy-rich materials will behave during extrusion. Also, different properties noticed in different varieties of the same raw material influence the product. The different behaviours during extrusion of maize with high content of amylopectin ("waxy" maize) and maize with a low content of amylopectin and a high content of amyllose are well known. The waxy maize promotes puffing and give an extremely light, fragile product. Therefore the relation between amyllose and amylopectin can be used to control the texture of the extruded product.

Another example of the possibility of regulating the texture is incorporation of gluten. Inclusion of gluten into vegetable proteins can yield tougher, chewier products if the gluten is prepared from hard wheat, while the use of gluten from soft wheat yields more tender, friable products.

Important process parameters for the sensory properties are i.e. water addition, retention time (which can be influenced by feed speed, screw speed, screw configuration, die size etc.), extrusion temperature and pressure.

In a study performed at SIK - The Swedish Food Institute we found that when extruding a fiberrich cereal material into a crispbread-like product the extrusion temperature decreased when the amount of added water increased. The effects on the product were that the structure became more open, the bitter and burnt tastes decreased, and the product became harder.

An after-treatment of the extruded material can also influence the properties. For instance, a too high addition level of water may give products that are tough and sticky. A drying step immediately after extrusion can change the texture so it becomes more crispy and friable. Often flavours are added after extrusion, for instance by spraying a
flavour solution on the surface. This procedure is often used for spices. Another way to add flavours is to mix temperature stable flavours into the raw material mix.

When preparing this speech I looked through the literature on extrusion cooking. Then I found out that very little information has been published regarding the relationship between raw materials, processing conditions, and sensory properties of the extruded material. I certainly believe that much work could and should be done in order to get knowledge of how the processing in an extruder influence the sensory properties.
High amylopectin → Higher expansion
Low amylose → Light, fragile products

Low amylopectin → Lower expansion
High amylose → Denser product

Gluten from hard wheat → Tougher, chewier products
Gluten from soft wheat → More tender, friable products

"Crispbread product"

Added water

Extrusion temperature

Sensory properties

More open structure
Decrease in bitter and burnt taste
Increase in hardness
ENZYMATIC HYDROLYSIS OF STARCH IN AN EXTRUDER

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HTST-extruder as an enzyme reactor

Linko et al. (1978) first demonstrated that significant residual α-amylase activities may be observed after extrusion cooking of cereal grain. Other active enzymes such as lipases and proteases have later been shown in extrudates. Short residence time owing to high feed rate and large die diameter, high feed moisture, and low mass temperature resulted in highest enzyme activity retention (Linko et al., 1980a,b). Figure 1 illustrates typical effects of moisture on residual diastatic activity and DE-value of barley starch extruded with added Termamyl 60L α-amylase. Optimum starch conversions were normally obtained at moisture levels >45%, at about 120°C. Using a compression screw with a Creusot-Loire BC-45 twin screw extruder, nearly no α-amylase inactivation took place at <130°C, die φ 4 mm, screw speed 100-150 min⁻¹, feed rate 175 g(d.s.) min⁻¹, moisture 45-50%. An increase in mass temperature resulted in a rapid enzyme inactivation.

Pretreatment of starch and cellulose

HTST-extrusion cooking may also be employed to pretreat starch or cellulose for subsequent enzymatic hydrolysis. Linko et al. (1979) extruded barley starch with Creusot-Loire BC-45 twin screw extruder at 150°C, screw speed 150 min⁻¹, feed rate 175 g(d.s.) min⁻¹, 25% moisture. At product DE-value of ~2, the degree of starch gelatinization was sufficient to reach a DE-value of ~98 in 10 h on subsequent hydrolysis with glucoamylase (60°C, pH 4.5), as compared with a DE of ~89 in 72 h without extrusion.
Brenner and coworkers (Anon., 1979) have demonstrated with a modified Werner & Pfleiderer ZDSK-53 twin screw extruder that the combining of thermomechanical treatment and mild acid hydrolysis of cellulose under pressure may result in about 60% conversion to glucose in one single operation. Our preliminary work has also shown the potentiality of HTST-extrusion processing as cellulose pretreatment for subsequent enzymatic hydrolysis.

![Graph](image)

**Figure 1.** Effect of moisture on residual diastatic activity (◦), and DE-value (●) (Creusot-Loire BC-45 with reverse screw element, barley starch with Termamyhl 60L α-amylase, die φ 5 mm, screw speed 150 min⁻¹, feed rate 154-175 g(d.s.) min⁻¹, Tbarrel 130°C, Tmass ~120°C).

**References**


Extrusion of Fish/Starch Mixtures

JTI's foodstuffs division has worked with extrusion of foodstuffs since 1972. The first two or three years we only worked with directly expanded starch products of the type corn curls. Since then we have worked a great deal on texturing of proteins. Primarily soya proteins, but also whey proteins. Finally during the last two or three years we have worked on third generation macks. At our disposal we have a Brabender Laboratory Extruder, type 20 DN.

Internationally Denmark is a great fishing nation. Every year we land about 2 million ton of fish. 20% of this amount is used for human consumption. The rest is used for feeding stuff, or goes to the fishmeal factories. As we want to use a greater part of the fish for foodstuffs, we have worked on extrusion of mixtures of fish and starch.

The amount of fish in the mixture is limited by the ability of the extruder to work with doughy substances. We have used up to 40% fish with a water content of about 80%. With a water content of that size it is impossible to produce directly expanded products.

The product is solid and almost limpid. After drying to below about 10% water the extruded strings are cut or broken into appropriate pieces called pellets. Pellets can be expanded e.g. in connection with deep-fat-frying.

The product can also be used in the production of spaghetti or noodles, and can be shaped according to the way you want to prepare them.

The keeping qualities of the pellets depend on how well the fish has been incorporated into the material. Especially when fat fish is used this is of great importance.

We have tried to use herrings, mackerels, sprats and cod in mixtures containing one or more starch products, e.g. potato flour, mashed potato powder, maize flour, corn starch, waxy maize transversely built, and wheat starch.

The appearance and the puff properties of the pellets depend on the degree of gelatinization, which again depends on the mechanical processing of the starch in the extruder.

If there is too much fish (water) in the raw article mixture the friction in the extruder will be to low, and the gelatinization will be bad. The same will happen if the fat amount is too high. Our experiments with addition of different emulsifiers to obtain a better "encapsulation" of fat in the starch substance has until now not been as successfull as we have hoped.
By not using emulsifiers, by not using too much fish, especially fat fish, by using a small nozzle, and/or by using a worm with appropriate compression an appropriate pressure can be obtained in the extruder. This means that the torque will be greater, and that the product will be worked in a better way.

Our best products until now we have obtained with a mixture of 31% cod mince, 33% wheat starch, 33% potato flour, and 3% salt - with a feeding regulation of 50, with 80 revolutions of the worm per minute, and with temperatures of 75°C, 140°C and 94°C in the 1st and 2nd zones and the nozzle of the extruder. The dimensions of the nozzle: 20 x 0.35 mm, and the compression of the worm: 1:2.

The work described here is a project paid by the "Teknologi Styrelsen". The work will continue by addition of bigger amounts of fish, and we will try to improve the keeping qualities of the pellets, especially those containing fat fish.
EXTRUSION OF HIGH FIBER CEREAL PRODUCTS

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Introduction

From a nutritional point of view it is of interest to increase the dietary fiber content in the diet. Several high fiber products have therefore been introduced, such as different types of crispbread varieties. Lately several companies have developed processes based on extrusion cooking for the production of crispbread.

The purpose of this investigation was to determine the influence of formula (different wheat bran, starch, and gluten levels) and processing conditions on chemical, physical, and sensory properties of an extruded product similar to a Swedish type of crispbread.

Materials and methods

The composition of the four formulas used is shown in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Composition of the formulas used for extrusion of crispbread like products.</th>
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</thead>
<tbody>
<tr>
<td>Formula</td>
<td>Ingredient % (w/w)</td>
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<td>I</td>
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Extrusion was carried out in a Creusot-Loire BC 45 extruder. Feed rate of the material was 400 g/min. and two screw speeds, 150 and 200 rpm, were chosen. Water was added at the levels; 25, 54 and 78 ml/kg.

The following analysis were performed: moisture, nitrogen, monosaccharides, disaccharides, starch, dietary fiber, and phytate content. The density and sensory characteristics of the extruded products were determined.

Results

The product density varied from 85 to 650 g/dm³. Highly expanded products with low density were obtained with high-starch/low-bran-mixtures. Shifting the screw speed from 200 to 150 rpm caused an increase in density.

A product similar to Swedish crispbread in structure, texture, and taste was obtained when extruding formula II with a water addition of 78 ml/kg. The amount of dietary fiber in this product was calculated as 20.4%, which is about 75% more than the most fiber rich crispbread varieties contain. A further increase in bran content resulted in extruded products with thin-bread character.

The water content of the extruded products was 6 - 7%, quite similar to Swedish crispbread.

During extrusion, the sugar content (glucose, fructose, and sucrose) was reduced by about 80%. In products without gluten in the formula the glucose and fructose content were higher than when gluten was included, indicating a sugar degradation reaction of the Maillard type.

Fibers rich in phytic acid interfere with the absorption of minerals. In this investigation the phytate content was closely related to the amount of bran in the formulas. The reduction in phytate during extrusion was found to be between 13 and 35%. 
Conclusions

Extrusion cooking is a suitable process for making bread-like products with high fiber content which after cutting are ready for packaging and distribution.
### CHEMICAL COMPOSITION OF INGREDIENT MIXTURES

<table>
<thead>
<tr>
<th>Formula</th>
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<td>%</td>
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### EXTRUSION TEMPERATURE AND PRESSURE

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<th>Extrusion conditions</th>
<th>Temperature</th>
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<tbody>
<tr>
<td></td>
<td>added water ml/kg</td>
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<th>Extrusion conditions</th>
<th>Temperature</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>added water ml/kg</td>
<td>screw speed rpm</td>
<td>%</td>
</tr>
<tr>
<td>II</td>
<td>25</td>
<td>150</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>155</td>
<td>6</td>
</tr>
<tr>
<td>54</td>
<td>150</td>
<td>150</td>
<td>10</td>
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<td>7</td>
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<td>78</td>
<td>150</td>
<td>144</td>
<td>10</td>
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<td></td>
<td>200</td>
<td>142</td>
<td>8</td>
</tr>
<tr>
<td>Variation</td>
<td>Appearance</td>
<td>Taste</td>
<td>Texture</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------</td>
<td>--------------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Increasing starch/decreasing fiber</td>
<td>More open structure</td>
<td>Increase in bitter taste</td>
<td>Decrease in hardness</td>
</tr>
<tr>
<td></td>
<td>Larger cells</td>
<td></td>
<td>Increase in gluness</td>
</tr>
<tr>
<td></td>
<td>Lighter brown color</td>
<td>Decrease in cereal-like taste</td>
<td>The material falls apart</td>
</tr>
<tr>
<td>Increasing screw speed</td>
<td>No difference</td>
<td>Increase in burnt taste</td>
<td>No difference in hardness and gluness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decrease in cereal-like taste</td>
<td></td>
</tr>
<tr>
<td>Increasing water addition</td>
<td>More open structure</td>
<td>Decrease in bitter and burnt taste</td>
<td>Increase in hardness</td>
</tr>
<tr>
<td></td>
<td>More like Swedish crispbread</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusion of gluten</td>
<td>More open structure</td>
<td>No difference</td>
<td>Some decrease in hardness</td>
</tr>
<tr>
<td></td>
<td>Lighter brown color</td>
<td></td>
<td>Some increase in gluness</td>
</tr>
</tbody>
</table>
WATER TURNOVER IN CATS FED DIFFERENTLY PROCESSED DRY DIETS.

Hans Jungvid, Bo Hallgren and Lars-Börje Sjöberg
Food and feed consultant Veddiee Sweden, The Swedish Nutrition Foundation and Semper AB Sweden.

Summary
Controlled test data from 30 adult male cats (6 different experiments) fed a variety of diets, indicate substantial variation in water turnover dependent on the type of diet. Only dry diets, either HTST-extruded or produced by a new method (low-temperature no-mechanical pressure), were fed. All extruded diets were found to give an elevated water binding capacity (WBC). The extruded diets resulted in low water intake, watery stools and a low urine production. Mineral balance from one typical experiment is discussed. Detrimental effects of a low urine production are demonstrated.

Introduction
For almost one decade concern has been expressed about dry cat-food and a disease called Feline Urological Syndrome (F.U.S.). This syndrome covers a very wide range of clinical signs table 1. The most severe complication in the male cat is acute urethral obstruction (Rich and Kirk 1968, Gaskell et al 1978). Numerous causes or contributing factors have been proposed for F.U.S. (Catcott 1975). These include vitamin A deficiency, crystaluria, heredity, bacterial infection, viral infection, unique urinary protein that may act as a matrix, dry cat-food, high ash diet, stress, decreased water intake, alkaline urine, lack of protective urinary colloids, castration, high magnesium - low calcium diets, bladder trauma,
limited exercise, mineral content of water and hyperparathyroidism table 2. In this study we have chosen to evaluate the effect of dry cat foods, produced by two different processes, on the water turnover in cats. A change in the water turnover may affect the patterns of water excretion and be a precipitating factor for F.U.S.

Experimental outline
All experiments were divided into two phases; the pre-experimental and the experimental period. In each experiment 4-7 adult male cats were individually housed in metabolic cages, kept in thermostatic rooms at 20 ± 2°C. The device allowed a separate collection of urine and feces. After a 4 week pre-experimental period, the test diet was gradually introduced following the procedure in table 3. All feed was given in the morning and in a dry form, immediately after careful cleaning of the cages. Water was given ad. libitum. During both the pre-experimental and experimental period daily feed and water consumption was determined. Urine excretion and water lossed by feces were also measured daily, as well as changes in bodyweight. Fecal consistency and presence of blood, in both feces and urine, were daily checked. Fresh samples of urine were analysed for presence of sediment (eg struvites or other crystals, epithelial cells, casts, blood etc).

Materials and methods
4-7 cats, 8-10 months old, weighing approximately 3.5 kg were obtained from the breeding farm run by the University of Gothenburg, or from breeders controlled by the University. Prior to transfer to the laboratory (Astra Nutrition AB Mölndal, Sweden), all cats were vaccinated against feline distemper. After arrival to the laboratory all cats were dewormed twice. Cats from the breeding farm had been brought up on an experimental dry diet produced by Astra Nutrition AB, using low temperature and no mechanical pressure (Swedish patent no 7503977-6), in the following called LTNP-diet. Cats from controlled breeders had been
brought up on a commercial fresh mink diet, produced by Svenljunga Mink AB Svenljunga, Sweden. All test diets were extruded, E and F by HTST (High-temperature-short-time) devices (Wenger single-screw extruder), also classified (by Smith 1967, 1969) as High-shear cooking extruders. Immediate moisture before processing 20-25%.

Ingredients in the diets A, B, C and F; corn, barley, soybean meal, alfalfa, wheatgerm, lard, fishmeal, meatmeal, skim milk powder, yeast, minerals and vitamins. D; wheat, corn, poultry meal, soybean meal, meatmeal, fishmeal, salt and yeast (according to package). E; Cereal grain, soybean meal, corn gluten meal, fat, skim milk powder, minerals and vitamins (according to package). In the diets A, B, C, E and F fat was mixed into the recipes before processing.

Final drying was performed by using hot air (max 80°C). Urine analysis; only absolute fresh urine samples were analysed. Spec. gravity was determined by a refractometer. pH by using pH-strips (Merck) or a pH-meter. Presence of protein, ketone bodies and blood was checked by using Labstix (Ames). Analysis of sediment such as crystals, epithelial cells, blood and fat etc was performed according to the following procedure; 12 mls of urine was poured into a conical centrifuge tube and centrifugated at 200-300 g, 1000 rpm for 5 minutes. For detection of lipids floating on the top of the centrifugated urine, a visual control was made. The resulting sediment was stained with Sedistain® (Clay-Adams) and examined in a microscope. The absence or presence of crystals, epithelial cells, casts, blood and fat was visually estimated and scored as follows; absence (-), presence in increasing amounts (+), (++), (+++), (++++)..

Proximate analysis of the dry diets; was performed using the following procedures.

Protein (Nx6.25), ash and water by AOAC methods.

Fat, by chloroform-methanol extraction.

Phosphorus, by a colorimetric method according to AOAC.

Sodium, potassium and calcium, by flame photometry according to AOAC.

Water binding capacity (WBC), 1 g of feed is weighed into a stoppered test tube. The fat is removed by
addition of 10 mls of acetone. The tube is shaken for 1 minute and centrifuged for 5 minutes. The acetone is decanted and the feed dried in a stream of air. 4 g of water is then added and the tube is shaken for 1 minute. After 1 hour, centrifugation for 5 minutes at 2000 rpm. The excess water is decanted and carefully weighed. Calculation: 4.00 - weight of decanted water = g water bound/g feed.

Results and discussion
Proximate analyses of the diets are shown in table 4. All LTNP-diets are higher in protein and fat, especially compared with the extruded diet D, and consequently the amount of carbohydrates is lower in these diets. The only difference between LTNP-diet C and the extruded diet F, is in the way the two products are manufactured. Obviously extruding results in an increased WBC. The ash content is very high in the LTNP-diets, compared with most extruded diets. This is of particular interest when it come to discussions concerning mineral excretion and prevention of struvites in urine. Commercial cat-food vary greatly in their mineral content (Chow et al 1975, Feldmann et al 1977), and it has been said that some contain mineral levels which, if fed over a long period, may result in an increased occurrence of sediment in urine and obstructed male cats (Chow et al 1976, Lewis et al 1978). This is probably true, even if we can not see this effect after feeding any LTNP-diet table 5 and 6. From diagram 1 it can be seen that cats on LTNP-diets drink more water than cats on different extruded diets do. All results are given as the mean value per day and kg cat on the experiment. Water requirement per kg bodyweight and day, as found in literature (Kaneko 1963, Scott 1971, 1975) varies somewhat; 57.1-76.9 ml mainly due to age (older cats show the lowest value). The sodium content is almost the same in all diets. Table 7 shows the ratio of consumed fluid and feed, and confirm the decreased water intake. Next diagram 2 shows the urine volume. Average daily urine volume in cats on LTNP-diets is approximately
40 ml per kg bodyweight and day, a figure quite close to literature data (Kaneko 1963). Diagram 3 shows different urine parameters during the experiment with LTNP-diet C and the extruded diet F. The extruded diet resulted in a decreased water intake and a lower urine volume, which in turn led to a more concentrated urine. The individual differences in fecal moisture, in these two experiments, are demonstrated in table 8. Table 9 and 10 confirm that the extruded diet, though a very careful introduction to the animals, resulted in intestinal disorder and a negative potassium balance. In diagram 4 water in urine, feces and retained water, expressed as percent of water intake, are summarized. Generally, cats on LTNP-diets excrete more water through the kidneys, and less water through the feces compared to cats on extruded diets. It is surprising that the percentage of water measured as retained water (by diff.), should be so varied but it might be an effect of hyperventilation. Another way of comparing the effect of diet to water intake and urine excretion is demonstrated in diagram 5. This diagram illustrates the ratio of excreted urine to feed consumed.

Based on this work, and work done by (Jackson and Tovey 1977), our conclusion is that cats on extruded diets drink less water and excrete much less urine per unit of consumed feed than cats on LTNP-diets do.
References

Catcott et al (1975) International symposium on oilseed proteins and concentrates, CFTRI, Mysore India.
Jackson and Tovey (1977)
Table 1. The definition of F.U.S.

F.U.S. stands for the Feline Urological Syndrome, this covers a very wide range of clinical signs;

2. Cystitis – inflammation of the bladder.
3. Urethritis – which means inflammation of the urethra.

These are minor troubles and all problem has been about;

4. Acute urethral obstruction, due to either;
   sabulous plug or
   matrix plug or
   micro-calculi.

The main crystal form, in the first and last of these plugs, has been well documented as being due to struvite crystals ($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$).
Table 2. Proposed causes or contributing factors for F.U.S.

Vitamin A deficiency,
Crystalluria,
Heredity,
Bacterial infection,
Viral infection,
Unique urinary protein that may act as a matrix,
Dry cat-feed,
High ash-diets,
Stress,
Decreased water intake,
Alkaline urine,
Lack of protective urinary colloids,
Castration,
High-magnesium low-calcium diet,
Bladder trauma,
Limited exercise,
Water mineral content and
Hyperparathyroidism.
### Table 3. Feeding outline

<table>
<thead>
<tr>
<th>Weeks</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>Test-</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
<th>8th</th>
<th>9th</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **100% LTNP-diet or**
- **100% Commercial mink diet**
- Plus water ad. lib

<table>
<thead>
<tr>
<th>Percentages</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
</table>

- **A gradual introduction of the test diet**

**PRE-EXPERIMENTAL PERIOD**

**EXPERIMENTAL PERIOD**
### Table 4. Proximate analysis of the diets

<table>
<thead>
<tr>
<th></th>
<th>LTNP-diets</th>
<th>Extruded diets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Protein</td>
<td>39.3</td>
<td>46.1</td>
</tr>
<tr>
<td>Fat</td>
<td>9.9</td>
<td>11.0</td>
</tr>
<tr>
<td>NFE (by diff)</td>
<td>36.7</td>
<td>25.4</td>
</tr>
<tr>
<td>Ash</td>
<td>9.2</td>
<td>12.5</td>
</tr>
<tr>
<td>Water</td>
<td>4.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Ca</td>
<td>1.90</td>
<td>2.80</td>
</tr>
<tr>
<td>P</td>
<td>1.50</td>
<td>1.90</td>
</tr>
<tr>
<td>Mg</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Na</td>
<td>0.52</td>
<td>0.82</td>
</tr>
<tr>
<td>K</td>
<td>0.32</td>
<td>0.88</td>
</tr>
<tr>
<td>WBC</td>
<td>1.60</td>
<td>1.54</td>
</tr>
</tbody>
</table>

Diet C and P based on the same formula.
Diet D, a commercial diet.
Diet E, the American grain mixture extruded in Sweden.
Table 5.
Presence or absence of struvites, fat, ketonbodies, blood, epithelial cells and casts in urine during the pre-experimental period.

<table>
<thead>
<tr>
<th>Cat</th>
<th>4-7</th>
<th>4-8</th>
<th>4-9</th>
<th>4-10</th>
<th>4-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Struvites</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Fat</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ketonbodies</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Epith. cells</td>
<td>+</td>
<td>+</td>
<td>(+)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Blood</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Casts</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Day</td>
<td>8/4</td>
<td>17/4</td>
<td>19/4</td>
<td>4/4</td>
<td>9/4</td>
</tr>
</tbody>
</table>
Table 6.
Presence or absence of struvites, fat, ketonbodies, blood, epithelial cells and casts in urine during the experimental period

<table>
<thead>
<tr>
<th></th>
<th>Cat</th>
<th>4-7</th>
<th>4-8</th>
<th>4-9</th>
<th>4-10</th>
<th>4-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Struvites</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Fat</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ketone bodies</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Epith. cells</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Blood</td>
<td>+1</td>
<td>-</td>
<td>-</td>
<td>+2</td>
<td>-</td>
<td>+1</td>
</tr>
<tr>
<td>White blood cells</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Red blood cells</td>
<td>+2</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Mucus</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Casts</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Day</td>
<td>20/5</td>
<td>24/5</td>
<td>30/5</td>
<td>4/6</td>
<td>5/6</td>
<td>9/5</td>
</tr>
</tbody>
</table>

1) WBC, Microscopic observation.
2) RBC, Checked by Labstix and confirmed either visually or microscopically.
Table 7. The ratio of consumed fluid and feed

<table>
<thead>
<tr>
<th></th>
<th>LTNP-diets</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Fluid intake</td>
<td>71.4</td>
<td>75.5</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td>= 3.05</td>
<td>= 3.04</td>
<td>= 3.13</td>
</tr>
<tr>
<td>Feed intake</td>
<td>23.4</td>
<td>24.8</td>
<td>22.0</td>
</tr>
</tbody>
</table>

|                | Extruded diets    |           |           |
|                | D                 | E         | F         |
| Fluid intake   | 44.4              | 47.0      | 58.3      |
|                | = 2.44            | = 2.39    | = 2.72    |
| Feed intake    | 18.2              | 19.7      | 21.4      |

1) ml/kg cat and day
2) g ts/kg cat and day
Table 8. Percent dry matter in feces of cats given a LTNP and an extruded diet (same formula).

<table>
<thead>
<tr>
<th>Cat No</th>
<th>LTNP-diet</th>
<th>Extruded-diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-1</td>
<td>34.8</td>
<td>27.7</td>
</tr>
<tr>
<td>5-2</td>
<td>40.4</td>
<td>32.1</td>
</tr>
<tr>
<td>5-3</td>
<td>40.7</td>
<td>33.5</td>
</tr>
<tr>
<td>5-4</td>
<td>34.5</td>
<td>32.4</td>
</tr>
<tr>
<td>5-5</td>
<td>46.4</td>
<td>32.3</td>
</tr>
<tr>
<td>Mean value</td>
<td>39.4</td>
<td>31.6</td>
</tr>
</tbody>
</table>

Table 9. Mineral balance in cats fed LTNP-diet C

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>% of intake</th>
<th>K</th>
<th>% of intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake by feed</td>
<td>1.23 g</td>
<td></td>
<td>1.58 g</td>
<td></td>
</tr>
<tr>
<td>Excretion by urine</td>
<td>0.94</td>
<td>76</td>
<td>1.52</td>
<td>96</td>
</tr>
<tr>
<td>Excretion by feces</td>
<td>0.12</td>
<td>10</td>
<td>0.08</td>
<td>5</td>
</tr>
<tr>
<td>Balance</td>
<td>+0.17 g</td>
<td>86</td>
<td>-0.02 g</td>
<td>101</td>
</tr>
</tbody>
</table>

Mean-values n=5

Table 10. Mineral balance in cats fed extruded diet F

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>% of intake</th>
<th>K</th>
<th>% of intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake by feed</td>
<td>1.43 g</td>
<td></td>
<td>1.84 g</td>
<td></td>
</tr>
<tr>
<td>Excretion by urine</td>
<td>1.19</td>
<td>83</td>
<td>1.95</td>
<td>106</td>
</tr>
<tr>
<td>Excretion by feces</td>
<td>0.17</td>
<td>12</td>
<td>0.16</td>
<td>9</td>
</tr>
<tr>
<td>Balance</td>
<td>+0.07 g</td>
<td>95</td>
<td>-0.27 g</td>
<td>115</td>
</tr>
</tbody>
</table>

Mean values n=5
Diagram 1. Water consumption in cats on different dry diets expressed as ml per kg cat and day.

Diet C and F based on the same formula.
Diagram 2. Urine volume in cats on different dry diets expressed as ml per kg cat and day.

Diet C and F based on the same formula.
Diagram 3. Different urine parameters during an experiment with LTNP-diet C and extruded diet F. (Green bar = LTNP-diet C).
Diagram 4. Water in urine (green bar), feces (yellow bar) and retained water (red bar) expressed as percent of water intake in cats on different dry diets.

<table>
<thead>
<tr>
<th>Diet</th>
<th>LTNP-diet</th>
<th>Extruded</th>
<th>Extruded</th>
<th>Extruded</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>15</td>
<td>23</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>D</td>
<td>27</td>
<td>31</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>E</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WBC 1.51 2.78 2.33 2.15

Diet C and F based on the same formula.
Diagram 5. The ratio excreted urine (ml) to consumed feed (g).

<table>
<thead>
<tr>
<th>Diet</th>
<th>Urine</th>
<th>Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>38.2</td>
<td>23.4</td>
</tr>
<tr>
<td>B</td>
<td>45.8</td>
<td>24.8</td>
</tr>
<tr>
<td>C</td>
<td>42.9</td>
<td>22.0</td>
</tr>
<tr>
<td>D</td>
<td>18.7</td>
<td>18.2</td>
</tr>
<tr>
<td>E</td>
<td>15.6</td>
<td>19.7</td>
</tr>
<tr>
<td>F</td>
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Diet C and F based on the same formula.
HISTORICAL DEVELOPMENTS AND FUTURE TRENDS
IN EXTRUSION COOKING

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HISTORY

Extrusion cooking is a relatively new development in modern food processing technology. Its history dates back to the first application of a single screw extruder used as a food chopper or meat mincer. This screw device forces soft meat products through a die plate to create a chopped meat product for the manufacture of sausages.

The second application of the extruder was the development of continuous macaroni processing equipment. Buhler designed and manufactured a single screw extruder to be used as a continuous pasta press in 1936. The pasta press mixes and kneads semolina flour/water dough and forces it through a die to create a variety of pasta shapes. Strictly speaking, the pasta extruder is not a cooking extruder in that the kneading/forming operation is done under low moisture conditions.

Next, the extruder was applied to the manufacture of ready-to-eat expanded breakfast cereals. This development had its beginnings in the late 1930's when General Mills, Inc. used a short variable pitched screw to further heat and work a precooked cereal dough to manufacture special shaped cereal pellets which were subsequently puffed and/or flaked. Strictly speaking, this application did not involve a cooking extruder even though it did heat the finished product while shaping.
Also in the late 1930's, the first cooking extruder application was developed. The Adams Corporation in the United States developed the first expanded corn (maize) collet or curl in 1936. This development involved the design, construction and application of the high shear collet extruder. The extruder takes raw corn grits, heats and cooks them, and produces a highly expanded cereal collet. Collet extruders are especially designed for expanding grits and so have little product flexibility.

The need to precook animal feed to improve its digestibility led to the expansion of cooking extruder applications to the field starting in the late 1940's. Original extruder designs were modifications of oil expellers or screw presses. Barrel jackets, preconditioning equipment and variable screws/barrels increased this equipment's flexibility to handle a wide range of moisture contents, ingredients, and cooking temperatures necessary for numerous food products.

Applications for cooking extruders increased with the development of dry expanded extrusion cooked pet foods, in the early 1950's, precooking of starch and the production of expanded and shaped RTE breakfast cereal manufactured by a single step process.

Three industrial laboratories performed fundamental research in the extrusion texturization of defatted vegetable protein starting in about 1960. These products were first commercialized as TPP (Texturized Plant Protein) in about 1969 and used the extruder to cross link and texturize principally defatted soy protein.

In the mid 1960's, research laboratories of the USDA undertook studies to apply the cooking extruder to the manufacture of nutritious, proteinaceous food products. This work centered on the extrusion of
whole soybeans and the denaturation of their anti-nutritional factors as well as on compounding of blended foods made from extrusion precooked cereal and defatted soy ingredients. These products have been distributed around the world and currently are produced under the name of corn soy milk, wheat soy milk, etc.

In the late 1960's, the pet food industry took another significant step in the application of cooking extruders. This step involved the production of semi-moist pet foods. These pet foods had their water activities reduced by the addition of sugars, propylene glycol, sorbitol, acids, etc. at moistures in excess of 30%. In this application, the extruder was used to cook and form the entire mass, creating a shelf stable high moisture product.

**EXTRUDED PRODUCTS**

There is a large variety of extrusion cooked food products. These include precooked and modified starches, ready-to-eat-cereals, snack foods, breading substitutes, beverage bases, soft-moist and dry pet foods, TPP, full-fat soy flour, soup and gravy bases, and confections. From this basic list, the variety is further expanded by relatively simple changes in flavoring and shape.

**FUTURE TRENDS**

A number of research items and developments will be addressed in the next decade which will further expand the applications of the cooking extruder to the food industry. These are:

1. **Ingredients:** Work undertaken to better understand the role and functionality of different types of ingredients. Specifically, this focuses on natural proteins as well as isolates and starches and modified
starches, for they serve as the principle ingredients in expanded and/or textured extruded products. Once the role of these ingredients and their interactions during the extrusion process is understood, improved and/or tailored foods can be made.

2. Additives: It is known that additives such as emulsifiers, fats, acids, humectates, etc. can have a substantial impact on finished extruded products. A model should be developed which describes the action of these additives on the extrusion and the finished product.

3. Fundamentals of Cooking: Cooking is used to describe the phenomena involving gelatinization of starch, denaturation of protein, and the chemical interaction of food ingredients. These are poorly understood, particularly in the low moisture high shear environment that exists within the cooking extruder. Models which describe the cooking reactions can lead towards the optimization of cooking extruders will be developed and further enhance product development and/or improve extruder productivity.

4. Modeling: To date, some effort has been made to model the activities or actions within the cooking extruder. They have been successful in describing the flow of food materials through an extruder and relating the residence time, flow rate and energy requirements to the extrusion process. Continued emphasis should be placed on this area so that simulations of the extrusion process can be made to improve control techniques and extruder designs.

5. Increasing Capacity and Reducing Energy: In the coming decade, further emphasis should be made on developing extrusion systems which have lower capital cost and require less energy or have improved energy efficiencies. The necessities of our time are demanding these types of developments on new and improved types of extrusion equipment, further
application of twin screw extruders, and the design of modified extrusion processes.

6. Co-extrusion: Increased novelty and extension of extruded products will be required for new product types. One area which should receive considerable attention is the development of improved co-extruded products. In this process, two ingredients are extruded simultaneously to produce products having interesting texture and visual characteristics.
FUTURE TRENDS IN EXTRUSION COOKING IN SCANDINAVIA

Samps Haarasila

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Ladies and Gentlemen,

The subject for my discourse, Future Trends in Extrusion Cooking in Scandinavia, does not allow a very objective treatment. Therefore it is essential that you, my hearers, know the point of view from which I am looking at it. For this purpose I shall in a few words attempt to describe the firm I am working for.

The abbreviation SOK comes from Suomen Osuuskauppojen Keskuskunta which means the Finnish Co-operative Wholesale Society. SOK is one of the biggest wholesalers in Finland. Besides the wholesale sector SOK also has an industrial sector. One branch of the SOK industry is SOK's Grain Processing Industry. My responsibility is with the Research and Development Department of this branch. Our branch includes wheat, rye and oat mills, a crisp-bread factory, a macaroni factory and several bakeries in different parts of Finland. Since last autumn we have had a cooking extrusion line. The central unit of this line is the Creusot-Loire BC-92 extruder. The first and only product we have launched from this line is the Cracottes wheat cracker. Several other products are planned to be launched during coming months and years.

In my discourse I shall consider only the situations in Sweden, Norway and Finland.

The first signs of an interest in cooking extrusion technology in Scandinavia could be observed at the end of the 60's and as early as at the beginning of the 70's several firms in Sweden invested in this technology. The equipments purchased were in most cases Wenger's machines. The extruders were used for production of both foodstuffs and feeds. As human nutrition e.g. expanded and shaped cereals and snacks were produced. An extruded mix of urea and
grain was produced for cattle. Also food for pets was produced by cooking extruders.

There is in Sweden a total of about 5-10 Wenger’s extruders, and some Anderson-Ibex and some Sprout-Waldron machines. After the first wave of interest new investments in extruders were not made. During the last years interest in cooking extrusion has increase again. There are two reasons for this. First: A new area of application for this technology has been found. Let me mention the cracker-type of bread, for the production of which there are or very soon will be 20-30 extruders in Europe. Second: The versatility of cooking extruders has been increased. Machines that make extrusion with a wider range of initial product moistures and product ingredients possible are available. Naturally the wearing of old machines increases the interest in the acquisition of new machines at present.

In Finland interest in cooking extrusion arose a few years later than in Sweden. Now, at the beginning of the 80’s the situation here is about the same as it was in Sweden some 5-8 years ago. Several companies have invested more or less heavily in the cooking extrusion process. There are in Finland 5 or 6 cooking extruders of industrial size planned to produce foodstuffs. There are also some machines for the production of pet foods and pregelatinised grain for feeding fur animals and 3 or 4 pilot plant machines. Most of the pilot plant machines and the machines for production of foodstuffs are from Creusot-Loire.

In Norway the interest in cooking extrusion has been less than in Sweden and Finland. Some small extruders are used by snack producers. In the fish food processing industry an Anderson-Ibex machine has been used. In addition to these extruders there is in Norway also a BC-72 extruder from Creusot-Loire.

By the cooking extrusion technique at least the following commercial products have been produced in Scandinavia:

1) Crackers
2) Breakfast cereals
3) Snacks
4) Pregelatinised flours
5) Pet foods
6) Animal feeds

The most interesting product in the future expressly in Scandinavia is the cracker bread made by the cooking extrusion method. Crisp bread, sour crisp bread (Finn crisp) and different kinds of flat bread are consumed in quite great quantities in Scandinavia. Moreover, consumption of this kind of products (excluding crisp bread) is expected to increase at least in Finland by the double in the following ten years.

Fig. 1. The consumption of different bread types in Finland during years 1964-78 and prognosis until year 1990. Source: Finnish Foodstuff Industry, the trends in the consumption during years 1964-78 and prognosis until year 1990, part 1, p. 167 (by J. Salomaa for Industrialization Fund of Finland Ltd., Ky Mäntän Kirjapaino, Mänttä, 1979)
The cooking extrusion technology offers a fascinating alternative in the production of this kind of products. At present there is in Scandinavia already one cracker bread producing cooking extrusion line. The trade name of this product is Cracottes, as I mentioned earlier.

According to my estimate there will in Scandinavia within 2 or 3 years be several, let's say about 5 cooking extrusion lines that produce cracker bread or direct substitutes for our well known everyday products like cream crackers, Finn crisp, crisp bread or Norwegian flat bread. The future will show, how strong a competitor the cooking extrusion will be for the traditional processes used e.g. for making crisp bread. My opinion, formed by comparing production costs, the need for energy and the need for investment capital, is that after a few years, when the production lines are not marred by defects typical for every new kind of equipment, the traditional crisp bread process will be beaten by the cooking extrusion process. However, hard work especially to improve the taste of the new products is required.

Different types of processes for the production of precooked flour are in existence. Several millions of kilos of precooked whole wheat flour made in cooking extruders are used for the feeding of fur animals. Quite small amounts of precooked flour made in a cooking extruder are used for human nutrition in Scandinavia. The cooking extrusion offers a good alternative in the production of precooked flour for this purpose, too. It is to be expected that the use of the cooking extrusion process in the production of precooked flour for human nutrition will increase in the future. The lack of exact knowledge of the nutritive value of cooking extrusion products seems at present to limit the use of extruded flour for baby gruels.

Few, if any, ready-to-eat cereal products based on cooking extrusion exist on the Scandinavian market. A larger use of cooking extrusion technology in the production of ready-to-eat cereals than at present is to be expected in Scandinavia in the near future. Products made from other raw materials than corn and rice, e.g. wheat and rye may be worth of trying. The production of highly expanded curls from corn or rice flour for the production of a variety of snacks is one of the first applications of food
extrusion in general. There has been some production of curls also in Scandinavia and even some trade with corn curls between Scandinavian countries. The use of corn for making curls will probably quite soon give way to the use of other raw materials like wheat and bran enriched wheat.

The climatic conditions with a view to cultivating wheat and rye are in most parts of Scandinavia rather unstable. Every year part of the harvested grain is sprout damaged and can not be used in baking. Inactivation or reduction of the enzyme activity in sprout damaged grain, especially rye, by heat treatment would make it possible to use this kind of grain as a component in baking. Heat treatment of grain with a cooking extruder might result in a process economical enough for the realization of this idea. Moreover, this kind of precooked flour would act as "Quellmehl" and thus function as an improving agent in baking.

The possibilities of cooking extrusion in the production of soft-moist foods and feeds have not yet been utilized in Scandinavia. It is probable, that some soft-moist products, e.g. pet foods, will be produced by applied cooking extrusion methods in the next few years in Scandinavia.

Gelatinised starch is split by amylases some hundred times faster than native starch granules. Normally batch cooking is used to gelatinise starch for the subsequent amylase treatment. Continuous gelatinisation of starch containing raw material by cooking extrusion could be an alternative for batch cooking. I am looking forward with interest to what kinds of applications the starch processing industry will develop for HTST-extrusion.

To summarise: Several Scandinavian companies are working in the area of cooking extrusion. As early as the beginning of the 70’s some companies invested in extrusion technology. At present, at the beginning of the 80’s a renewed interest in cooking extrusion technology is visible. As a consequence on this several companies without earlier experience of cooking extruders are now investing in such machinery. New cooking extrusion products have been launched and in the next few years they will undoubtedly be followed by others. Besides being a tool for making quite new products cooking extrusion technology will be an alternative in
making products that now are made by other processes. In some cases this new technology has good chances of supplanting the old technology, providing, however, that the factors affecting the properties of the products are known and can be controlled better than now, and that the effects of the extrusion process on the nutritive value of the products is studied in detail and nothing disadvantageous is found.