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Extrusion technology in feed and food processing

THEMATIC PROCEEDINGS

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PREFACE

Research center for animal products and feed, as an organizational unit within the Institute for Food Technologies in Novi Sad (FINS) at the University of Novi Sad, is the only scientific research organization specialized in the feed technology, and there is no similar organization in the region, in the former Yugoslavia, or in other countries in the Balkans or the EU member states in the region. We have come a long way since the establishment in the year of 1963, to the modern research center and a renewed grant, supported by the EC FP7 REGPOT-2007-3 project "FEED TO FOOD" (full name of the project: "Development FEED-TO-Food Research Centre at the Institute of Food Technology, University of Novi Sad", GA-no 207043).

We are proud of the fact that we decided to accept new challenges and try to get involved in European science courses, as soon as we showed up for that possibility. We wanted to confirm the reputation we have had in Serbia and the region, and to prove ourselves on a larger scale. We worked a lot, but we have reason to be satisfied. Already in the first FP7 REGPOT-2007-3 call, intended for research infrastructure strengthening, our project was in a group of 11 funded projects, in the competition of 107 applicants. Of these, seven projects were from Serbia, of which 4 projects from the University of Novi Sad. One of the four projects was our "FEED TO FOOD", as only one related to food in the research area. The name of the project has contained core business of renewed "Research Center of Excellence for technology products and animal", which continues the 47 year long tradition of the Institute of Feed Technology, which operated within the Yugoslav Institute for Food Industry and Faculty of Technology in Novi Sad, until the moment when FINS was established.

Considering the complexity and variety of technological processes, close connection with agriculture, food and other industries, and it's very important place in the food chain, animal food requires a serious and comprehensive approach and offers great opportunities for research. But "FEED-TO-FOOD" is not a research project. This project will enable future research work. The project directly involves 30 researchers from five Europian institutes:

- Institute for Food Technology, FINS, Novi Sad – Serbia (coordinator)
- International Forschungsgemeinschaft Futtermitteltechnik, IFF, **Braunschweig – Germany**
- Institute Nationale de la Researche Agronomique, INRA, **Clermont-Ferrand / Theix-France**
- National Research-Development Institute for **Animal Biology and Nutrition, IBNA, Balotesti – Romania**
- **Institute of Animal Science of LVA, IAS, Baisogala-Litvania**

Many people from different research institutes, laboratories, small and medium enterprises and other participants from EU and other regions, are involved by means of knowledge transfer (workshops, round tables), different activities of EC like "FOOD CLUSTER INITIATIVE" and other activities. Making new connections throughout the

EU and exchanging of results and experiences is very important, but what inspire us mostly in this project, besides of employment of young researchers, is getting new pilot-scale equipment for single processes in feed production (milling, mixing, extrusion/expansion, pelleting, conditioning, drying/cooling, vacuum coating). Equipment is fitted out with devices for measuring of throughput, pressure and temperature of material and/or working parts. This equipment will be used for scientific investigations, for development of new technologies and products, for applied investigations, for organizing of courses for people from feed industry, for PhD students, etc.

Through FEED-TO-FOOD project, we made contacts with institutes across the Europe. We became member of EUFETEC, European Center for Feed Technology. We have signed an agreement of interregional cooperation with Romania and Bulgaria. We are actively involved in IFIF (International Feed Industry Federation). We are members of žčćžč, and thanks to our international cooperation and iniciative, the whole association became member of FEFAC, European Federation of Feed producers.

Again, this thematic proceeding is a result of activities in the FEED-TO-FOOD project in the frame work package trough which is planned transfer of knowledge related to the topic “Technology in extrusion processing of food for animals and people”, an important contemporary theme for the development of scientific knowledge and production.

We have done a lot, but there is still so much we can. Feed to Food project has enabled us to establish conditions for the start of young researchers. Without them, our efforts and work would be pointless. We hope that they will do what we miss and that they will have sufficient reason to set Serbia as the place where they live with a normal and desirable dose of the mobility of a scientist.

Project coordinator and editor
Dr Jovanka Lević

CONTENT

HEAT TREATMENTS IN ANIMAL FEED PROCESSING

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ABSTRACT

Heat treatments are used to improve the nutritional, hygienic, physical and chemical and other animal feed properties. The paper provides an overview of heat treatments (cooking, roasting, popping, steam flaking, toasting, conditioning, pelleting, micronisation, expanding and extrusion), each different in purpose, the heat source, construction of the device or the applied process parameters. It explains the most important reasons for application of heat treatments as well as positive and negative impacts of these processes on quality of feed. This paper deals with researches focusing on the selection of production parameters of different heat treatments, because there aren't conditions that are optimal for all products, but duration of the process, humidity, temperature and turbulence of the material must be controlled variables dependent on what is processed, the effect that should be favoured and the device that is used. It shows the dependence of temperature and time of its activity for certain heat treatments and gives the ranges of these parameters in which positive and/or negative effects can be expected. This paper was written to assist the animal feed producers in the selection and adequate application of heat treatments, and thus in fulfilling the set criteria for quality of the finished products.
***Key words**: heat treatments, antinutritional substances/factors, technology, animal feed*

INTRODUCTION

In the world that is rapidly changing, where standard of living is constantly rising, and consumption leads to economic progress, we must not neglect the importance of keeping our food of animal origin safe and in sufficient quantities to meet the growing demand. The UN Food and Agriculture Organization (FAO), World Health Organization (WHO), European Feed Manufacturers' Federation (FEFAC), International Feed Industry Federation (IFIF) and many other organisations are involved in the debate on the future development of the "Common Agricultural Policy" and they all say that agriculture in the EU must continue its primary mission of production of safe agricultural products, offering a large selection of different types of products, of varying quality and meeting the consumers' demands [2, 4, 5]. It is expected that global demand for animal products will grow dramatically in the coming decades, driven by constantly increasing population and increasing per capita income, which is translated into increased consumption of food of animal origin. In 2050, it will be necessary to feed 9.2 billion people whose demand for food of animal origin will be far more extensive than it is today, when the population is slightly over 6 billion [6]. The demand for feed is also developing under a rapid pace, and it is of crucial importance for animal feed industry to be incapacitated to meet these requirements in a sustainable manner. Agricultural-food sector of the EU has to produce more, better, everywhere and at affordable prices. When it is known that the production must come from agricultural surface that are reduced and degraded in many areas, a drastic increase in efficiency of resource use will become the necessity [2, 3, 16].

Feed industry is an important link in the food chain, which plays the key role in terms of sustainability and sustainable use of resources. It is an important factor in resolving of the current global food crisis, has great economic importance in the European Union (EU) and it is necessary to pay due attention to research and development in this area [5, 6, 39, 40, 63].

Many raw materials in the basic form are not usable as animal feed and nutritional value of certain raw materials is often lower than expected based on the content of individual nutrients. Most often, the reason for that are chemical and physical characteristics that reduce the biological value and digestibility of one or more ingredients. In order to enable the optimal use of nutrients, the technological processes in which the mixtures and/or raw materials for their production can be translated into usable, namely more usable forms of feed, are studied. Heat treatments have found a significant practical application among the most studied technological processes to improve the usable value of feed [20, 21, 61, 62].

TYPES OF HEAT TREATMENTS

Heat treatments are used to improve the nutritional, hygienic, physical and chemical and other animal feed properties. There are many heat treatments, each different in the heat source, construction of the device or process parameters applied, and their efficiency depends on a range of factors. Two unavoidable factors of all heat treatments are temperature and time of their application, although the impacts such as humidity, pressure, shear force and others causing additional effects cannot be neglected either. Combining of these parameters is the starting point for development of all kinds of heat treatments and devices that are used in feed industry. Basically, all the different process techniques increase the temperature of the product. If you are adding moisture in the process, we are talking about hydrothermal treatment. Most of the processes that are used are hydrothermal treatments because even when moisture is not introduced from the outside moisture released from the material to be treated participates in the process. Another effect is mechanical and it can be located in or out of the heat treatment device. No matter where it is carried out, the mechanical treatment causes an additional effect to heat treatments so that they become thermo-mechanical processes. Thus, there are many possible combinations, and types of heat treatments in animal feed processing, and most frequently used are cooking, roasting, popping, steam flaking, toasting, conditioning, pelleting, micronisation, expanding and extrusion [7, 19, 35, 50, 53].

Cooking

Cooking is a relatively simple and easy to perform method. Raw kernels are soaked in water and heated for 30 to 120 minutes, and then they are dried, and given to animals as food, whole, milled, or rolled. Pressure cooking is a variation of this process, when the treatment is carried out in closed vessels under the pressure of steam that is created. In this way, we can achieve temperatures higher than 100°C. These processes have limited use because they are not flexible enough [12, 32, 41]. Explosive cooking is the cooking process in which material is heated by steam. It takes place in the vessels under the pressure of 2.3 to 3.0 MPa. Opening of the vessel upon completion of treatment creates a sudden pressure loss in the vessel due to equalising by atmospheric pressure and provides for further expansion of grain and additional effect on the treated material. The process of explosive cooking is much more flexible than the previously mentioned types of cooking. This process can achieve a wide range of different temperatures and pressures and is suitable for treating of all types of granular raw materials [15, 33].

Roasting

Roasting is intensive dry heating of raw material to the temperature of 110 - 170°C, depending on the type of device used and the desired product quality. If the roasting temperature is too high, it reduces the availability of nutrients in the surface layers of grain, while the central portion may remain under-treated. The lower temperature reduces the risk of burning out and burning, but it also reduces the capacity of the device. Many different systems of roasting are used all over the world. Most of these systems involve a direct effect of heat on seed, and due to a direct contact with the grains of different types and sizes, the quality, consistency and degree of roasting as well as grain colour can vary widely [33]. The simplest way of roasting of soybeans and other granular raw materials for animal feed is roasting in different types of dryers. The most widely used systems are those that are based on rotating drum-type dryers because they are suitable for small investments, and easy to handle, and because they do not require any large space to accommodate even large supporting installations. The grain in these devices is usually heated directly by hot air heated by burning gas, solid or liquid fuels. The product is mixed by drum rotation and fixed blades in its interior. Some devices of this type use microwave radiation in combination with direct heating by hot air stream [36, 63]. Conveyer dryers using air heated by heat exchangers as fluid are also used for roasting. The advantage of this type of device is that the grain is not exposed to direct flame and combustion products.

A newer high efficiency drying technology of fluidised bed type use dry overheated air that is blown through the grain and that keeps the product in a permanent suspension and movement under the controlled temperature and time of product retention. The grain is "cooked" by its own moisture, and this process gives a very clean product of uniform high quality. The output hot air can be recycled, dried, and re-used thereby increasing the economic efficiency of the process [32].

Popping

Popping is the process of roasting of dry grain on a hot plate (t <400°C) in a short time interval. Such treatment of grain leads to rapid loss of moisture, grain exploding into popcorn and increasing of its volume. All kinds of grain can be treated this way, and it is the best to use this treatment on corn since the lowest share of unpopped grains is recorded [15]. Rolling can be carried out after popping to increase the bulk density of the product [41].

Steam flaking

Steam flaking is the process in which the grain feed are exposed to effects of water vapour in the conditions of atmospheric or high pressure, and then rolled to obtain thin sheets - flakes. The thickness of flakes is defined by adjusting the spacing between the rollers and it ranges from 0.4 to about 2.0 mm. There are many variations of this procedure, depending on the pressure and temperature values and duration of the procedure. Steam flaking is used as a heat treatment of all types of grains and cereals such as corn, barley, wheat, etc. Moisture content in grain, thickness of flakes, grain temperature, and duration of the process affect the process efficiency. Grain temperature during the treatment reaches about 100°C [15].

Treatments using the wave emissions

Grain can be heated by a variety of processes that use emissions of the waves, which differ in part of the electromagnetic spectrum that is used.
Micronisation is a specific heat treatment in which the layer of grain on the conveyor belt is continuously carried under ceramic radiators emitting radiation with wavelength in the near infrared region ranging from 1.8 to 3.4 μcm. The emitted rays, which are directed to a product, cause the frequencies from 80 to 170 million mega beets per second inside the grain, which leads to rapid heating, increased stress of water vapour and rapid water evaporation. Micronisation decreases the moisture content of grain by 30-40%. The intensity of infrared rays' translation into heat and its effect depends on the type of material to be treated [7, 52].
The conveyor belt within the microniser can oscillate in order to tumble the grain and expose well all its surfaces to waves effect. The most important parameters of this treatment are the speed of the conveyor belt, thickness of product layer, space between the product and the radiation source and certainly the achieved temperature [7].

Toasting

Steam that is injected directly into the toasting vessel is a hot fluid in this procedure. The vessel may have different structures and it can have the sections through which the product passes. The standard treatment is the one with the length of retention within the vessel from 10 to 20 minutes and the released temperature of up to 120°C. After heat treatment, mechanical pressure between two rollers can be used to form flakes, and then the product is cooled. This procedure can be applied to treat various types of raw materials. Common is its use in edible oil industry, where it is used to extract the solvent from the meal after oil extraction. Its effect on the decrease of anti-nutritive substances that are possibly present in the treated products are favoured [54].

Conditioning

Conditioning gains in importance in modern production when it comes to technological preparation of materials for different processes, as well as the method for mixtures higyenisation. Conditioning is a general term for processes in which the material is prepared for the next technological operation. In feed industry, conditioning usually implies preparation of materials (raw materials or mixtures) for pelleting or extruding and expanding. Basic methods of conditioning are: water conditioning, steam conditioning (short and extended) and mechanical conditioning, and it result with:

- Improved physical quality of the product
- Higher capacity of the device that follows in the process
- Lower energy consumption
- Less wear of working parts of the devices that follows the process
- The possibility to treat more raw materials
- Increased hygienic correctness of products
- Increased usable value of products [55].

The simplest method of conditioning is to add water into the conditioning device. Even when hot water is added, it is not possible to achieve a substantial increase in temperature of the material to be treated through this procedure.

Moisture and heat are achieved in a more efficient way in steam conditioning procedure. Due to its gaseous state, steam disperses through the material in a more homogenous way. This process is carried out by direct injection of dry saturated steam into the material and its temperature can reach 95°C. The process of steam heating is limited because it causes an increase in moisture content of the material for 1% for every 12-15°C of temperature increase. The necessary prerequisite for good conditioning is dry saturated steam pressure of about 8-10 bar with the temperature of 150-180°C [11, 34, 55]. Reduction of pressure on the spot of use by about 1.5-3.0 bar causes steam temperature decrease and the released heat "dries steam" or overheats it, if there is no condensate in it. In this way, the over-wetting of material is avoided and it is heated in the most efficient way. Using a lower steam pressure more moisture is introduced in the material for the same heating level [60]. During the steam condensation, a thin water film is created around a particle, which together with the increased temperature facilitates mutual binding of particles. The main factors in conditioning include the temperature, moisture content and treatment duration. Temperature and moisture quantity are obtained by adding steam, and the time factor depends on the type, size and functioning of the device.

The device for short-term conditioning is a continuous paddle mixer to which water or dry saturated steam is added. The material is transported through the feeder with variable rotation speed. First particles of the material leave the mixer in only a few seconds and that time is not sufficient to use all the conditioning potentials. The average time of material retention in this type of conditioner is 10 to 30 seconds. By combining multiple devices for short-term conditioning, the process becomes "medium durable", since the time of material retention is extended to 0.5-3 minutes. This does not disturb the continuity and does not reduce the capacity of the line in which it is installed, and better effects of conditioning are achieved [55].

Rippeners, i.e. chambers for extended conditioning enable better diffusion of moisture, and heat into material particles. Steam is added into the device for short-term conditioning before ageing. After aging, the particles surface is relatively dry and they can receive additional liquid quantities. Therefore, another device for short-term conditioning can be placed at the exit from the aging chamber and it can be used to apply

additional quantities of steam. Rippener usually contains a mixer that is used to mildly move and tumble the material during aging. If the material does not move during aging this leads to its coalescence, which requires multiple screw extractors for chamber discharge and paddle mixer that will shake the material before further processing. Ageing lasts for at least 10 minutes although it can be much longer, which slows down the production process and reduces its flexibility and capacity, and the problem is more pronounced if the types of products are changing during the operation. The lack of prolonged conditioning is the inability to accurately control the retention time of material in the chamber due to non-fulfilment of the so-called "first in-first out" requirement. We can speak only about the average retention time, and to ensure more uniform retention time of each particle it would be necessary to apply the flow equal to the one on the conveyer belt or in the aging chamber with several levels. If the retention time is not uniform, a part of the material will be overheated and a part will remain untreated [56].
When materials of poor bonding properties are pelleted, steam conditioning is not sufficient to achieve the satisfying pellet quality. Therefore, a combination of steam conditioning and mechanical conditioning is applied. By mechanical conditioning, the material is compressed and excess air is extracted, which provides for dosing of large quantities of bulk material on the pellet press. Thicker die, adjustable thickness of material layer on the die and increase of engine power of electric motors are the ways to extend conditioning of materials in the process of pelleting. In plants where such raw materials are normally processed, more drastic solutions are applied, and additional pallet press, compactor, expander or extruder are installed as special systems for mechanical conditioning in order to heat up the material to 100-140° and even up to 170ºC before final pelleting. An increased consumption of energy is inevitable, so that the application of this type of process is justified only in cases when the final price of the product can stand investments in equipment and production [58].

Pelleting

Pelleting is one of the basic technological operations in animal feed industry and it can be defined as an agglomeration of individual ingredients or mixtures by compacting and forcing it through openings in the die and cutting off of the pressed forms to the desired length. It is usual to condition animal feed before pelleting. In this way, the temperature of the material usually increases to about 80°C before entering the press for pelleting. Additional heating is achieved during the pelleting process via mechanical action of force, two or more rollers, with the same or different diameters, which rotate along a horizontal die, or inside the ring die. Rollers pass over the material and compress it. The pressure continuously rises from the point where the rollers touch the material and start pushing it towards the hole on the die to the point where the pressure is large enough to implant a small disc of material into the opening of the die channel and unite it with the pellet, which was already in it. The pressure reaches its maximum at the point where the gap between the roller and the die is the smallest, so that a part of the formed pellet is pressed out on the other side of the die opening. The pressure decreases when the roller moves away from the opening. This process is repeated every time the roller passes over the opening, so that individual steps turn into a continuous process due to high speed of rotation. Particles of pelleted material are bound by adhesion forces. The strength of these forces can be enhanced by increasing the pressure, which causes the increase in temperature of the product as well [34].

Roller pressure forces should overcome the friction forces, which depend on the nature of the material to be treated, its humidity and pre-treatment (grinding, conditioning), use of liquid components and binders, and characteristics of the pellet press such as the type and quality of materials that rollers and dies are made of, precision of machining, the dimensions and number of rollers, the distance between rollers and dies, shape and size of dies and the number and distribution of channels (openings), length, diameter and shape of the die channel. The selection of components, grinding, conditioning, adding of binders, liquid components (molasses, fat) a. ...), etc. it is possible to influence the reduction of friction, or an increase of adhesion forces that bind the particles in the pelleting process, and thus the quality of produced pellets that are expressed as % of rubbing or hardness and consumption of power necessary to achieve the required pressure through the installed power of electric engine load [13, 57].

Pelleting presses with different rollers are manufactured depending on the product application. The number, diameter, width, shape (cylindrical or conical), and surface of rollers are selected to allow the most equalised distribution possible of mass and pressure along the whole surface of the die. Larger number of rollers is in favour of lower energy consumption, and larger free area of the die in favour of better distribution of materials with low filling weight, and these ratios have to be harmonised. The spacing between the rollers and the die is another important parameter regulating the process of pelleting. The consumption of electricity (kWh / t) necessary for pelleting increases with the increase of this distance. The length of the opening i.e. die thickness also affects the capacity of the pelleting press, and pellet quality. Increase of the die thickness results with the reduced capacity and increased pellet hardness [34].

The type of the material that is pelleted conditions the die structure. Whether it is a plate or cylindrical die depends on the purpose, and the number of channels has to be harmonised as well as their distribution, diameter, length, and shape. The number of channels determines the capacity of the pelleting press. If the die has more channels for pressing the open die working surface is larger, along with the capacity of pelleting presses. If the open die surface is too large, the high pressure may break the thin walls of the channels in the die, and cause it’s rapid wear and reduced service life. The problems can also occur with too small or too large openings on the die so that diameters ranging from 3 to 8 mm are usually used for the optimal pelleting regime [34].

After pelleting, the increased humidity and temperature are eliminated in the cooling process of vertical or horizontal (belt) coolers. It is necessary to reduce these sizes into the frameworks guarantee the storing stability.

The development of new technologies, pelleting does not lose significance as one of the first hydrothermal and mechanical treatments. The improvements of this process tend towards higher automation, which should enable continuous control and adjustment of process variables, its higher efficiency, and better pellets quality (chemical, nutritional, microbiological, physical...).

Extrusion

Extrusion is the process in which the material (feedstuff or mixture) is pushed through the barrel by means of screws of different configurations and pressed through the die at the end of barrel. The basic concept of extrusion process is high temperature, short time, whereby the high temperature is a direct result of friction (dry extrusion), or pre-conditioning and steam injection (wet extrusion), or a combination of both. The humidity of treated material in dry extrusion is about 30% while it is up to 80% in wet extrusion . Extruders can be classified as those with one or two screws, and the latter may have screws that are rotating in the same or in opposite directions, and screws can also narrow in a conical shape. Extrusion is the process in which the material is exposed to high temperatures (up to 200°C) for 1-2 minutes or more precisely the material temperature increases progressively within the last 15 to 20 seconds up to the optimum one to achieve the desired effects [50]. Therefore, this process is classified as heat treatment with high temperatures and short period of its action. At the same time, the material for extrusion is also exposed to relatively high pressure, which can range up to 25 MPa. The pressure difference between the inside of the extruder and the external environment causes partial evaporation of water at the exit point, and hence the expansion of the product. Thanks to extrusion, it is possible to achieve a range of effects on the treated material, such as grinding, hydration, cutting, homogenisation, mixing, dispersion, compression, heat treatment, inactivation of antinutritional substances, compression, expansion, binding of particles, formation of porous structure and partial dehydration and sterilisation. The type and intensity of induced changes depend on the added energy in relation to time and quantity of product, design of screws (spiral shape, segments for slowing down, type and length of individual segments, the ratio between the length and diameter), type and structure of the material to be treated, humidity and fat content, capacity, additional heating and cooling of each barrel section, and die geometry [8, 19, 20, 21, 22].

Extrusion is a complex and complicated technological process, but it is very flexible and provides the possibility for processing of a range of different raw materials [53]:

- **Oilseeds** (soybean, sunflower, rapeseed, cotton seed, peanuts, etc.)
- **Cereals** (wheat, corn, barley, rice, oats, etc.)
- **Legumes** (beans, peas and field pea)
- **Raw materials with high moisture content** (fresh fruits and vegetables, animal, fish and milk proteins)
- **Combinations of raw materials** (different portions of some of the above raw materials which are mutually complementary in nutrient content)
- **By-products and wastes from the food industry** (e.g. rendering plant products, meat and meat and bone meal, waste from fish processing industry, by-products of dairy industry, breweries, sugar refineries, etc.)
- **Complete animal feed mixtures** (balanced meals for piglets, calves, poultry, dairy cows and horses, fish feed, pet food, etc.).

Extrusion is the technological treatment that modifies the most the internal structure of material. After treatment, the product is often quite different, from nutritional point of view, compared to the raw material from which it is composed. The material that has

been properly extruded is much better, according to its nutritional and physical properties than the pelleted material. Animal feed components undergo a whole range of changes during extrusion. These are primarily changes in starch and protein components. Friction and shear of the product during the extrusion provide an additional effect caused by the splitting of oil cells, and cell walls. Given that this is the treatment with high temperature and short duration, the loss of useful substances is minimised. However, it should be noted that irregular extrusion might result in negative effects [8, 36].
Regulation of process parameters can affect the final product characteristics such as moisture, expansion, solubility, absorption, texture, flavour, density, buoyancy, etc... The specific form of a screw with segments that can be exchanged and combined, variable screw speed and possibility of regulation of flow and other parameters are make the extrusion the most flexible heat treatment process [50].

Expansion

The extrusion and expansion processes are based on the same principles. Basically, the expanders are very similar to extruders, and they differ in the method of shaping of the final product and intensity of treatment [48, 50]. Expanders are commonly used as mechanical conditioners for treating materials which are difficult to pellet, to increase the digestibility of cellulose and protein components in order to perform feed hygienisation [7, 18].

CHOOSING THE RIGHT HEAT TREATMENT

The effect of heat treatment is not always positive. Depending on the nature of raw materials, as well as the conditions applied in heat treatment conducting, it is possible to find both positive and negative effects on product quality. Knowledge on both positive and negative impacts is important for animal feed manufacturers in order to better set up and handle the technological process, as well as for consumers to know what quality of products is available to them. Tables 1 and 2 present the list of major positive and negative effects of heat treatments [7, 8, 48, 50, 51, 53].

To obtain positive effects from heat treatments it is necessary to maintain exactly the defined temperature and length of the process, and these parameters must be accurately controlled by appropriate measuring instruments during the process.

Table 1. Positive effects of heat treatments

Increased digestibility of components	
	Starch
	Protein
	Celluloses
Destruction of anti-nutritive components such as:	
	Trypsin inhibitors
	Lectins
Inactivation of undesirable enzymes such as:	
	Urease
	Peroxidase
	Lipoxigenase
	Mirosinase
Destruction of toxic components such as:	
	Glucosinolates
	Gossypol
	Aflatoxins
Destruction of micro organisms such as:	
	Bacteria
	Salmonella
	Yeasts
Structuring and shaping of components and mixtures	
	Texturing of high protein components (soybean, blood meal)
	Fish feed
Taste improvement	
Increased metabolic energy	

Table 2. Negative effects of heat treatments

Negative effects: Destruction of thermo-sensitive vitamins and other additives such as:	
	Vitamin A
	Vitamin C
	Vitamin B_1
	Pigments
Inactivation of enzymes such as:	
	Amylase
	Phytase
Destruction of amino acids such as:	
	Lysine
	Methionine
	Cistine
Undesirable chemical reactions such as:	
	Mallard's
	Starch-fat

When selecting the heat treatment and equipment for their application, the basic questions before making investment decisions are what will be processed and what quality of the final product is required. The products may be required to be: with reduced trypsin inhibitor, with gelatinised starch component, with increased or decreased protein digestibility, with preserved activity of ingredients and additives, starchy, hard pelleted, crumbled, specially shaped, expanded, flaked, with defined density, guaranteed Salmonella free, Salmonella free, manufactured in the cheapest way, manufactured from cheap raw materials, etc. There are no conditions that are optimal for all products, but the temperature and length of the process, as well as humidity and turbulence of the material must be controlled variables. One must make a compromise between the biochemical characteristics of raw materials, the type of heat process, the applied process parameters and requirements of an animal [22, 46, 50, 51, 64].

Figure 1 shows the areas in which, depending on the temperature achieved and length of its action, one can expect certain positive and/or negative effects of heat treatment on antinutritional substances, destruction of protein, starch gelatination, destruction of Salmonella and volume expansion. Thicker parts of lines parallel to abscissa and ordinate show the ranges of time, namely temperature in which the listed appliances operate (toaster at atmospheric pressure, ripener- prolonged conditioning, toaster with high pressure, A.P.C - anaerobic pasteurising conditioner, yetsploder-roasting, extruder, expander, microniser, conditioners of the pelleting mills, B.O.A-compactor) [64].

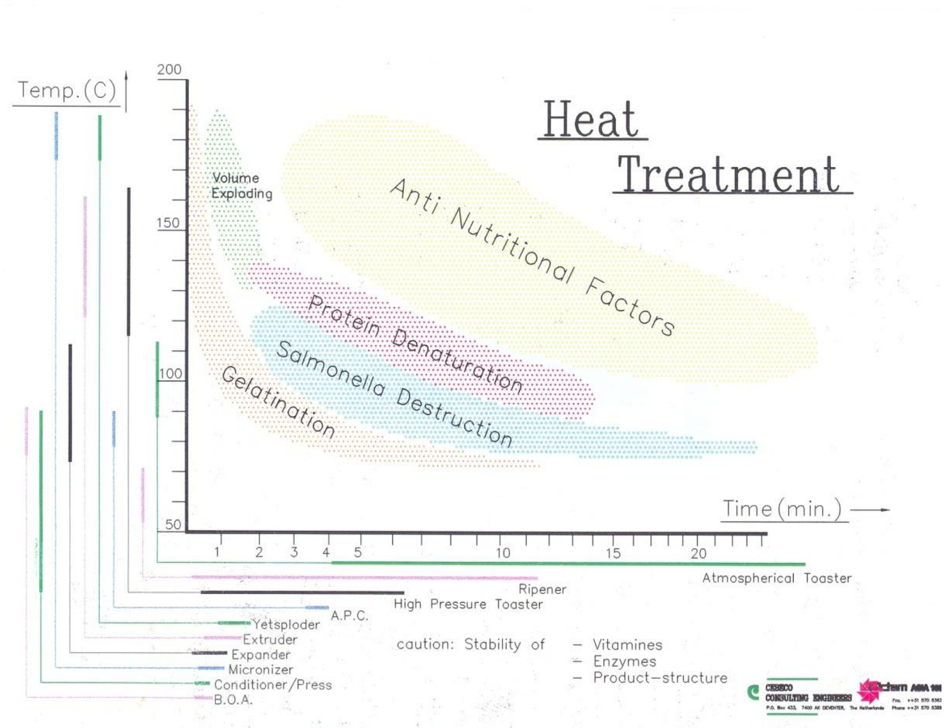

Figure 1. Dependence of heat treatment effects on time and temperature

ANTINUTRITIONAL SUBSTANCES

The most common reason that limits the use of some raw materials for animal feed, especially legumes, is the presence of antinutritional factors (ANF), including inhibitors of digestion, toxins and other substances. These factors affect negatively the appetite, absorption of feed and/or metabolism of animals. Even a low level of ANF in feed can cause interferences in animals. Better understanding of ANF allows higher flexibility in the selection of raw materials, for example, the use of larger quantities of soybeans in the diet of young animals and the increased use of peas, beans and rapeseed in animal feed industry [10].
Table 3 listed ANF and levels of their presence in certain feed raw materials [23].

Table 3. Antinutritional factors (ANF) of some raw materials [23]

	Antinutritional factors (ANF)			
Raw material	Protease inhibitors	Lectins	Tannines/polyphenolic compounds	Other
Wheat	- / +	-	-	-
Barley	- / +	-	-	-
Ray	- / + /++	-	-	-
Rice	- / +	-	-	-
Millet	- / +	-	+ /++ /+++	-
Corn	- / +	-	-	-
Soybean	++ /+++	++	-	-
Horse bean	- / +	+	++ /+++	+ /++ /+++[1])
Peas	- / +	+ /++	+ /++	-
Lupine	-	-	-	+ /++ /+++[2])
Rapeseed	-	-	-	+ /++ /+++[3])
Sunflower	- / +	-	+ /++	-
Cotton	- / +	-	-	+ /++ /+++[4])
Peanuts	-	-	+ /++[5])	-

[1]) vicin/convicin, [2]) alkaloids, [3]) glucosinolates, [4]) gossypol, [5])16-18% of tannin in the membrane

- Below the detection limit, or very low level
+ Low level
++ Medium level
+++ High level

Protease inhibitors are peptides that form complexes with proteolytic enzymes such as pancreatic enzymes trypsin and chymotrypsin. In this complex, trypsin and chymotrypsin are inactivated, and protein digestion is reduced. A well-known example is the trypsin inhibitor in soybean grain. It is a low-molecular globular protein that binds to trypsin and inhibits the activity of proteolytic enzymes in the digestive tract. The trypsin inhibitor in crude soybean grain represents about 6% of total proteins. In addition to trypsin inhibitors, the presence of lectins in soybean grain is also important. These are proteins that have an affinity to bind sugars and damage the bowel wall, which interferes with digestion and absorption process [12, 13, 24]. Among other listed ANFs, it is significant to single out rapeseed glucosinolates, due to production of this raw material, which has been constantly rising over the recent years. Glucosinolates in animals block the metabolism of thyroid gland and indirectly reduce the efficiency of use of meals and slow down the growth of animals [17]. Antinutritional factors such as racing, reclining, spooning, allergens, also reduce or inhibit the wider use of certain raw materials for animal feed [29].

The elimination or inactivation of the ANFs and increased digestibility are the major challenge for animal feed industry. Many of ANFs can be eliminated or reduced significantly by using proper heat treatments. Heat treatments causing the destruction of ANFs such as lectins, trypsin inhibitors and tannins, by destroying the protein molecule, which means that it does not have an inhibitory effect [31]. Heat inactivation of trypsin inhibitor activity (TIA) and the lectin activity (LA) was extensively studied and the results showed that the degree of destruction varied highly in individual processes, as shown in Table 1 [46].

Table 4. The influence of various heat treatments on inactivation of TIA and LA [46]

Heat treatment	Inactivation	
	TIA [%]	LA [%]
Cooking (100°C; > 15 min.)	65-97	90-100
Cooking under pressure (121°C; > 15 min.)	85-100	99-100
Roasting (different temperatures and time)	54-82	85-99
Extrusion (145°C; > 16 s.)	78-98	93-98

Urease, an enzyme present in raw soybean grains is inactivated by heating. Reduction of urease activity is correlated with reduction in trypsin inhibitor units. Measurement of urease activity in reduction of pH of test solution of urea is used as a method of quality control in processing of soybean grains, because this analysis is easier, faster and cheaper than the analysis used to determine TIA [42, 43].
Glucosinolates are also sensitive to the effects of temperature. Heat treatments reduce the level of glucosinolates in rapeseed depending on the intensity of treatment. At 105°C, glucosinolate content is reduced by 8% with infrared radiation, and by 23% with hot air. Higher temperature (125°C) and longer duration of the process with infrared radiation help reduce glucosinolate content by 38%, which in the investigated case corresponds to the final glucosinolate content of 8.5 μmol /g [17].

EFFECTS OF HEAT TREATMENTS ON NUTRITIONALLY VALUABLE FEED INGREDIENTS

The intensification of heat treatment does not results only with reduction of ANF content, but with highly complex changes of nutritionally valuable feed ingredients that occur at the same time. It is therefore necessary, in addition to the ANF content, to know about physical and chemical characteristics of raw materials, including primarily the shape and size of particles that are treated, content of starch, protein and heat sensitive ingredients and additives, as well as about the effects of heat treatment on these components and their physical, chemical, nutritional and hygienic properties.

Starch

It is known that animals utilize their feed better if a portion of starch in it is previously gelatinised. This is explained by the fact that amylase enzyme acts more efficiently on such a modified starch material. Starch is stored in the grain in the form of spherical crystals and its molecules are not accessible to enzymes action. During the heat treatment, starch granules absorb water and, depending on the nature and properties of materials, and process conditions (temperature, pressure, length of the process, etc.), the crystalline structure of starch granules is destroyed, which leads to gelatination. As the degree of gelatination is higher, the enzymes will dissolve starch more easily [7, 41, 48, 50].

Presence of water is a necessary precondition for the process of gelatination of starch component, but it also acts as a lubricant and bonding agent increasing the contact surface, and cohesive force between material particles. Moisture can be absorbed deep into the starch particle or cell or it may be on its surface. Location of moisture depends on previous treatment, namely on the ways to add water, and time of material aging [7, 8]. Finer grinding facilitates the penetration of moisture. Surface moisture can cause bonding of the material and equipment clogging [14].

According to our previous studies, pelleting increased the degree of starch gelatinisation by 49.6% in feed mixtures for chickens, by 22% in feed mixtures for pigs and by 16% in feed mixtures for young bulls [26]. Each component of animal feed mixture has its own pelleting ability. Under the impact of moisture and heat during pelleting. Starch component of cereals is clustering and transforms into gelatinous state, which contributes to easies binding of other components and creation of solid pellets. Pelleting process requires a higher content of starch to form solid granules compared to the extrusion process [27, 28, 30, 48].

The influence of expanding on the degree of starch gelatinisation in some raw materials and finished feed mixture is shown in Table 5 [48].

Table 5. The influence of expanding on the degree of gelatination [48].

	Degree of gelatination [%]	
	Before expanding	After expanding
Raw materials:		
Wheat	8	45
Barley	15	51
Corn	5	41
Animal peas	6	41
Horse beans	10	50
Animal feed mixture for:		
Broilers	18	57
Laying hens	22	35
Pigs	25	47
Trout	46	85

Generally speaking, complete gelatination of starch is achieved at temperatures higher than 120°C with humidity of 20 to 30%, or at lower humidity (10-20%) with the additional effect of shear found in extrusion.

Protein

Wet heat treatment causes changes in plant proteins. These changes are positive only to a certain point and result in improved protein digestion and increase of their nutritional value, which is explained by the increased availability of proteins for enzyme activity and inactivation of ANFs of protein nature that block the effect of proteolytic enzymes [10, 19, 33].

Overheating results with changes in proteins themselves or causes the reaction between proteins and other components. Too high temperature and extended duration of treatment reduce protein digestibility and reduced content of essential amino acids. Table 6 shows the effects of expanding and pelleting processes on stability of amino acids in feed mixtures [26, 48].

There is also a decrease in protein solubility. Protein solubility is used as an indicator in soybean processing. There is a correlation between protein solubility in KOH and TIA. In cases of insufficient heat treatment in soybean processing it is used for evaluation of heat treatments [36, 42, 43]. From the standpoint of protein digestion, it is not irrelevant whether the feed is intended for ruminants or monogastric animals and it is necessary to manage the processes to obtain products with pre-defined characteristics in accordance with nutritional requirements of animals. The reduced solubility is desirable in production of by-pass protein for ruminants, and undesirable for monogastric animals.

Table 6. The influence of expansion and pelleting on stability of amino acids in feed mixtures [26, 48].

Product - treatment	**Content of amino acids [%]**		
	Lysine	Methionine	Treonin
Feed mixture for pigs			
Before expanding	0.84	0.56	0.61
After expanding Temperature 120 [^{o}C]	0.83	0.55	0.59
After expanding Temperature 130 [^{o}C]	0.78	0.54	0.57
Feed mixture for chicken			
Before pelleting	1.12	0.47	0.75
After pelleting Temp. of conditioning 85[^{o}C]	1.08	0.45	0.71

Heat treatments must be carefully controlled to avoid destruction of high-quality proteins by overheating. This means that one must make a compromise between different final effects. The optimal heat treatment needs to be achieved, which is strong enough to reduce the TIA, and not that strong to damage the quality of nutritionally valuable proteins [36, 46].

Fats

Heat treatments affect the quality of fats in two ways. Large friction and high pressure lead to destruction of cell walls and release of oil from spherosome, which increases oil digestibility. At the same time, complexes of fats and carbohydrates are created and stability is enhanced, i.e. the oxidation processes is prevented, through inactivation of lipolytic enzymes [25, 53].

Fibrous ingredients

Pectins, hemicellulose, cellulose lignin, and similar substances, which are the components of cell walls of plant materials, have low digestibility in monogastric animals. Breaking of their structure in heat treatment increases their digestibility [53].

Heat sensitive additives

Vitamins, antibiotics, probiotics, coccidiostats, enzymes and other materials for feed are differently sensitive to moisture, temperature and other impacts to which they are exposed in the process of mixture production. Sensitivity depends primarily on their nature, the nature of other substances present, and production processes and conditions that are applied during the animal feed manufacturing process. Loss of activity during heat treatments cannot be avoided, but it can be minimised by controlling the conditions of the process [1, 47].

Generally speaking, antibiotics, vitamins and protected coccidiostats are completely stable after pelleting and even double pelleting, but their activity depends on the process parameters, time of conditioning, temperature and physical wear and losses, which reach the value as high as 10-20% during the pelleting at about 70 ºC [49]. According to our previous studies, vitamin A is destroyed by 6.5% - 11.5% in the pelleting process [26].

The impact of extrusion on vitamin activity is shown in Table 7. The mixtures for trout were extruded at the temperatures of 100 °C., 120 °C and 132 °C. The decrease of vitamin activity was higher at higher temperatures [1]. According to Albers, the length of conditioning has stronger impact on stability of vitamins than temperature [1].

Table 7. Effects of the extruding process on vitamin activity [1]

Vitamins	Remaining activity [%]
Vitamin A *	80
Vitamin D_3	75
Vitamin E	80
Vitamin K_3 **	20
Vitamin B_1	90
Vitamin B_2	>95
Vitamin B_6	>95
Vitamin B_{12}	>95
Biotin	>95
Folic acid	>95
Nicotine acid	>95
Pantothenic acid	>95
Vitamin C crystal	25
Vitamin C polyphosphate	-

* Hardened product
** MSB = menadion- sodium-bisulphite

According to their chemical nature, enzymes are proteins with specific and complex protein structure, which can be irreversibly modified by increasing the temperature and humidity. The activity of carbohydrates (DF-glucanase) is reduced by 40% at the temperature of 75°C, by 70% at 95°C, and it is completely lost at 110°C. The critical temperature for phytase above which significantly it loses in activity is 70 ºC. Most of the heat treatments are therefore too aggressive for enzymes and subsequently it is recommended to add enzymes to the formed pellets, or to extrudates or expandates. [47].

Table 8. Effects of pelleting on enzyme activity and physical quality of feed for pigs [47]

	Enzyme activity [%]	Physical quality of pellets	
		Rubbing [%]	Hardness [%]
Mixture	100		
Pellets Temperature of conditioning [^{o}C]			
65[^{o}C]	81	3.44	86.1
80 [^{o}C]	1	3.83	89.4
95 [^{o}C]		4.21	91.1

Table 8 shows some examples of effects of temperature and humidity on enzyme activity and pellet quality. As expected, there is a clear effect of conditioning temperature (65-80-95°C) on enzyme activity, which drops to a complete loss of activity at 95°C. These

data also point to the contradiction that exists between the desired effect on the pellets hardness and undesirable additional effect the stability of additives [47].
In order to protect the activities of sensitive ingredients it might seem logical to reduce the aggressiveness of the process, but it would diminish the positive effects of heat treatment on other ingredients. Therefore, in recent years more and more products are protected forms of vitamins, enzymes and related accessories that can retain activity after intensive heat treatment [44].

EFFECTS OF THERMAL PROCESSES ON HYGIENIC ANIMAL FEED QUALITY

Contamination of food with pathogenic organisms can cause food poisoning and result in disease of food consumers, which are undesirable and unacceptable effects. Important pathogens in food products of animal origin include Salmonella, Campylobacter, Listeria and E. coli. Salmonella is far the most important pathogen in cattle feed. Moulds can also be a sanitary risk, especially in relation to possible creation of mycotoxins. Naturally, animal feed is not the only possible source of contamination of food products, but in the chain of human health protection all potential sources of contamination, including animal feed must be kept to the minimum and, if possible, eliminated [48].
Neither pelleting, nor double pelleting nor extended conditioning, under normal circumstances, destroys Salmonella sufficiently that it could be possible to talk about feed without Salmonella. Feed free of Salmonella refers to the product where Salmonella is not found in a sample of 25 g. [64]. Pelleting of mixtures reduces the number of total micro organisms, as shown in Table 9

Table 9. Impact of pelleting on the number of micro organisms in different mixtures [26, 27, 28]

Mixture for:	Sample	Conditioning temperature [^{o}C]	Number of micro organisms	
			Saprophyte bacteria / g	Moulds / g
Broilers	Before pelleting After pelleting	30 83-85	1.085.000 10.000	50.000 Not isolated
Pigs	Before pelleting After pelleting	30 75-78	982.000 22.000	26.500 3.500
Cattle	Before pelleting After pelleting	30 80	225.000 15.000	16.500 2.000

Making the conditions of the process more agresiv and prolonging the residence time of materials in special devices, or combining the temperature and duration of its action with pressure or other mechanical effects, results with more voluminous destruction of Salmonella. Through expansion, the temperature is raised above 140°C, which is sufficient to destroy Salmonella [64]. This process achieves a significant effect of reduction of mixture contamination with moulds and Enterobacter and E-coli bacteria [48].

As with other effects of heat treatments, the temperature, treatment length and moisture content are important parameters that determine the degree of reduction of micro organisms. At higher temperatures, it takes less time to achieve the same result. One cannot ignore the impact of product moisture. At the same temperature, and under the same other conditions of the process, the higher moisture content causes higher reduction in micro organisms count [9, 37, 48].

More recently, specific types of devices have been developed based on conditioning, which are used for destruction of Salmonella and they perform the task successfully due to higher temperatures that were applied, increased treatment length and construction of the device. We can recognize them by the names given by equipment manufacturers (SIRT, A.P.C , BOA) [64].

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ROLE OF EXTRUDERS IN FOOD AND FEED INDUSTRIES

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Extrusion is simply an act of forcing material through a die and has been practiced for over 50 years. Initially its role was limited to mixing and forming food and feed ingredients. Now, the extruder is considered a high-temperature short-time bioreactor that transforms a variety of raw ingredients into modified intermediate and finished food and feed products. During extrusion cooking, temperatures can be as high as 200 C, but the residence time is usually 15-20 seconds. For this reason extrusion cooking is called HTST. There are several function/actions that take place during the short time in the extruder. Food or feed material is forced to flow under one or more of a variety of conditions of mixing, heating, and shear, through a die which is designed to form and/or puff-dry the ingredients. In other words extrusion combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. Several types of extruders are used for processing food and feed products. Some are single screw, some are twin screw, some have internal steam locks, some have grooved barrels, some have continuous flights, and others have interrupted flights. Some extruders generate their own heat by friction for cooking and other use additional heat sources like steam for cooking purposes. All these extruders work depends upon their application.

Extruders are not new to the food and feed industry. Very short L/D (barrel length/diameter) high shear extruders for making puffed snack foods have been manufactured for over 55 years, single screw cooking extruders for nearly 20 years and co-rotating twin screw extruders for 25 years. Basic extruder technology has been used in various forms and industries for many years. New equipment designs have increased the range of extrusion applications in food and feed processing. Today's consumers are demanding a broader selection of foods and feeds. Extrusion processing equipment has become the standard in many foods and feed industries throughout the world. Presently, extruder manufacturers are trying to make these extruders more efficient and less expensive. There are approximately 17-20 major extruder manufactures domestically and overseas. There are very few manufacturers who make both single and twin screw cooking extruders. It is common knowledge that single screw extruders are more economical in cost, maintenance and operation for making products that do not require twin screw extruders. As of now no twin screw extruder manufacturer has added a single screw machine to its product line during the past two decades. But single screw extruder manufacturers have entered the twin screw market.

HARDWARE COMPONENTS

An extrusion system includes a live bin/feeder, preconditioner, extrusion cooker, and die/knife assembly as shown in Figure 1. Each component is designed to accomplish a specific function in the process of cooking and forming feed products. The operating conditions can be adjusted to vary the characteristics of the finished product. The live bin/feeder provides a means of uniformly metering the raw materials into the preconditioner and subsequently into the extruder. As the material leaves the preconditioner, it enters the extruder barrel. Here the major transformation of the raw preconditioned material occurs which ultimately determines the final product characteristics. The initial section of the extruder barrel is designed to act as a feeding or metering zone to simply convey the preconditioned material away from the inlet zone of the barrel and into the extruder. The material then enters a processing zone where the amorphous, free flowing material is worked into dough. Most of the temperature rise in the extruder barrel is from mechanical energy dissipated through the rotating screw. It may be assisted by the direct injection of steam or from external thermal energy sources. The screw profile may be altered by choosing screw elements of different pitch or with interrupted flights, or by adding mixing lobes configured to convey either in a reverse or forward direction. All of these factors affect the conveying of plasticized material down the screw channel and therefore the amount of mechanical energy added via the screw.

All extruders consist of a screw(s) which conveys the premixed ingredients through the barrel. Regardless of whether the machine is single- or twin-screw type, several principles apply to all. Screws generally are suspended only from the drive end of the barrel, and rest on the product at the exit end. As a result, the greatest stress and wear on the screw and barrel occur at the exit, and these parts need refurbishing or replacement first. But, complete screws and barrels of even small commercial-size extruders are heavy and difficult to transport and set up in lathes or surface machining equipment. Except for very small or old extruders, both the screw and barrel are segmented. The screw typically consists of a shaft that is splined, equipped with a keyway, or hexagonal shape onto which various elements flight sections, flight "worms" of different design, and shearlocks/steamlocks slip before being tightened in place. In twin-screw extruders, each screw consists of modular components, also. This design has two major advantages: 1) the elements can be arranged in a variety of configurations as needed for specific applications; and 2) the worn exit segment can be replaced as needed, or moved back on the shaft to a position where it's increased clearance with the barrel is less critical.

In addition to segmented barrel sections, which often have liners that can be replaced as wear proceeds, provisions must be made to keep the product from turning with the screw. Screws act as positive displacement pumps in twin-screw extruders, and the barrel wall typically is smooth. In the intermeshing co-rotating design, each screw wipes the other in moving product forward; in the intermeshing counter-rotating design, the screws jointly squeeze the product forward. Other provisions must be made for moving product forward in single-screw extruders. The oldest design solution was introduced in meat grinders in the latter 1800s. Rifling or parallel groves were cut (more often cast) into the barrel. Both "wet" and "dry" single screw extruders include this feature. Because the barrels and screw flight sections are segmented, a ring-like “steamlock" or "shearlock" can be placed between each section, turning the previous section essentially into a pressurized mixing-shearing- reactor cell. Typically, clearances between the "lock" and the barrel wall decrease as the product is conveyed forward, resulting in zones of increasing pressure. The second design solution to preventing the product from spinning with the screw was borrowed from the Anderson continuous oil screw press, invented at the end of the 1800s. Instead of the screw segments aligning to form a continuous forward conveying flight, space was intentionally left between the flights, giving rise to the term "interrupted flight." The barrel inside this type of machine is smooth walled, but "shearing bolts" protrude through the barrel wall into the space between the flights. As needed, a hollow bolt can replace a solid bolt and convey steam into the product during processing. The die plate at the discharge end of the extruder is the only restriction to product flow and, conceptually, the entire barrel is one reactor cell.

PROCESS PARAMETERS

Extrusion and similar agglomeration techniques have been utilized to process various feedstuffs for many years. Extrusion cooking is universally recognized as a high temperature, short time process. The higher temperatures employed during the extrusion process present an interesting challenge in the assessment of nutrient retention. During extrusion, the recipe and its constituents are subjected to a succession of almost instantaneous treatments or unit operations. These variables include moisture and temperature profiles, extruder configuration, extruder speed, and preconditioning of the material prior to extrusion. The critical process parameters could be summarized into four areas – specific mechanical energy, specific thermal energy, retention time, and moisture levels. All the extruders are basically screw pumps through which material is forced, while in the meantime, subjected to heat, cooking and shear forces. Parameters that affect the quality of the end product when using extrusion technology are particle size of the ingredients; extruder shaft speed; preconditioning moisture and temperature levels; residence time, percentage of moisture added and temperature reached within the extruder barrel; barrel configuration of the screw and shear locks and die design and restriction in the die.

SELECTING AN EXTRUDER

Many options, which sometimes confuse buyers, are available in the marketplace when selecting extrusion systems for product development. For example: 1) Is a single- or twin-screw extruder required?; 2) Should it be a "wet" or "dry" extruder?; 3) Should it have internal steam locks or a single face die plate?; 4) Should it have continuous or interrupted flights?; etc. Appropriate selection depends on several factors:

- Physical and sensory properties of the end product.
- Formula ingredients: their physical nature (i.e., will the product utilize high levels of fresh meat?), moisture content; constant availability or seasonal ingredients; and substitute ingredients that may be used occasionally.
- Kind of product to be extruded? Food grade or feed/pet food? Should each piece be multi-colored or center-filled? Is the shape general, exotic, or detailed? What is the target bulk density? In case of feed, how much fat needs to be added in the formula? How much can be applied to the surface?
- What is the production rate? The size of an extruder depends on market size since extruder’s function best operating at full throughput per hour.

- What is the source of energy? Is steam or electricity (for product heating) more economical where the extrusion plant will be built? If it is a small operation in a developing country, would a tractor power take-off drive be more suitable?
- What about capital availability and the recovery date target? Would a used extruder fill the need better for a start-up operation?
- Choosing the proper extruder configuration is critical for successful extrusion. The extruder manufacturer should be able and willing to assist in tailoring screw, barrel, and supporting equipment configurations for processing specific products. All these factors should be considered when deciding which kind of extruder best fulfills needs. The four most commonly-used types of cooking extruders currently are: single screw "wet" extruders, single screw "dry" extruders, single screw interrupted-flight extruders, and Twin-screw extruders. Once the appropriate extruder is selected, it must be assembled correctly and then adequately maintained. Operator training is important, and the supplier of extrusion equipment must be able to provide this service.

TYPES OF EXTRUDERS:

There are several different styles of extruders available in the market. This may cause a difficulty for food and feed processors to select a proper extruder for their products. During extrusion, a number of functions occur in a short time, i.e., conveying, mixing, homogenization, heating/cooling, cooking, sterilization, forming/shaping, expansion, texturization, flash drying, and center filling. In general, extruders are divided into two major categories: single-screw and twin-screw.

Single-Screw Extruders

Single-screw cooking extruders have compressive screws with decreasing channel depth turning at high speeds to increase shear and mechanical energy input for heating. The resulting friction induces heating of a product. In some cases, the barrel is jacketed for steam to allow additional contact heating in the metering section. To increase capacity and efficiency, it is common to preheat ingredients in a pre-conditioner by adding steam before they enter the extruder. Categories of single-screw extruders include.

Cold forming (Pasta-type) Extruder

Deep flight, smooth barrel, low shear speed. Little or no cooking. Used for pasta, pastry dough, cookies, egg-rolls, ravioli, processed meat and certain candy.

High-Pressure Forming Extruder

Grooved barrels to prevent a slip at the wall and greater compression in the screw design. Commonly used for pre-gelatinized cereal and fried snack foods.

Low-Shear Cooking Extruders

Moderates shear machines with high compression machines and grooved barrels to enhance mixing. Soft-moist foods and meat like snacks such as simulated jerky.

Collet Extruders

High shear machines with grooved-barrels and screw with multiple shallow flights. Used for puffed snacks and expanded curls or collets.

High Shear Cooking Extruders

High shear machines, with screws of changing flight depth, HTST devices. Make pet food, Ready-to-Eat Cereal (RTE), candy, crisp breads, precooked food ingredients, pre-gelatinized corn flour, dried food mixes, instant beverage powder, croutons and breading, crackers and wafers, enzymes' deactivations of full fat soy flour, imitation nuts, famine relief feeding, texturized vegetable protein (TVP), and deactivation of enzymes in cereal and oilseeds.

Twin-Screw Extruders

Twin screw consists of two parallel screws in a barrel with a figure-eight cross section. The use of twin-screw extruders for food processing started in the 1970s, with an expanding number of applications in the 1980s. Twin-screw extruders are generally one and one-half times or more expensive than single a screw machine for the same capacity. Yet the degree of quality control and processing flexibility they offer can make them attractive to food industries. Twin screws produce a more uniform flow of the product through the barrel due to the positive pumping action of the screw flights. Some other advantages of twin screw are:

- Handle viscous, oily, sticky or very wet material and some other products, which will slip in single screw extruders, (It is possible to add up to 25% fat in a twin-screw extruder)
- Less wear in smaller part of the machine than in single screw extruder.
- Wide range of particle size (from fine powder to grains) may be used, whereas Single screw is limited to a specific range of particle size.
- Because of the self-wiping characteristics clean up is very easy.

Four types of twin-screw extruders are possible:

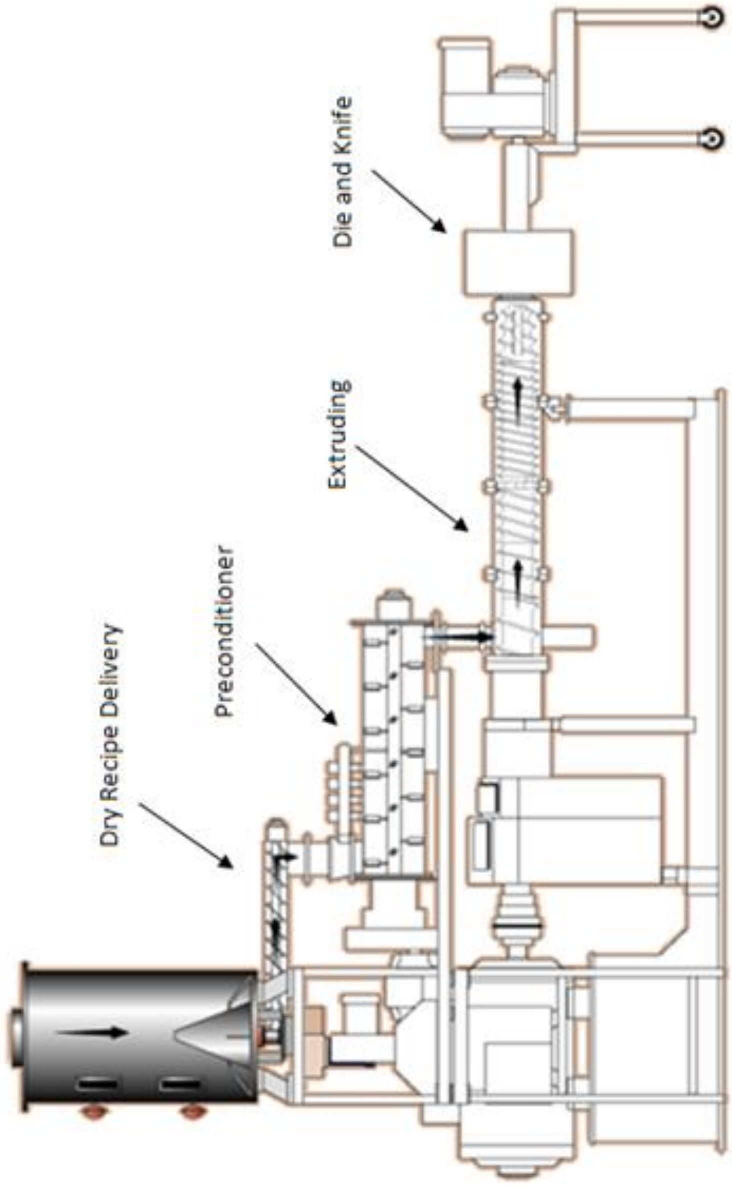
1) Non-intermeshed, co-rotating; 2) Non-intermeshed, counter rotating; 3) Intermeshed, co-rotating; and 4), Intermeshed, counter rotating. From these four types of twin-screw extruders, co-rotating, intermeshed screw type has found the widest acceptance in the food industry.

Extrusion technology provides several different advantages over the traditional methods to the food and feed processing industries. The continuous process greatly reduces production time for many products by removing the "time and motion" restrictions of batch processing. Results are obtained quickly to allow immediate product changes during production as they become necessary. Extruder flexibility is another benefit, as it gives food processors the ability to react quickly to market trends by reducing the time cycle of new product development. Finally, extruders allow food processors to maximize productivity. The equipment lends itself to automation and is easy to reconfigure for multiple processing applications. With the Extrusion process ample varieties of products are feasible by changing the minor ingredients and the operation conditions of the extruder. The extrusion process is remarkably adaptable in being able to accommodate the demand by consumers for new products. A variety of shapes, texture, color and appearances can be produced with an extruder, which is not easily done using other production methods. Extruders operate at relatively low moisture while cooking food products, so less re-drying is required. Extrusion has lower processing costs than other cooking and forming processes. We can save 19% raw material, 14% labor, and 44% capital investment. Extrusion processing needs less space per unit of operation than other cooking systems.

Extruders play a very important role in processing food, feed and ingredients for the industry. Currently extruders are being used to process all kind of food products. Following is the partial list of the food where an extrusion technology can be used or being used presently. Bran stabilization (general, rice bran, wheat bran, oat bran), breading substitutes, breakfast cereals (expanded, flakes/pellets, bran), crisp bread, croutons, confectionery (miscellaneous), cooked grain (barley, corn, milo/sorghum, mixed), cracker, corn chips and tortilla, fabricated potato chips, full-fat and partially defatted soy flour, gums, half product (3G snack, miscellaneous, starch base), imitation nuts, industrial products (general, dehydrated), infant foods, legumes (miscellaneous, precooked), meat products (snacks, jerky), pasta products (noodle, spaghetti, macaroni), precooked and modified starches, pretzels, proteins (textured, gluten), ravioli, ready-to-eat-cereal, rice (miscellaneous, precooked), semi-moist foods, snacks (mixed or other, corn, fruit/nuts, potato, rice, wheat, co-extruded) and many more.

Extrusion technology currently being used for processing several different types of animal and aquaculture feed. Following is a brief list of different types of feed being processed using extruders.

- Full fat soybeans and other high oil ingredients for feed application
- Piglet feed and calf starters
- Hygienic feeds for poultry
- Protein by-pass feeds for ruminants
- Aquatic feeds (floating, sinking, high fat)
- Pet foods (dogs, cats, reptile, birds, etc)
- Feeds containing high levels of wet byproducts



Picture 1. Extruder parts

TWIN SCREW VERSUS SINGLE SCREW IN FEED EXTRUSION PROCESSING

J.M. Bouvier

1. INTRODUCTION

Dry expanded pet foods, pet treats, aquafeed pellets are processed on extrusion processing technologies which allow to convert, texturize and shape continuously highly concentrated biopolymer-based mixes, to high quality end products. Extrusion processing technology has brought tremendous advantages to product manufacturers such as: flexibility and versatility from the process standpoints, low operational costs, low manpower and space requirements, easy operation and upgrading, reliable technology. And these advantages have strongly contributed to the fast development of pet food industry and aquafeed industry over the last decades.

Two different technological concepts are currently available for extrusion: Single Screw Extruder (also referred in this paper as SSE) and Twin Screw Extruder (also referred in this paper as TSE). They are composed of a thermally regulated barrel in which one screw turns (case of SSE) or two intermeshing screws turn (case of TSE).

Single screw extruders are the simplest and the cheapest on the market. But their process functions are limited, particularly when the formulations become complex and require, for example, a high degree of mixing, or when flexibility and high quality products are desired. Process and product drawbacks of SSE can be handled by TSEs thanks to their specific “shear-time-temperature” histories in the screw-barrel assembly.

Among the numerous technical differences between SSE and TSE technologies, there are important distinctive characteristics which affect tremendously the performances of extrusion processes and the properties of resulting products. So, when investigating an investment project, manufacturers of extruded pet food and aquafeed pellets do need to understand those differences from the technical and process standpoints.

2. TSE VERSUS SSE: QUESTIONING AND ARGUMENTS

The comparison of TSE and SSE is a complex and permanent debate in the extrusion community, particularly in industry when discussing process limitations or deciding an investment. Fortunately, scientists and engineers can bring valuable experimental data, modelling and objective discussion, to enlighten the TSE/SSE debate.

When pet food or aquafeed producers decide to invest in an extrusion processing unit, they have key questions to ask as to understand advantages and drawbacks relative to both TSE and SSE, such as:

- What are the differences (process/products) between TSE and SSE?
- Can you describe the process advantages of TSE versus SSE?
- Is TSE more productive than SSE, or inversely?
- What products can TSE give that SSE cannot?
- What about the operational costs (wear, energy…) of TSE versus SSE?

- Can you justify the capital cost difference between TSE and SSE?
- Why should I buy a TSE rather than a SSE in feed processing?
- Is my operational staff skilled enough to handle TSE/SSE?
- Potential investors would learn the following classical arguments from SSE promoters:
- Low capital cost
- Low wear cost
- Low mechanical energy input, which may allow SSE promoters to pursue in arguing low energy cost
- Simple machinery which may allow SSE promoters to deduct « easy operating and maintenance »

At first sight, these arguments are very attractive, as the SSE economics seem significantly more advantageous from the operating standpoint (lower operating costs, easier operation, in particular). But, it happens that many pet food and aquafeed producers do invest also in TSE technology since a long time. And when potential investors go and ask TSE promoters to comment that actual fact, they would learn the following:

- High process flexibility
- High process consistency and productivity
- High product quality
- Easy adaptation to changes in recipe composition, raw materials, product specifications

Of course, these are important and valuable advantages. In fact, extrusion technology is a long term investment, and such advantages should allow the investors to adapt their production unit according to the market requirements over the long term (15 years and more). Thus, the investors do need to investigate more in depth the extent of SSE limitations from the process and products viewpoints compared to TSE.

3. TSE VERSUS SSE: PROCESS ENGINEERING AND ANALYSIS

3.1. Processing characteristics of SSE technology.

3.1.1. Process functions.

The SSE usually has a one-piece screw with a channel of variable depth and constant pitch, or a splined shaft that accepts modular screw sections with a constant channel depth and variable pitch. As regards the process functions, the screw-barrel assembly is normally composed of three sections (Figure 1):

- a **feed section**, with a high transport capacity (deep channel or large screw pitch) for solid and particulate raw material (solid powders and particulates);
- a **compression section**, where the material is compressed and densified under the compressive effect of the screw (in a channel of decreasing depth or pitch). At the same time, the material is heated by inter-particular friction and conductive heat transfer until melting occurs. In this section, the material changes from a solid particulate state to a continuum (viscous fluid);

- a **metering section**, with screw elements of small channel depth or pitch, where the material is strongly sheared in laminar conditions. The mechanical energy dissipated is transformed into thermal energy (increasing the temperature of the material) and also used to modify the material physically and chemically, and to bring it to a rheological state compatible with satisfactory shaping. This section is also a pumping section in which the pressure needed to convey and feed the material through the die opening is built up. This section operates more or less as the only effective working section of the SSE.

3.1.2. Flow characteristics in the screw channel.

In the metering section of SSE, once the material is molten, the flights of the rotating screw convey the viscous material down the barrel. The adhesion at the barrel wall prevents the material from turning with the screw, allowing the positive pitch of the flights to push it along the barrel. This is a **drag flow**, and its velocity is directly proportional to the screw speed. In the SSE, the material is conveyed by the friction forces whose efficiency depends mainly on the friction with the barrel walls. If this friction does not exist, the material turns with the screw, to the detriment of the shearing rate, which can reach zero. On the other hand, if the material adheres to the barrel, the maximum shearing will occur. Therefore, it is necessary to reduce the friction coefficient with the screw (by polishing its surface) and to increase the friction coefficient with the barrel (by striation of the barrel walls). As drag flow moves the material forward, a **pressure flow** is developed as well which results from the die restriction downstream. Pressure flow causes a reduction in the net flow of the material exiting the extruder. Thus, the net volumetric throughput of SSE is a combination of drag flow and pressure flow (Tadmor and Klein, 1970).

The operational throughput is a global response of the characteristics within the screw-channel assembly of SSE. It is worthwhile to analyze the local flow characteristics in the screw channel as this determines the mixing efficiency, the convective heat transfer, the residence time distribution, the distribution of shear rate and strain….. Actually, these different response variables do affect importantly the extent and quality of the material conversion which flows into the screw channel.

Flow in the screw channel can be simply analyzed through some classical assumptions (Tadmor and Klein, 1970; Janssen, 1989); which leads to describe the velocity profiles in the different directions. As shown in Figure 2, a helical flow is obtained in the down channel direction, which puts in evidence that each fluid particle has different velocities depending upon their position in regards to the centre of the channel: the closer to the centre, the faster the velocity; which leads to a relatively large dispersion of residence time of the fluid particles in the screw channel. In the cross section of the channel, the flow pattern indicates that the stream lines of the material do not interact with each other, which means that the fluid particles do not mix and so, the mixing in the screw channel is very poor. Mixing in SSE can be upgraded in some extent by use of cut flights screw elements and increased backpressure behind the die; but, this invariably leads to decrease significantly the extruder capacity. So, the flow analysis in the SSE channel clearly shows that mixing is rather limited by the laminar flow conditions, and residence times are extensively dispersed. And any flow restrictions to enhance mixing through special screw designs for example, would depress importantly the extruder throughput.

Low mixing in the screw channel means consequently low convective heat transfer, low mechanical energy input. And diversity of flow velocities means not only dispersion of residence times, but also dispersion of shear rates and strain in the screw channel (Harper, 1989); consequently, this leads to obtain a dispersion of cooking extents and temperatures of the material at the end of the cooking section, which gives some heterogeneities of the melt properties when exiting the die for expansion and texturization: local heterogeneity of melt temperature, composition, lipid binding, rheological behaviour, in particular. Of course, these local heterogeneities do affect negatively the final quality of products: surface aspect and shape, internal structure and texture, durability, fat stability….

3.1.3. Effect of screw wear and melt slip.

With new extruders, the flight clearance (the clearance between the top of the flight and the barrel wall) is usually small, and the converting material in the screw channel acts like a lubricant in this gap and so prevents metal-to-metal friction. As the extruder operates, the flight clearance increases due to screw wear caused by material abrasion and corrosion. Screw wearing in SSE affects importantly the extruder performance, until it reaches beyond a tolerable level. As screw wear increases, **leakage flow** is generated which leads to invariably decrease the extruder throughput (Figure 3). In addition, the magnitude of screw wear depresses as well the mixing degree, the heat transfer coefficient, the mechanical energy input; which means that as the screw wear progresses, the quality of the melt conversion and of the final product decrease. So, screw wear causes also some inconsistency from the process and product standpoints.

In SSE, optimum performance of the extruder is obtained when the material adheres to the barrel wall, at which condition throughput and shearing are maximum. If the material adherence to the barrel does not exist, extruder performance would drop dramatically: this is what happens when the material slips at the barrel wall. Slip phenomenon depends on the rheological characteristics of the melt in the cooking section of the extruder; and so, it depends closely on melt composition.

Basically, the melt is composed of biopolymers together with various low molecular weight components. Slip phenomenon in the screw channel starts when internal friction between macromolecular segments of biopolymers decreases, due to some ingredients which interact with macromolecular segments and interface those segments, and finally act as “slip inducers”. In pet food and aquafeed extrusion processing, slip inducers are: moisture, meat slurries, protein hydrolysates, fat…… That is why SSE performance starts to decrease when fat content and meat slurry in the recipe are over 8% and 15% respectively; and as the content of those ingredients increases, the degradation of SSE performance decreases. Of course, in SSE extrusion processing, slip inducers in the melt affect importantly the performances of the extruder: decrease of throughput, mixing degree, mechanical energy input, and increase of melt heterogeneities and quality of end products.

3.2. Processing characteristics of TSE technology.

3.2.1. Process functions.

The TSE has two splined shafts that hold modular screw elements with a constant channel depth, and various pitches and designs (reverse pitches for shearing, mixing disks for intense mixing, large positive pitches for venting….). It has identical features to the SSE (Figure 4):

- a **feed and conveying section** with large pitch screw elements;
- a **compression section**, where the screw elements are of decreasing pitch;
- at the output of this section, the densified material enters a so-called **working section** or processing section, where special dedicated screw elements orientate the features according to the required goal: for example, counter-threads (with reverse pitches) for shearing, or mixing disks (monolobe or bilobe) for intense mixing. The intensity of shearing and mixing is then governed by the geometric characteristics of the screw elements. In addition, the screw elements can be single flight, or double flight (rarely more) according to the number of parallel channels along the screw. In comparison with single flight screw elements of the same channel depth and pitch, mono-thread screw elements have less conveying capacity, higher pressure build up and a more limited range of variation of the residence time. In addition, double flight screw elements have the advantage of applying a more uniform shearing rate within the screw channel, which is a positive factor for achieving uniform processing of the material.

The pressure profile down the barrel length on TSE (Figure 4) can be varied to allow different process functions (mixing, shearing, venting, partial cooling, on line feeding of ingredients….), which can be designed in series according to process purposes. Such a succession of working zones in series brings a high level of process flexibility when compared with SSE.

3.2.2. Flow characteristics in the screw channel.

TSE works in a different way to the SSE. The interpenetration of the screws creates a positive movement of the material although the machine is not filled. Corotative TSE is a positive displacement pump which allows large range of materials behaviour to be handled (viscous, oily, sticky, very wet…) with the same level of pumping efficiency. Therefore, the throughput and screw speed are independent within a certain range of variations, which allows multiple operating points for given throughput and formulated feed mix to be applied. It must be noted that positive displacement pumping effect of the screws leads to a narrow residence time distribution, and that throughput is independent of die pressure (Harper, 1989).

Unlike the screw channel in the SSE, much of the channel of TSE is not completely filled. When the flow is restricted by the screw configuration (counter-thread, mixing elements, die), material accumulates upstream, creating a fully filled working section (an active area where the material is worked by shearing), which contributes to its physical and chemical transformation, and its heating by viscous dissipation (Janssen, 1989).

The screw configuration may hold several working sections, or process sections, in series and any flow restrictions in the screw profile or at discharge create a filled section. The succession of process sections down the barrel length of TSEs, permits to dedicate process-oriented functions according to the whole process requirements. For example, a mixing/cooking section, followed by a venting/cooling section can be configured easily (Figure 4). This ability to design process functions in series in the screw configuration is a key process advantage in extrusion processing. For given screw configuration, the length of fully filled sections depends mainly on throughput and screw speed: it would decrease when decreasing throughput, and increasing screw speed.

The previous discussions on flow characteristics show how high is the flexibility of TSEs: multiple working sections in series, independency of throughput and screw speed, and multiple operating points.

Flow analysis in TSE is much more complicated than that of SSE, and complete modelling of the flow is not available, even if reasonable assumptions are made. Nevertheless the flow in the C-shaped chambers of the screw-barrel assembly can be described as long as the end effects near the intermeshing zone are neglected. And thus, partial modelling of the flow together with experimental observations, allow the process performances of TSE to be discussed.

The mixing function is performed effectively in a TSE (Figure 5), partly because of the interpenetration of the screws and partly because of the efficiency of the mixing elements that are generally full. As a result, the TSE provides a high level of micromixing (mixing of ingredients at the molecular level), making it perfectly suitable as regards the physico-chemical reactions. In addition, the increase in the degree of mixing is very favourable for heat transfer in a viscous medium. Lastly, residence times are notably less dispersed than in the SSE; in particular, there are no stagnant zones that show the presence of the characteristic “tail” often found in the SSE.

When compared with SSE, TSE technology (corotative TSE) makes it possible to handle more efficiently the basics of the processing conditions such as: mixing degree, heat transfer, residence time distribution, and consequently the shear-time-temperature history in the screw-barrel assembly. Homogeneous melts can then be obtained, with very good molecular bindings (lipid binding in particular). Altogether, this allows die expansion to develop optimally ensuring consistent product density, texture and shaping as well as uniform colour of final products.

3.2.3. Effect of screw wear and melt slip.

Like in SSE, screw wear does occur in TSE, particularly at the restrictions and preceding screw elements. But, screw wear does not affect the process performances of TSE in a large range of operation. In fact, as screw wear increases, throughput and mechanical energy input still remain at the required levels by increasing the screw speed which is throughput-independent. As shown in Figure 3, TSE throughput is maintained at the nominal level for most of the lifetime of screw elements. Besides, in corotative TSE, melt slipping does not affect either the throughput, thanks to positive pumping of the screws.

When operating TSE technology, throughput and screw speed independency together with positive pumping action of the screws, give tremendous advantages to product manufacturers in terms of process productivity and efficiency, in terms of recipe management, and finally in terms of product quality, over the lifetime of the screws. Of course, this brings determinant benefits from the economical standpoint.

3.3. Comparison of TSE and SSE: synthesis.

Based on the aforementioned analysis and discussion on process and flow characteristics of TSE and SSE, it is worthwhile to draw a comparative synthesis of both extrusion technologies. The main conclusions of the comparison are gathered in Table I.

4. CONCLUSION

TSE and SSE technologies are nowadays well recognized in feed industry, as they allow various recipes to be handled (having from few compatible ingredients to numerous non compatible ingredients; from simple to complex formulated feed mixes), and extensive ranges of end products to be produced (from simple shaped to sophisticated products; from low to high added-value products). Both technologies are rather easy to operate and maintain, thanks to equipment manufacturers who have designed appropriate and efficient training programmes to allow new comers and operators to exploit properly extrusion equipment and process. They also have smart upgrading offers which permit existing equipment to be improved significantly as well.

As far as capital and wear costs are concerned, SSE technology is cheaper, thanks to its simple mechanics. That is why SSEs are classically used to produce basic, from low to intermediate added-value products. But, though special hardware adaptations can be added to the basic equipment to improve its flexibility, SSEs are rather limited from the process and products standpoints; besides, those adaptations are costly and they tend to depress the capacity performance of SSEs.

TSE technology does offer performance consistency as well as process flexibility, thanks to the extensive possibilities to organize the screw configuration, and the independency of throughput and screw speed variables, which allow various recipes to be handled (from simple to complex recipes) and extensive range of products to be produced (from low to high added-value products). Screw speed is a very influential and responsive variable which permits to maintain throughput and product quality over the lifetime of the screws; besides, it allows the mechanical energy input to be adjusted in real time, with no need of complicated, costly extra equipment to be added. TSE technology shows a very efficient micromixing in the screw-barrel assembly, which leads to obtain better process stability, more control of process response variables (temperature, shear and strain, residence time…) and consistent product quality (shape and surface aspect, internal structure and texture, density, colour…).

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Table 1. Comparative analysis of Twin Screw and Single Screw processing and technology

CHARACTERISTICS	TWIN SCREW EXTRUSION	SINGLE SCREW EXTRUSION
Initial investment cost	Higher investment cost (TSE/SSE = 1.4 to 2)	Smaller investment cost
Process operation		
Wear cost	Slightly higher wear cost (TSE/SSE = 1.1 to 1.5)	Slightly lower wear cost
Energy	Large range of mechanical energy input	Low mechanical energy input
Process flexibility		
Processing sections	Multiple	Single
Operating points	Multiple	Single
Dependency of process variables	Independency of throughput and screw speed	Dependency of throughput and screw speed
Recipe flexibility	Large range of raw materials and recipes	Tight specifications of raw materials and recipes
Process performances		
Throughput consistency	Very low sensitivity to recipe composition & wear	Very sensitive to recipe composition & wear
Mixing degree	Good	Poor
Mechanical energy input	From low to high	Low
Convective heat transfer	Good	Poor
Residence time distribution	Relatively low dispersion	Relatively high dispersion
Shear rate and strain	Uniform	Non uniform
Melt characteristics		
Cooking extent	Uniform and complete	Non uniform, may be incomplete
Melt temperature	Uniform	Non uniform
Melt composition	Homogeneous	Heterogeneous
Physico-chemical binding	Good	Incomplete

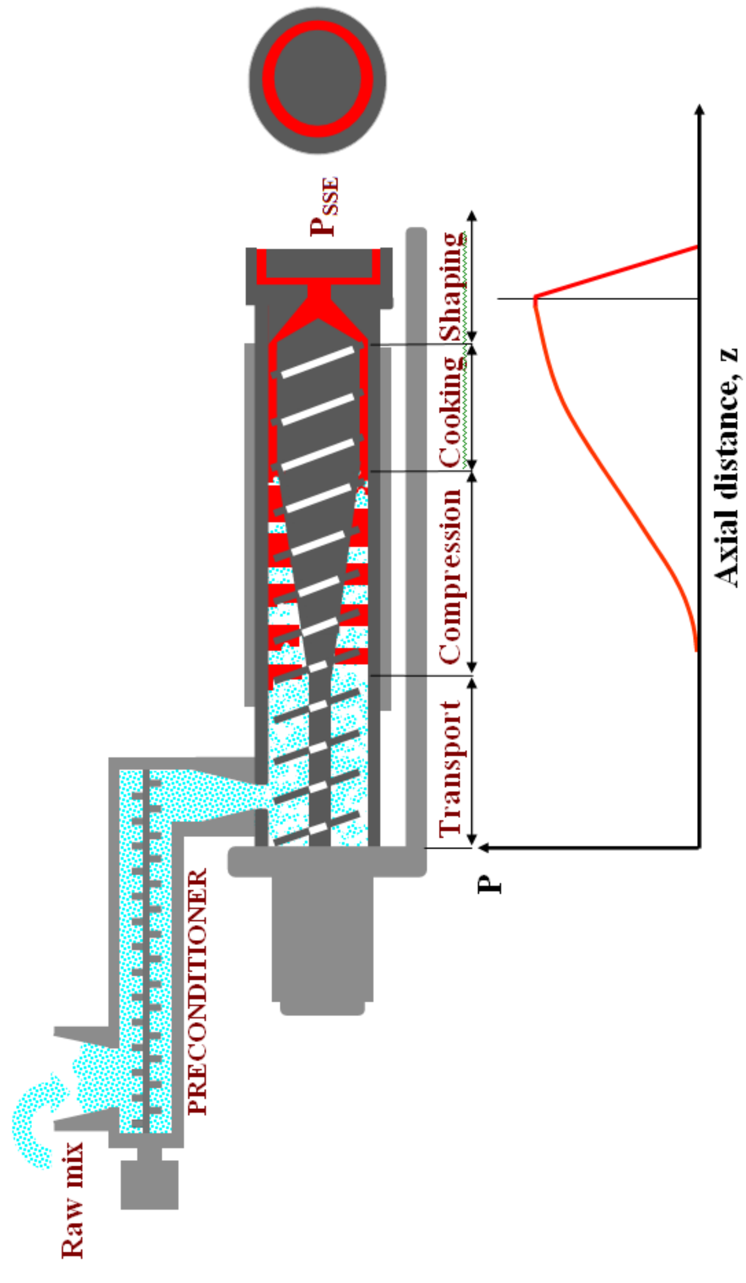

Figure 1. Processing in Single Screw Extruder

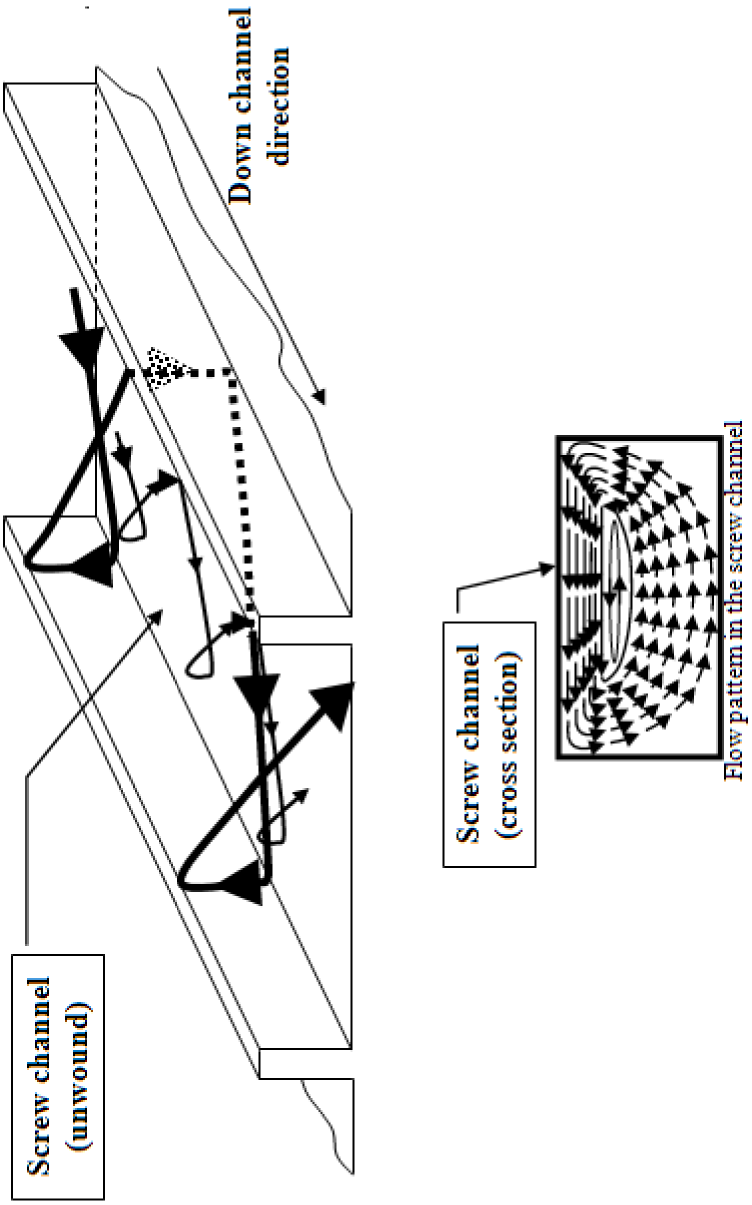

Figure 2. Velocity profiles in the screw channel of a SSE

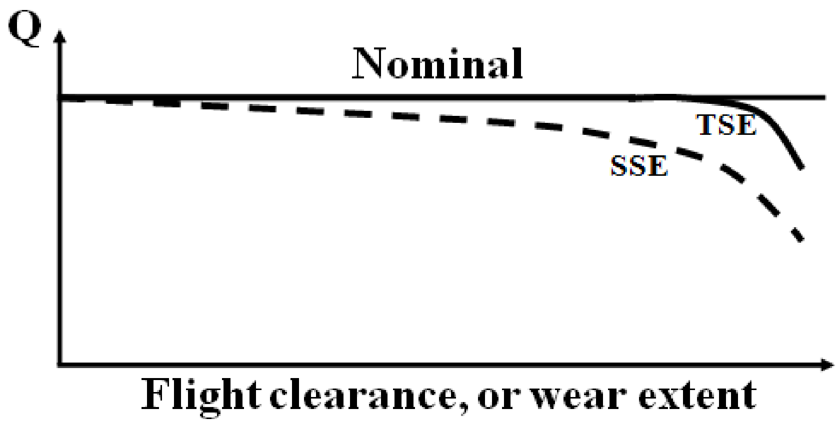

Figure 3. Comparative effect of screw wear on throughput of SSE and TSE

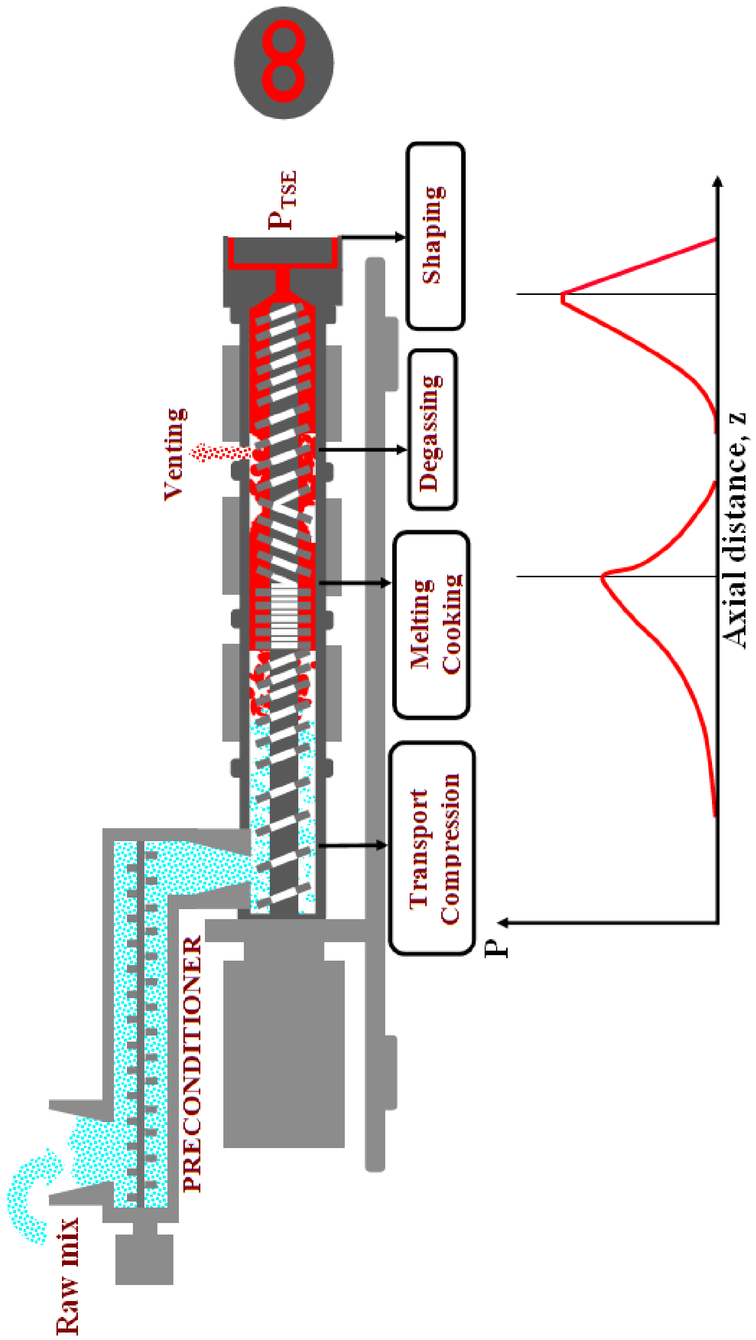

Figure 4. Processing in Twin Screw Extruder

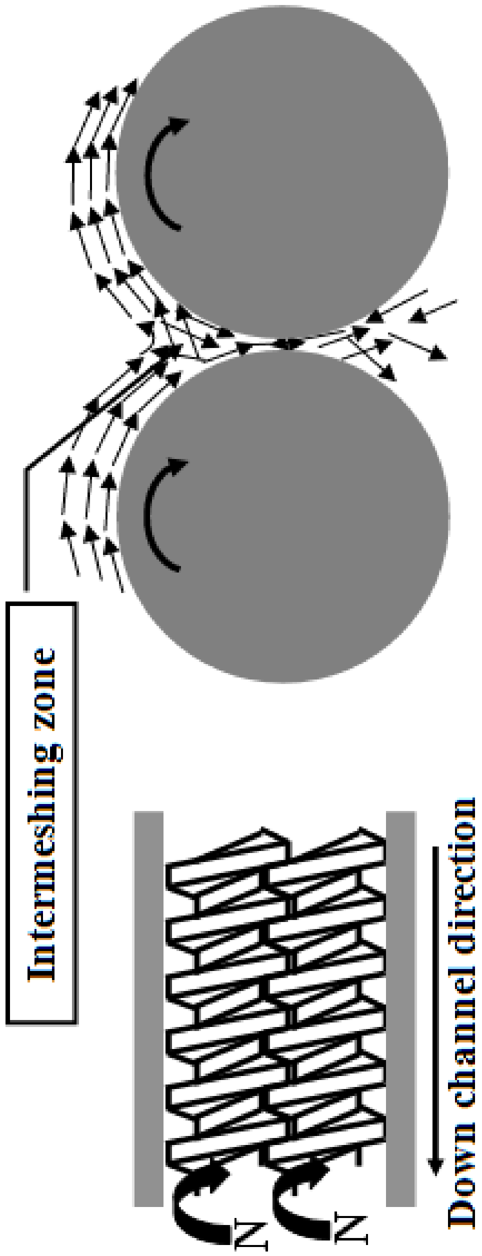

Figure 5. Flow pattern and mixing function in TSE

EXTRUSION-COOKED BROAD BEANS IN CHICKEN DIETS

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ABSTRACT

Improvement of broad beans (*Vicia Faba*) by extrusion-cooking has been investigated. Attention was focused on process requirements as well as on the nutritional effects of extrusion-cooked broad beans in a chicken feed formulation. The optimal thermal process conditions required for a product of good quality from broad beans are given. Feeding trials showed possibility to replace at least 60% soya in a chicken ration. This work demonstrates that extrusion-cooking of broad beans is an acceptable process for animal feed in respect of protein quality, particularly in countries where this plant is commonly cultivated.
***Keywords**: broad beans, extrusion-cooking, feeding value, chicken nutrition*

INTRODUCTION

The broad bean (*Vicia Faba*) is a legume with a high protein (up to 28%) and a high lysine (6 g/16 g N) content, which is cultivated in many countries. It is used to different extents as a food as well as an animal feed [4, 6]. The utilization of this crop is less than its potential offers, particularly in animal feeding. For example, in the East European countries it is more popular to cultivate that plant as a green fodder for animals than for its beans which are little used. One way in which broad beans can be made more nutritious is to process them thermally [4, 7, 8]. The object of the experiments reported here was to answer the question: what is the effect of extrusion-cooking of broad beans on their nutritional value and how could such extrusion-cooked beans compete with soya, which is a widely-used component in feed formulations?

MATERIALS AND METHODS

For this investigation grounded broad beans (without separation of hulls) of the Polish variety *Bobik Nadwislanski* were used. The composition of this raw material is shown in Table 1. The beans were grounded in a hammer mill to a particle size of 0,1-0,01 mm. Different samples were processed under different conditions in a extrusion-cooker to produce products with different properties. The process variables investigated were: screw speed, feed moisture content, compression ratio of the screw, die diameter and process temperature profile along the barrel [4]. Three runs at each set of conditions were made and analysed statistically.

The single-screw extrusion-cooker was a Polish design unit type TS-45 with L/D = 12 and screw's diameter of 45 mm. Experiments were carried out with screw compression ratios of 1,15; 2,4 and 3,0 with die diameters between 4 and 10 mm and rotational speeds of 1.0-2.0 revs s^{-1}.

Table 1. Composition and Form of Broad Beans Used

Protein (Nx6.25) (%)	Carbo-hydrate (%)	Fat (%)	Ash (%)	Fibre (%)	Moisture content[a] (% w/w)	PDI[b] (%)	Particle Size ($Mx10^{-3}$)
28.6	61.8	1.14	3.51	3.96	10.0	74.0	0.01-0.1

[a] Dry basis.
[b] Protein dispersibility index [1].

Temperatures were measured with thermocouples mounted at desired locations on the inside surface of the barrel. All experiments were repeated at selected feed moisture contents in the range 20-30%.

The throughput, energy input (including heat) and the mechanical and structural properties of the product were determined for each run.

Following product characteristics were determined using standard methods:

- Bulk density: determined by weighing a specified volume of product vibrated on a Rossen-Muller apparatus.
- Water Absorption Index (WAI) and Protein Dispersibility Index (PDI): measured on 50 ml of the material according to the AOAC methods [1].
- Organoleptic estimate of the colour (browning effect), taste, texture, structure etc. [3, 4, 11].

The nutritional value of the broad beans was assessed by feeding trials on 16 groups each of 27 or 54 broiler chickens Euribrid, aged between 1 day and 8 weeks (first step, 0-4 weeks, second step, 5-8 weeks) by replacing the soya grits in their daily ration, following standardized rules for feeding trials. The scheme of the feeding trials is shown in Table 2. The compositions of the feeds used are shown in Table 3.

The objective of the feeding trials was the determination of the effect of each feed by measuring:

- growth of chickens after 4 and 8 weeks of feeding;
- feed consumption per kg of body growth (feed conversion ratio);
- percentage of the chicken body weight recovered in the slaughterhouse for human consumption (butchered effectiveness).

Table 2. Scheme of the Feeding Trials[a]

Chicken group	Feed	Number in group	Mixture code	
			0-4 weeks	5-8 weeks
I	Wheat + barley + soya	27	S-1	F-1
II	Wheat + barley+soya+aa[b]	27	S-2	F-2
III	Wheat + barley +uncooked broad beans	54	S-3	F-3
IV	Wheat + barley +uncooked broad beans+aa	54	S-4	F-4
V	Wheat +barley+extrusion-cooked broad beans	54	S-5	F-5
VI	Wheat +barley+extrusion-cooked broad beans+aa	54	S-6	F-6
VII	Wheat+barley+extrusion-cooked broad beans with 6% NaOH	54	S-7	F-7
VIII	Wheat+barley+extrusion-cooked broad beans with 6% NaOH + aa	54	S-8	F-8

[a]All experiments carried out in duplicate.
[b]aa, Addition oflysine and methionine (see Table 3).

Table 3. Composition of the Feeds Used (%)

Materials	Mixtures							
	S-1	S-3	S-5	S-7	F-1	F-3	F-5	F-7
Wheat grits	42,1	31,0	31,0	31,4	51,0	40,0	40,0	40,4
Uncooked broad beans	-	20,0	-	-	-	20,0	-	-
Extrusion-cooked broad beans	-	-	20,0	-	-	-	20,0	-
Broad beans extrusion-cooked with NaOH	-	-	-	20,0	-	-	-	20,0
Barley grits	20,0	20,1	20,1	20,1	24,0	24,1	24,1	24,1
Soya grits (toasted)	34,0	25,0	25,0	25,0	21,1	12,0	12,0	12,0
Calcium carbonate	1,02	1,02	1,2	1,2	1,2	1,2	1,2	1,2
Calcium phosphate	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Salt	0,7	0,7	0,7	0,3	0,7	0,7	0,7	0,3
Trace minerals and vitamins[a]	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Supplement of lysine[b] in kg of feed (g)	0,34	-	-	-	3,25	2,85	2,85	2,85
Supplement of methionine in kg of feed (g)	2,14	2,60	2,60	2,60	2,76	2,88	2,88	2,88

[a]Polish commercial composition of the indispensable trace minerals and vitamins for broilers [5]
[b]1 kg of chicken feed should contain: 11-5 g of lysine and 5-5 g of methionine.

RESULTS AND DISCUSSION

The factors found to have the biggest influence on the physical and chemical properties of extrusion-cooked broad beans were process temperature, feed moisture content and the shear rate created by the screw in the pumping zone of the extruder. Moreover, unsuitable process conditions caused serious operating difficulties, such as blockage, which of course decrease the extruder throughput. In practice, optimum process conditions are determined as a compromise between the required product properties, satisfactory throughput and energy input to the extruder [4, 11].

Very important is the correct temperature profile for the particular material processed. This particular material is very sensitive to temperature which rapidly influences the product quality and throughput of the extruder. At temperatures higher than 180°C there was a decrease in product quality (Maillard effects), particularly when the feed moisture content was less than 24%. The water content of the material slightly influenced the functional properties of the product and the extruder output. Higher feed moisture contents produced a more compact and harder product, with greater bulk density (see Table 4).

Table 4. Some Properties of the Products Obtained by Extrusion-cooking of Broad Beans under Different Process Conditions

	Bulk density (kg m^{-3})	Water absorption (%)	Color and texture (-)	Energy Input (kWh kg^{-1})	Output (kg h^{-1})
T=140 d=6 n=1,33 f.m.c.=24	445	164	Moderate	0,18	23,2
T=160 d=6 n=1,33 f.m.c.=26	460	155	Good	0,16	26,8
T=180 d=8 n=1,5 f.m.c.=28	470	124	Moderate	0,13	31,5
T=200 d=8 n=1,5 f.m.c.=30	478	101	Bad	0,13	32,2
T=160 d=4 n=1,33 f.m.c.=22	425	168	Bad	-	Blockage

T-temperature (ºC); d-diameter (mm); n-rotational speed (rev s^{-1}); f.m.c.-feed moisture content (% w/w, dry basis)

A relationship was found between the expansion ratio, bulk density and mechanical strength of the extruded broad beans. If the product expanded more following extrusion-cooking, it possessed a smaller bulk density and was more fragile.
The optimum process conditions were chosen from the range of experimental results obtained. The results in Table 5 are those near to the optimum, consistent with the necessary product quality and acceptable extruder output.
The results of the feeding trials showed a much greater chicken growth using extruded broad beans than with the same proportion of unprocessed material (see Table 6). When unprocessed broad beans were used in the chicken diet formulation, the decrease in growth was about 18% compared with the control group (group I). The addition of synthetic amino acids helped a little but the weight gain was still less than in the control group.

Table 5. Extrusion Conditions Selected as Optimum

Feed Moisture Content (% w/w, dry basis)	Com-press. Ratio (-)	Temp.[a] (ºC)	Die Diam.(mm)	Bulk Density (kg m^{-3})	WAI (%)	PDI (%)	Out-put (kg h^{-1})	Screw Rotat. Speed (rev. s^{-1})	Energy Input (kWh kg^{-1})
26	3,0	170	8	460	150	21	30	1,33	0,15

[a] Temperature in the high pressure zone of the extruder.

Table 6. Results of the Feeding Tests

Production effectiveness	Chicken group							
	I	II	III	IV	V	VI	VII	VIII
1. Chicken weight: by fourth week (g)	721	705	642	626	626	651	631	635
by fourth week (relative to control, %)	100	98	89	87	87	90	88	88
by eight week (g)	1815	1809	1497	1606	1648	1804	1635	1738
by eight week (relative to control, %)	100	99	82	88	91	99	90	96
2. Feed conversion ratio (kg kg^{-1})	2,67	2,56	3,10	2,89	2,96	2,71	2,84	2,67
3. Butchered effectiveness (%)[a]	68,7	69,7	68,6	70,0	69,4	69,9	68,5	69,1

[a] Weight of chicken carcass as % of body weight.

The influence of the extrusion-cooking of broad beans on the production effectiveness of the chickens was examined. Broilers in group V weighed 1648 g by the eighth week, 150 g more than those in group III fed on a mixture containing unprocessed beans. With supplementary lysine and methionine in the feed formulation (group VI), the production effectiveness of the chicken was similar to that in the control group fed on soya grits (1804 g, against 1809 g). The same trend was observed in feed conversion ratio, which also showed that extrusion-cooking increased the feed value of broad beans.
Increasing the disintegration of the broad bean protein structure, by the addition of sodium hydroxide prior to extrusion-cooking, did not produce any significant effect.
In this investigation no negative influence of the different feed formulation on the healthy conditions of the chickens was observed.

CONCLUSIONS

In the light of the results obtained during feeding trials, it can be concluded that extrusion-cooking is a good way of improving the animal feed quality of broad beans. In the feed formulation for chicken rations, extruded broad beans can replace at least 60% of soya grits, which can be very important, particularly in those markets where soya is expensive and/or has to be imported. The cost of processing by extrusion-cooking in comparison with conventional thermal processing of vegetable materials is relatively low. The total energy input was about 0-15 kWh kg^{-1} product, which is approximately half the cost of, for example, autoclaving [4, 7]. The resulting increase in production effectiveness more than compensates for the cost of processing.

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INFLUENCE OF THE DIE DESIGN, SCREW SPEED AND FILLING GRADE ON PHYSICAL PROPERTIES, PROCESSING PARAMETERS AND OUTPUT RATE OF THE EXTRUDED FISH FEED

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ABSTRACT

Salmon mixed feed was extruded in a five section Bühler BCTG 62/20 D twin screw extruder at 300, 450 and 600 rpm of extruder screw speed with different production output of 34kg/h and 66kg/h for each screw speed respectively. This experimental design was used for different die geometry intended to have cylinder or funnel shape pre nozzle hole (PNH). The length, shape and the diameter of the nozzle was the same for both, cylindrical or funnel shape design.
The specific density of fish feed pellets was positively influenced by the extrusion die without the dead flow areas such as funnel PNH when compared to the cylindrical PNH.
Funnel PNH has greatly influenced radial expansion of extruded feed while longitudinal expansion was influenced more by cylindrical PNH. The physical quality of extruded feed pellets was considerably better when funnel PNH was used. The power, specific mechanical energy (SME) and torque were higher while using the funnel PNH compared to cylindrical PNH. The die pressure increase was mainly influenced by feeding rate and screw speed but not by PNH. The temperature along the extruder barrel was influenced by PNH's as well as feeder rate and screw speed.
In general terms the data indicated that by consuming the similar energy while feed extruding, the funnel PNH can have higher production output rate with noticeably better product quality.
Keywords: *Extrusion, die, fish feed, screw speed, filling grade, bulk density, durability, SME, torque, PDI (%), power, pressure*

INTRODUCTION

Extrusion processing, as formerly defined by Smith (1976), is thermo-mechanical treatment by which moistened, expansible, starch and/or proteinous materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, and thus pre-define shaped through the die opening at extruder outlet. The essence of pre-defining shape is the die design. From the engineering point of view it is difficult to predict what will happen to the extrudate once it leaves the die. At this point effects as the extrudate swell, moisture flash-out, cooling and relaxation of the extruded material affect the actual size and shape of extrudate. The objective of extrusion

die is to distribute melted feed extrusion polymer in the die nozzle flow channel such that the material exits the die with a constant velocity (Harper, 1981). A few general rules are important for the extrusion die design such as to avoid the dead spots in the flow channel and to avoid the abrupt changes in the flow channel geometry (Rauwendaal, 2001). Bouzaza et al. (1996) have explained that the die design and the production throughput have influenced the radial as well as longitudinal expansion at the same specific mechanical energy (SME). A number of authors have shown that the die properties are important for greater radial expansion and minimizing the energy consumption during the extrusion process (Sokhey et al., 1979; Michaeli, 1984). However, the variables that should be taken into consideration are the rheological properties and thermodynamic of conditioned feed material in the die, as well as in the expansion processes present between the die and the feed material. The extruders screw speed has crucial effects on the physical quality of the extruded product while feed rate has no effect (Brncic et al. 2006). Models on effect of extrusion processing outputs on expansion and textural properties of extrudates have been proposed by several authors (Owusu-Ansah et al., 1983; Bhattacharya & Hanna, 1987). Entanglement of the extruded material molecules is related to a few important factors such as the extrusion dwell time, temperature and pressure (Gordon et al., 2007).
Designing the die geometry for the purpose of this research had an attempt to find the optimal die pre nozzle hole (PNH) shape, which will minimize the internal forces, unnecessary strain and energy consumption and hence better product quality. The shape of the die between the entrance and the die nozzle has been selected by experience rather than rigorous engineering principles. In this paper, the bulk density, radial (RE) and longitudinal (LE) expansion, as well as the durability measurements were all performed on the extruded pellets in order to analyze the influence of PNH shapes with different screw speeds and output rates on processing parameters. The benefit of this research is for any feed and food industry that uses the extrusion cooking.

MATERIALS AND METHODS

Prior to the experimental feed production a simulation of an internal sheer stress formation in the die was examined by the computer software (SolidWorks 2003 and SolidWorks Flow simulation, 2009) in cooperation with Department of Mathematical Sciences and Technology (IMT) at the Norwegian University of Life Science (UMB), Ås, Norway. An actual experimental production was performed at the Centre for Feed Technology, Fôrtek, UMB. Feed was formulated to meet or exceed the nutritional requirements for salmon fish (table 1).

Experimental design
Wheat was separately ground in the hammer mill fitted with two 0.8 mm screens and thereafter mixed with the rest of the ingredients (table 1) followed by grinding of the entire feed mix through the same screen. This batch was divided into two sub-batches that were extruded either with funnel or cylinder alike pre-nozzle die hole. For each of these die settings extruder was run with three different speeds and two different output rates. Therefore this was a three-factorial experiment with two levels of die types, three

different extrusion screw speeds and two different output rates. The experiment was run twice to obtain duplicates.

Processing

The hammer mill (Bliss Industries, Inc. Oklahoma U.S.A. Model E-22115-TF) was fitted with two screens (0.8mm) and was driven by an 18.5kW electric motor with a rotational speed of 2970 rpm and had an invariable amperage of 5 amps with milling output of 250kg/h. Air was sucked through the hammer mill screens by the speed of 7.2 m/s with the use of a Jesma Co (Sprout Matador A/S, Esbjerg, Denmark) fitted with a type DFC filter. Mixing of experimental diet with the batch of 150 kg was done in a twin-shaft paddle mixer Dinnissen (Pegasus Menger 400 l, Sevenum, Holland) for 180 seconds. Thereafter a feed compound was run through 0.8 mm hammer-mill screens in order to obtain uniform particle size distribution.

Subsequently the experimental feed compound was fed manually to the twin screw feeder (K-Tron KT20, Niederlenz, Switzerland). A feeder was adding 34 kg/h and/or 66 kg/h of the experimental feed compound into the twin screw, five barrel sections extruder (BCTG, Bühler, Uzvill, Switzerland) with the co-rotating twin screw speed of 300, 450 and 600 rpm respectively. Moisture was added in all experimental diets directly into the extruders 2^{nd} section as 21 º C water. Water was added 25% of total feeding production rate in order to keep the same drag flow. Screw configuration was the same for all the experimental runs (100R100, 80R80, 80R80, 80R80, 60R60, 60R20, 80R80, 60L20, 60R20, 60L20, 60R20-90° twist off, 80R80, 60R60, 60L20, 60L20-continually, 80R80, 60R60, 60L20, 80R80, 60R60, 60R60, 60R60, 60R20, 60R60) with a screw length of 1260 mm. R indicates forward conveying element, while L indicated backward conveying element. The first number in the element of screw configuration codes the pitch length of the screw, while the second number after the letter gives the elements length. All numbers are presented in millimetres. At the end of the screw elements the peek-die nozzle was used. The dies used for this research were with pre-nozzle hole shaped geometry of a cylinder (PNHC) and/or a funnel (PNHF) with the same die nozzle shape (cillinder), length (5mm) and diameter (3mm). The design of the dies is presented in the figure 1. The experimental extrudate was cut with 6 knifes and the cutting speed of 2900 rpm. Production data reported are means of values manually recorded as an instant observation. All the diets were dried in batch dryer for 40 minutes on 65 (+/- 5) °C.

Analysis of physical properties of extruded fish feed

All extruded feeds were representatively sampled after drying in form of uncoated pellets (in order to avoid any possible variation caused by fat addition during feed analysis). Bulk density was measured 24h after the production as the mean of four measurements by filling a cylindrical 1 liter container that was wiped off at the top and weighed out. The durability analysis was performed by measuring pre-sieved sample accurately 120g and put into Doris durability pellet tester (type 80000, Akvasmart AS, Bryne, Norway) that is consisted of an Archimedes screw that feeds pellets into a vane, simulating stress that pellets are exposed to during the pneumatic conveying in fish farm feeding systems. Thereafter the sample was sieved. Sieving procedure was the quantification of the amount of dust formed after the durability analysis where sieve shaker (Retsch, AS control 200) was run for 30 seconds with vortexing amplitude of 1.5 mm.

Table 1. Fish feed formula

Fish feed diet	(%)
Major ingredients	
[1]Fish meal	76.17
[2]Wheat	22.39
Minor ingredients	
*Carophyle pink	0.04
**Vitamin-Mineral premix	1.4
SUM (%)	100

[1]NorsECO, Egersund Sildeoljefabrikk AS, Egersund, Norway.
[2]Whole wheat, Felleskjøpet, Kambo, Norway.
* Carophyll® Pink 10% CWS, DSM Nutritional Products, LTD, Basel, Switzerland.
**Vitamin-Mineral premix - Fish, Norsk Mineralnæring, Hønnefoss, Norway.

The size of the sieve was 2,8mm. Sieve size was chosen as closest available to the extrusion die-nozzle diameter. Feed pellets that remained in the 2,8mm sieve after shaking were considered as non-fractured. Thereafter those pellets were weighed and the weigh difference between the pre-analyzed and analyzed-sieved sample has given the results for pellet durability index (PDI%). The durability analysis was performed in duplicate. RE and LE rate was recorded with electronic digital caliper (Würth, Germany) and the results presented are the means of 15 radial and longitudinal pellet measurements for each collected feed sample.
Three way analysis of variance with variable die geometry, feeding rate and screw speed was performed using GLM procedure of SAS software (SAS Institute Inc., 1999). Significant differences between treatments were determined by using the Ryan-Einot-Gabriel-Welsh F-test. The influence of previously mentioned factors on the responses such as the expansion rate, bulk density, durability, SME, torque, die temperature and the die pressure as well as the temperature change within the extrusion sections was presented with the level of significance 0.05.

RESULTS

The obtained shear stress simulation has shown the possibility that PNHF in the die have better pressure build-up and hence steady product formation when compared to PNHC (figure 2). The simulation has shown that PNHF requires less pressure to keep the same flow rate. The major pressure build-up in the die with the PNHC simulation showed to be just before the nozzle and within the nozzle’s channel.

Physical properties of extruded fish feed

The obtained ground fish feed premix after grinding had 95% of particles from 0.1 to 0.5 mm. The RE of the experimental fish feed was positively influenced by PNHF and hence the density of the product (table 2).

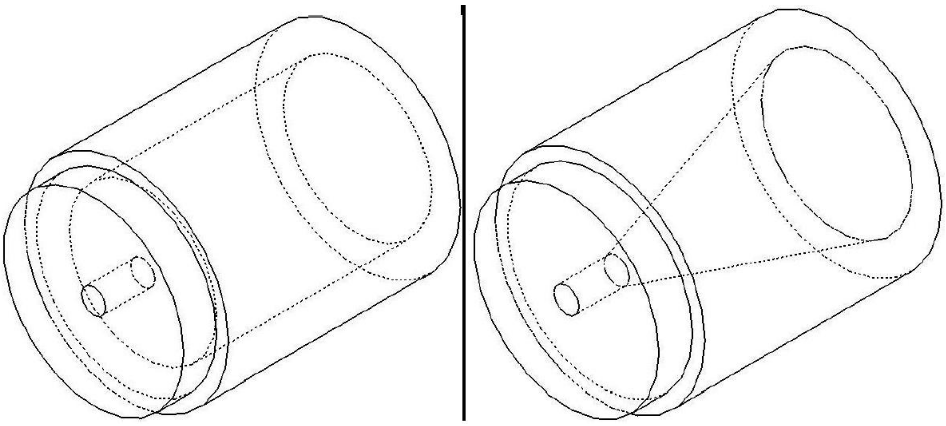

Figure 1. Experimental die design: cylindrical and funnel pre-nozzle hole

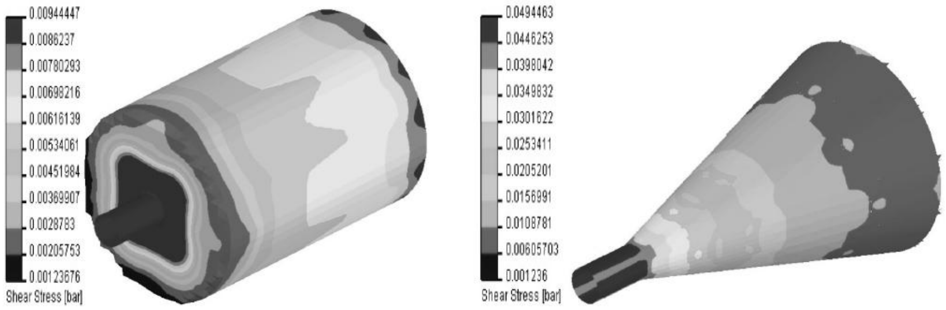

Figure 2. Shear stress simulation expressed in bars

The density was greatly influenced ($p<0.05$) by feeder rate and the screw speed. Further on, the LE was influenced by PNHC which has no valuable meaning for fish feed extrusion. Higher feeder rates have positively influenced RE due to higher pressure and torque increase, while no effect was found by increase of the screw speed. This can be explained due to driving force for melt expansion increase. The PDI (%) was positively influenced by usage of PNHF while no important changes in the feed quality were observed when compared the feeder rates. Up to 450 rpm of the screw speed the physical quality of fish feed was not changed. However, as the screw speed was increased up to 600 rpm the physical quality was significantly ($p<0.05$) decreased.

*Table 2. Effects of Die Geometry, Feeding Rate and Screw Speed on extruder processing**

	Die Geometry		Feed Rate(kg/h)		Screw Speed (RPM)			*p values*		
	PNHC**	**PNHF*****	**34**	**66**	**300**	**450**	**600**	Die Geometry	Feed Rate(kg/h)	Screw Speed (RPM)
Physical properties										
Radial expansion (mm)	3.63b	3.79a	3.63b	3.79a	3.73a	3.69a	3.73a	0.0001	0.0001	0.5880
Longitudinal expansion (mm)	7.74a	7.34b	7.74a	7.34b	7.07b	7.45b	8.11a	0.0310	0.0266	0.0001
Density (g/l)	392.7b	410.4a	416.1a	386.9b	437.8a	417.3b	349.4c	0.0015	0.0001	0.0001
Pellet Durability Index (%)	91.8b	94.8a	93.8a	92.9a	95.5a	94.9a	89.6b	0.0024	0.3430	0.0001
Processing parameters										
SME (Wh/kg)	1034.5b	1181.4a	1378.8a	837.1b	833.2c	1162.9b	1327.6a	0.0030	0.0001	0.0001
Torque (Nm)	57.8b	66.0a	59.5b	64.3a	67.4a	62.5b	55.9c	0.0002	0.0117	0.0001
Power (kW)	11.8b	12.9a	11.9b	12.9a	9.6c	12.8b	14.9a	0.0009	0.0019	0.0001
Die pressure (bar)	22.6a	21.8a	18.8b	25.6a	25.2a	23.7a	17.7b	0.2162	0.0001	0.0001
Temperatures (°C)										
Die temperature	118.4a	108.4b	106.5b	120.4a	102.4b	121.2a	116.8a	0.0013	0.0001	0.0001
Temp. 1st section	27.7a	26.8a	26.7a	27.8a	26.1b	28.6a	27.0ab	0.2264	0.1423	0.0322
Temp. 2nd section	53.9a	39.7b	41.3b	52.3a	45.8a	44.4a	50.2a	0.0021	0.0130	0.4896
Temp. 3rd section	111.8a	104.8b	106.2a	110.3a	101.8b	110.6a	112.5a	0.0091	0.1015	0.0039
Temp. 4th section	124.1a	116.6b	116.2b	124.5a	111.9b	122.2a	126.9a	0.0195	0.0108	0.0017
Temp. 5th section	131.9a	119.2b	116.2b	134.8a	115.4b	130.2a	130.9a	0.0008	0.0001	0.0011

**Means without common superscript within a row are significantly ($P<0.05$) different in a Ryan-Einot-Gabriel-Welsh pair-wise F-test.*
***Pre-Nozzle Hole Cillinder*
****Pre-Nozzle Hole Funnel*

Processing responces

The die geometry has influenced the extrusion processing to a great extent ($p<0.05$). Producing the extruded fish feed with PNHF have influenced the decrease of the production temperatures within the extruder. The extrusion temperatures have increased when feeding rate has increased where more screw flights are filled by the extruder melt, and therefore the positive conveying capacity of the screw have increased to achieve the greater flow rate and hence greater wall friction. The SME was directly affected by the changes in the screw speed and feed rate. The SME as well as the torque and power were increased by usage of PNHF. With higher feeding rates the SME was significantly ($P<0.05$) decreased and the die pressure increased. The SME was linearly increased by increasing the screw speed. Presented results in table 2 shows that the SME, torque and power were increased by using the PNHF instead of PNHC but not the die pressure. The torque, power and the die pressure were all influenced by feeder rate and the screw speed. Torque was increased by increasing the feeder rate ($p<0.05$) but decreased by increasing the screw speed ($p<0.05$). The temperature increase in 3^{rd}, 4^{th} and 5^{th} section in the extruder as a result of increased speed is in correspondence with general literature. However, by increasing the feeder rate the temperature increase in the last two sections have amplified ($p<0.05$), and it has influenced on the die temperature as well as the die pressure ($p<0.05$). On lower screw speeds the extrusion temperatures were also low. By increasing the screw speed up to 450 rpm the temperature has significantly increased, presumably due to increased friction between the wall and extrusion melt. The temperature increase was not observed by increasing the screw speed from 450 further to 600 rpm most probably because of similar viscous properties between the extrusion melts.

DISCUSSION

An increase in throughput leads to an increase in the wall shear rate and consequently to an apparent viscosity change of the melt at the die and hence increased RE. The increased RE by usage of PNHF can be explained by gradual pressure accumulation in the PNHF which allows the melt temperature to increase when pressure increases rapidly in very short distance and thereafter enters the atmospheric pressure. The product’s LE was increased by increasing the speed most probably due to viscosity change. These results are not in accordance with Rosentrater et al. (2005) who neither saw a change in RE nor LE as an effect of increased screw speed, while Lam and Flores (2003) have seen non-significant indications. Increased PDI (%) corresponds well with findings by Brncic et al. (2006) and Kraugerud and Svihus (2008). Effect of increased SME, torque and power by PNHF should be investigated more in detail before establishing this as a general judgment. The temperature increase by increased screw speed match findings by Bouzaza et al. (1996). A proposition made by Unlu and Faller (2002) that the screw speed and a feed rate influences the SME can be comparable to our findings. The phenomenon observed in our experiment where increasing the feed rate have increased the torque and increasing the screw speed have decreased torque is well elucidated by Chang and El-Dash (2003)

CONCLUSION

Funnel alike PNH may influence physical quality of fish feed pellets. The expansion rate and hence the density may be increased and/or manipulated by using PNHF with slight energy consumption increase. Overall, by using the PNHF, the higher production output rate is possible with noticeably better product quality.

ACKNOWLOEDGEMENTS

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PRESERVATION OF COARSE GRINDING STRUCTURES IN PIG AND POULTRY FEED PRODUCTION BY STRIKING NEW PATHS IN FEED PROCESSING

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INTRODUCTION

Worldwide, turning away from fine grinding and a clear trend towards so-called structural grinding of feed mixtures can be observed. Due to the realisation that fine grinding of feed can cause serious health and performance problems in pigs (NIELSEN 1998; KAMPHUES 2007) and poultry (TAYLOR 2004), the compound feed industry more and more prefers uniform, coarse crushing of feed mixtures and components by means of crushing roller mills. The positive effect of coarse feed structures on the development of the gastro-intestinal tract as well as on the fattening yield of broilers (TREVIDY 1995) is confirmed by integrators and fatteners.
Concentrate feed is mainly pelleted. During the pelleting process, however, the pan grinder rollers of the pelleting presses post-crush the coarser feed particles significantly (SVIHUS et al. 2004; GROßE-LIESNER 2008), so that the grain size distribution of the primary particles approaches that of pellets made from finely ground mixtures. Positive structural effects are therefore not or only partially effective. - If not pelleted, however, coarsely ground feed mixtures are particularly susceptible to segregation.
During expansion, on the other hand, the coarse feed particles largely remain unchanged despite intense compression and kneading stress. Moreover, it has already been known for a long time that expansion has positive nutritional effects, such as starch and crude fibre modification (BOLDUAN et al. 1993), higher crude fat digestibility (LIEBERT 1995), elimination of anti-nutritive factors (OUMER 2001; FARAHMAND and LUCHT 2002), minimization of the "cage effect" and ME-increase (PEISKER 1994). - Concerning the "calibration" of feed, unpelleted Expandat does not meet the requirements of many final customers, although it has proven to be an alternative to pellet feed, as its nutritional benefits have become effective in practice.
Therefore, the feed industry urgently needs a pelleting or agglomeration process which does not exert any post-grinding effect. Besides, it is to ensure good feed hygienisation and to confer additional positive nutritive and metabolic properties to the feed.

MATERIAL AND METHODS

a) Particle structure optimisation using the crown expander:

The methodological approach to particle structure optimisation was to link the expansion process with the pelleting process: At the expander outlet a tube extension ("crown") with drilled holes was mounted which resembles the annular die of a pelleting press (see Fig. 1).

The hydraulically adjustable closing cone of the expander is moved into the tube end. As a result, the product is forced to leave the machine through the holes of the crown. An orbital cutting device, the knives of which rotate around the crown, cuts the emerging product strands into pellets.
An important process characteristic is the fact that the energy inputs in the expander are controlled by the position of the cone in the crown: The deeper the cone is moved into the crown, the more holes are closed by it and the higher rises the mechanical energy required for pressing the product through the holes.

Fig. 1: View of crown, cone and cutter

b) Feedstuff, grinding, analysis, feeding tests

Commonly used fattening feed mixtures as well as barley, wheat and maize, which were ground with a hammer mill or crushing roller mill, were processed. A reference feed mixture consisting of 35 % maize, 35 % wheat, 25 % soybean meal, 1 % vegetable oil and 4 % premix and salt was used preferentially.
A particle size analysis of the feed mixtures and mono-components before and after processing was carried out by means of wet screening according to KAMPHUES, described by GROßE-LIESNER (2008).
The starch modification was determined by the International Research Institute for Feed Manufacturing IFF, Braunschweig, according to the AMG analysis method. First acceptance and feeding tests were realised in cooperation with the Institute for Animal Physiology, University of Göttingen, as well as by integrators of the customer.

RESULTS AND DISCUSSION

Using the crown expander, pellets having diameters of 2.5 to 10 mm and bulk densities in the range of 0.5 to 0.56 kg/l (Fig. 2) could be produced with moderate energy inputs. With slotted instead of perforated crowns, coarser lumpy aggregates were produced or crumbly Expandat structures with a low fines content in case of a low energy input. When treating mono-components, starch modification degrees of more than 80 % could be reached with high energy inputs.

The "crown" pellets surprised by their excellent *post-pelleting* properties: In a cool dry state, they absorbed subsequently added vegetable oil quantities of 12 % by weight and more.

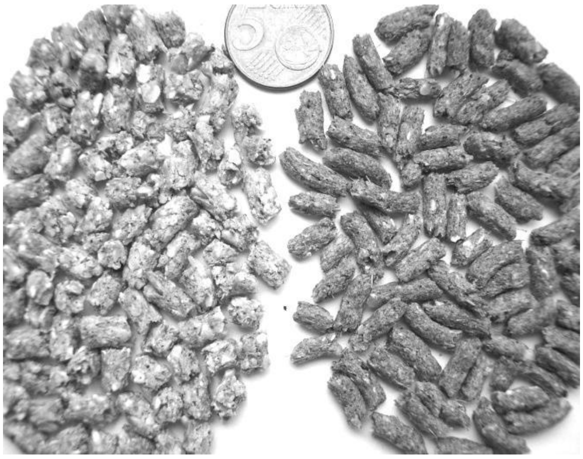

Fig. 2: Crown pellets
Left-hand: coarse grinding structures
Right-hand: finely ground, with 20 % maize silage

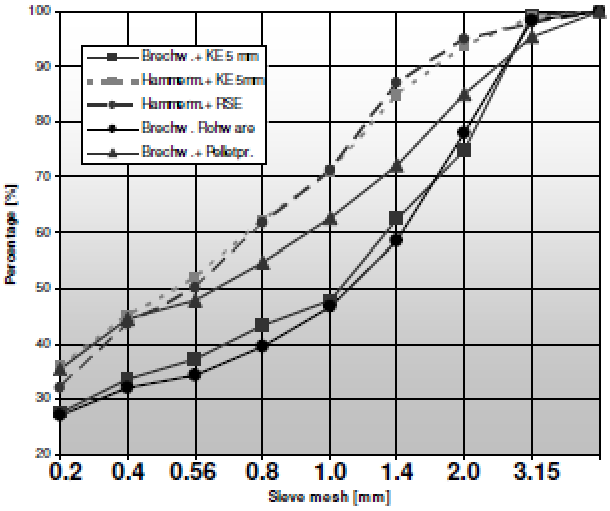

Fig. 3: Influence of coarse and fine grinding as well as of different treatments on the particle size distribution of a reference feed

The particle size distribution of differently ground (hammer mill; crushing roller mill) and processed feed mixtures is shown in Fig. 3:
Crown-pelleting hardly influenced the particle size distribution of coarsely ground feed. It largely matched that of the untreated raw material. – The pellet shaping and particle preservation reached with the reference feed could be reproduced with all other feed mixtures used.
Traditional pelleting of the coarsely ground raw material caused a clear post-crushing effect. As a consequence, the particle size distribution strongly corresponded to the fine grinding level of the raw material after hammer mill grinding and expansion. – This result confirms the knowledge gained so far on the effect of the pelleting press on structure grinding of the feed.
Furthermore, the effect of a treatment with only minimal mechanical energy input on the particle size distribution of the reference feed was tested. For this purpose, cone and cutting device were removed and a crown with a weight-loaded flap at the end, but without bores or slots, was mounted (Fig. 4). With this equipment, the feed mixtures could be exposed very easily and without controlling measures to a compression and kneading treatment (friction) at low mechanical energy inputs o 4 to 6 kWh/t after pre-conditioning with steam. This also resulted in a slight increase in temperature. – The effect on the particle size distribution is shown in Fig. 5:
This friction treatment produced an agglomeration of the fine particles, particularly in case of the coarsely structured feed. This coarsening of the fine fraction minimized the segregation tendency significantly. The additional temperature increase due to the mechanical energy input had the positive side-effect that during subsequent cooling by means of ambient air the product was re-dried satisfactorily – contrary to steam treatment alone, where more moisture condenses in the product than is expelled again during subsequent cooling with ambient air.

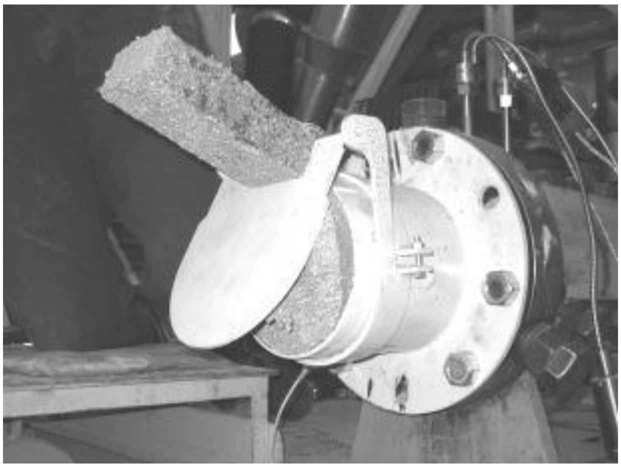

Fig. 4: Expander frictioning crown

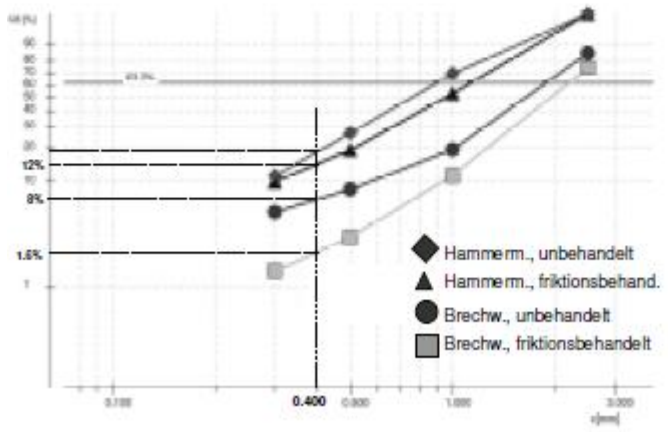

Fig. 5: Influence of friction treatment on the particle size distribution of a reference feed mixture

CONCLUSION

Crown pelleting combines the advantages of expansion, extrusion and pelleting while substantially avoiding their disadvantages. The feed aggregation while preserving the coarse structure, the outstanding *post-pelleting* properties of the pellets and the nutritional benefits as a result of the hydrothermal process recommend the process for large-scale application in the compound feed industry.

The frictioning process must be regarded as optimised hygienisation and conditioning process in which the raw material maintains its meal feed character, while the fine particle fraction is coarsened, however, and thus the mixture stabilised. – This technology is recommended for simple and inexpensive treatment of compound feed in meal structure for different animal species

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NEW TECHNIQUE OF EXTRUSION AND ITS APPLICATION

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ABSTRACT

The new development of the extrusion and expansion technique in the food and feed industries was introduced. The intensified conditioning technique is an effective way for increasing the output of an extruder. The conceptions of the shearing technique with stabilized flow in the extruding process and the stabilized flow technique in the discharging process were set forth here. The extrusion process parameters were optimized by means of configuration of the modularized screws. And the research progress of supercritical carbon dioxide ($scCO_2$) applied for the extrusion and expansion technique in the food industry was also discussed.

Keywords: *extrusion; expansion; intensified conditioning; stabilized flow; modularization; supercritical*

The extrusion and expansion technique has been applied fully in the food and feed industries at present. In recent years, new techniques come forth ceaselessly in the extrusion and expansion fields, and their application has promoted the substantial development of the extrusion and expansion equipment in the efficiency, energy consumption and reliability as well as the quality and processing scope of the products.

HIGH RIPENING AND INTENSIFIED CONDITIONING TECHNIQUE

The materials should be conditioned prior to entering the extruder. The conditioning aims at pre-gelatinizing the materials. The gelatinizing effects will directly affect the working performance of the extruder and the quality of the extruded products. Therefore, the conditioning technique is a major key process for the extrusion system.

The common conditioning technique is that the materials are mixed with water and steam simply: the water and heat cannot be uniformly penetrated into the materials in the simple mixing; as for materials, especially for some oily materials during conditioning, viewing from micro particles, the water cannot be into the inside of the particles due to surface tension of water, accordingly, the gelatinization cannot be increased inside the particles. It certainly will need much more steam and longer time to improve the conditioning effect.

The high ripening and intensified conditioning technique is not only the simple mixing, and it emphasizes the heat transfer during conditioning, the relative movement speed of the mass transfer as well as the penetrating velocity. The penetrating velocity of the heat transfer and the mass transfer is dependent on the factors such as steam, temperature, velocity and moisture gradients between the inside materials and the interfacial layer of the powdery particle materials as well as material properties (density, particle size and water content). However, the high-speed conditioning may increase the temperature, velocity and moisture gradients, and improve the conditioning effect accordingly.

The sub-functional paddles are provided in the high ripening and intensified conditioning technique, enabling the materials and mass transfer to form a certain relative movement speed in the machine body and a strong contact and strong permeability, thus to reduce the conditioning time and steam consumption. Also, since the materials are not settled fully in the housing bottom during conditioning, but the partial materials float inside the housing, thus to increase the fullness of the materials inside the conditioner housing and prolong the conditioning time further.

The high ripening and intensified conditioning technique enables the fullness of the extruder increased from 30～35% to 55～60%. As for the conditioners with same effective capacity, under precondition of the same output, the conditioning time can increase from 40～45 seconds to 180～200 seconds, the gelatinization can increase from 35～40% to 50~55%, and the steam consumption can be reduced by about 20%. Compared with commonly conditioning, the new technique enables the extruder output to increase by 10～15% and to reduce the energy consumption of the extruder because the materials are intensively conditioned and sufficiently ripened; and also, the increase of the pre-gelatinization of the materials enables the extruder to run smoothly, to reduce the abrasion of the screw and the lining in the expansion chamber obviously and the cost for replacing the wearing parts accordingly, so as to realize the energy-saving, high-efficient and environment protective conditioning in the extrusion and expansion technique.

STABILIZED SHEARING AND EXTRUDING TECHNIQUE

Stabilized flow and stabilized shearing technique in extruding process

The extruding process is of the most core technological progress in the extrusion and expansion equipment. From viewpoint of improving the efficiency and reducing the energy consumption, the Muyang personnel engaged in research and development of the extrusion equipment set forth the assumption on the stabilized flow of materials in the extruding chamber, which is helpful for improving the quality of the extrusion products, and also set forth the theory on the stabilized shearing, which is validated by testing. The application of this theory effectively enables to increase the output of the extruder, reduce the energy consumption, reduce the abrasion of the screw and chamber body and improve the quality of the extrusion products. Also, the application of this technique has enlarged the processing range of the extrusion products, enabling the single-screw extruder to process 1.0mm small particles and even to process more small particles in the long-time stable production.

Material stabilized flow technique in extruding process

Due to existence of the pressure difference in extruding process, there are multiple flow patterns of the materials in the screw, shown in Fig 1, the leakage and cross flow of the materials seriously affect the quality of the materials. Due to leakage in the extruding chamber, the time of cross flow and forward flow of the materials stayed in the extruding chamber is very different, which directly results in difference in the expansion coefficient of the extruded food or feeds, finally affects the quality of the extrusion products, e.g. inconsistent particles and non-uniform gelatinization.

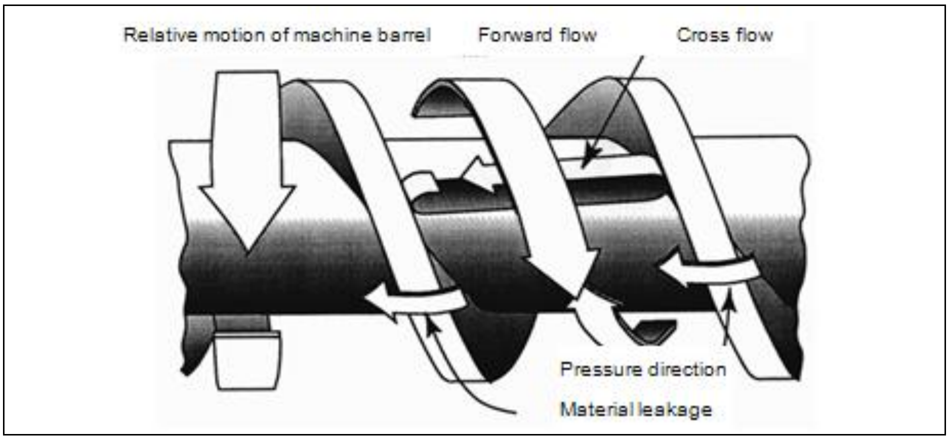

Fig 1. Materials flow in extruding screw

The screw configured in the new technique and “zero” space designed between screw and extruding chamber can reduce the leakage of the materials as much as possible and also the subdividing mixture structure was used for fully mixing the leaked material flow and other material flow, so the extruded materials ripened uniformly and the extruded and cut particles were uniform and beautiful, and the energy dissipation caused by the leaked materials stayed in the extruding chamber for a long time was effectively reduced.

Stabilized shearing technique in extruding process

In the extruding technique for the feeds and foods, the shear rate should be enhanced for ripening materials in the extruding chamber generally. In the present technique, the process of the materials fed from the inlet of principal machine of the extruder and discharged from the die plate is a rush shearing process. The rapid shearing was attended by high pressure, high energy consumption and high abrasion as well as unstable material flow, thus, the high technology is required for the discharging die of the extruder in this means. Only the good discharging die can release the unstable material flow and enables the materials to become the uniform expanded pellets.

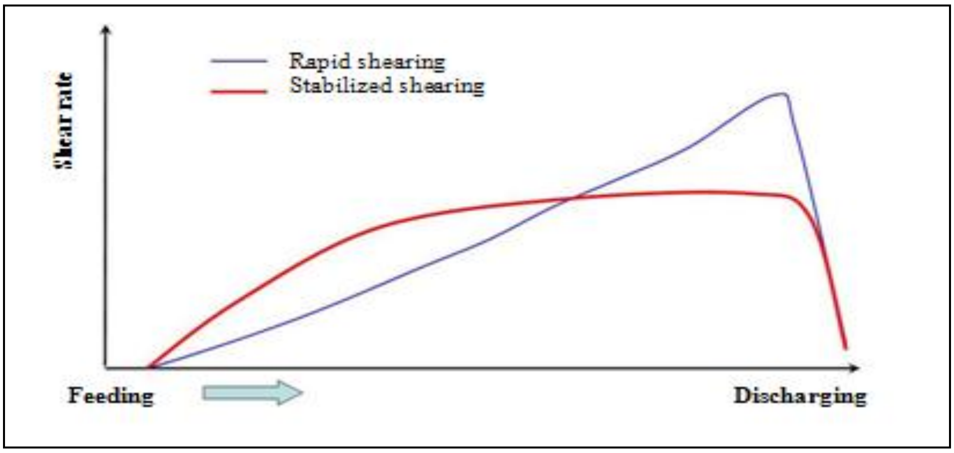

Fig 2. Rapid shearing and stabilized shearing

The stabilized shearing was emphasized as a shearing process and a stable shearing process. In this process, the peak value of shearing was smaller than that of rapid shearing, but, through rational allocation of the screw, keep uniform gelatinization and rapid shearing of the materials after stabilized shearing, and even increase the gelatinization further.

Since the peak value of shearing was smaller than that of rapid shearing during shearing, the abrasion of the screw and chamber body was reduced accordingly. The service life of the wearing parts was prolonged, it is most important to enhance the safety and reliability of the extruded and expanded foods. Because the stabilized shearing is a process with small fore and aft difference, so the leakage of the materials was reduced relatively in the overall process, the materials are uniform in the extruding chamber, the equipment ran more stably, and the finally extruded expansion pellets were more uniform and more beautiful. It was proved by practice that the stabilized shearing is a shearing process to reduce the energy consumption, the extruder applying the stabilized shearing technique can increase the output by about 15%, the power consumption per ton materials of the extruder system may be decreased by about 12%. The stabilized shearing is a economic and stable means farthest to reduce the energy consumption.

Stabilized flow technique in discharging process

The discharging die technology is one of the core technologies in the food and feed extruding field. It will directly affect the application scope and the quality of the expansion foods.

At the tail end of the screw, the materials rotate at a certain speed and unstable, if the materials directly enter the die to be shaped, which is adverse to shaping and uniformity of the expansion pellets. The stabilized flow technique is a process for improving this unstable material flow.

By additionally setting a stabilized flow device between extruding chamber tail end and discharging die, first stopped the rotated materials and then made the material flow to form an annular extruding area, the annular surface of this area was uniform with die area, the constraining force of the material flow increased slowly and the flow velocity was slowed down, finally, the materials were distributed uniformly to the right ahead at holing area of the die. This material flow may ensure the materials uniformly to enter the discharging die, accordingly guarantee the shape uniformity of the materials. Also, since the materials extruded from the screw first entered the annular extruding area, thus the impact force of the materials to the die was reduced greatly, the impact force reduced to the die reduced the damage extent of the die as much as possible and prolonged its service life.

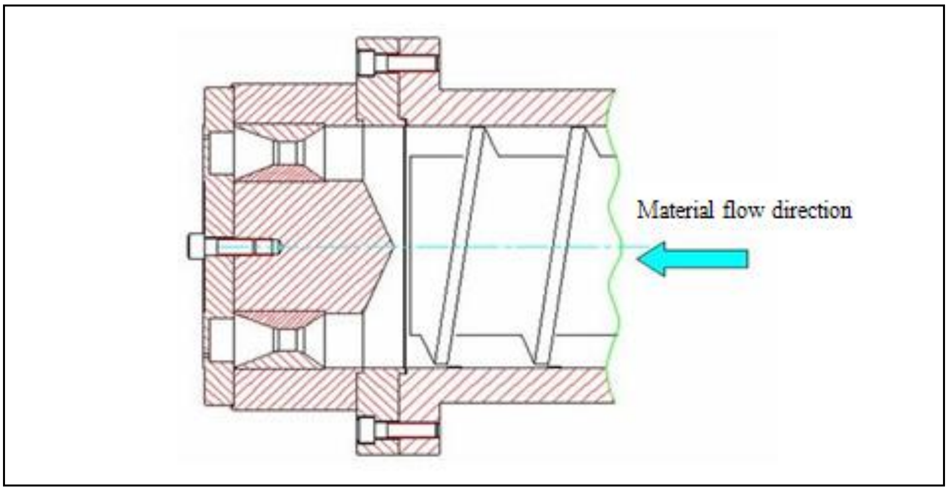

Fig 3. Stabilized flow discharging structure

MODULARIZED FLEXIBLE SCREW COMBINATION AND OPTIMIZATION OF TECHNOLOGICAL PARAMETERS

Modularization and flexibility of screw combination

The screw combination is another core technique of the extruding equipment. For different raw materials and different requirement for extrusion and expansion, the different type of the screw should be configured according to different material property and also the different type of the screw should be combined with technological parameters of the extruder, only the combined effect can produce the high-quality expansion products.

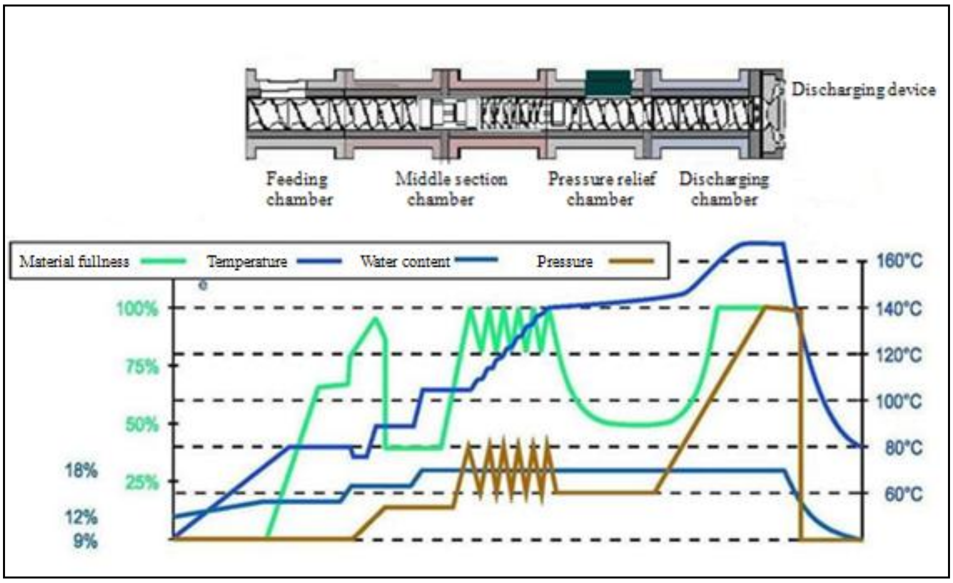

Fig 4. Screw combination and technological parameter

For adapting the different raw material property and being adequate to the different expansion demand of various expansion products, the screw was designed to the standard variable combination modularization type. In this way, the adjustable configured screw with different technological parameters enabled the same extruder adequate to the different expansion demand of various expansion products in the food and feed industries.

The modularized flexible screw combination may save the resource maximally, enabled one production line to process the multiple expansion products and avoided the overlapping investment.

Control and optimization of technological parameters

The appropriate screw configuration was only one of important and necessary conditions for processing the high-quality expansion products, but the proper processing technique was another important and necessary condition.

The wide application range of the extruder and different technical parameter required for expansion products determined the different technological parameters used in the extruder; in each manufacturer, either in the food industry or in the feed industry, the formula for processing the expansion products was ceaselessly regulated according to demand of the market all along, which directly affected the timely adjusting of the technological parameters of the extruder as required; even sometimes, the raw materials fro different place of origin had a certain affect on the expansion products, thus, all of above factors determined the very different technological parameters of the extruder.

At present, the technological parameters of extruder is mainly controlled by the skilled operator, and the skill level of the operator directly affects the quality of the expansion products, so this is a basic reason that at present, many extruder users use the same type extruder of the same manufacturer, but the use effect is different in the different extruder user.

The control and optimization of technological parameters first provided a standard recording method for very different technological parameter. The standard data can be read by the control system of the extruder to direct the extruder carrying out the standardization production through operation by the extruder operator.

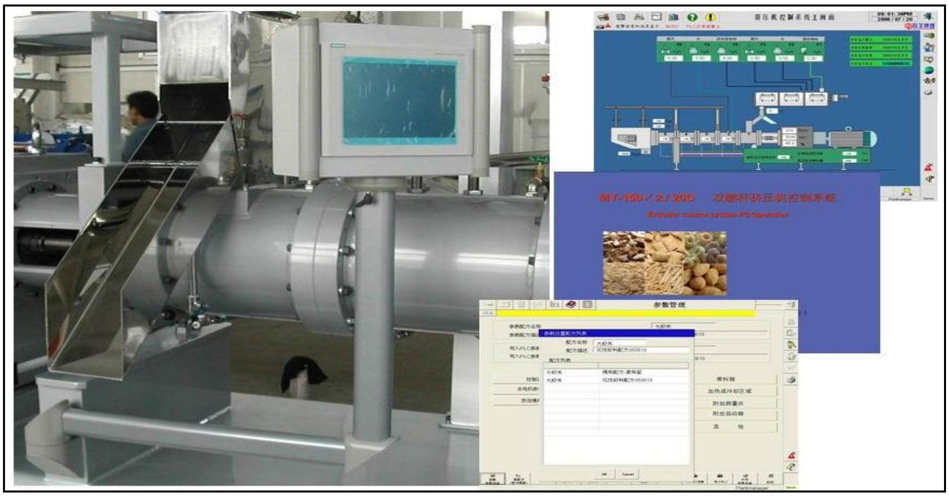

Fig 5. Technological parameter database and its application

The control and optimization of technological parameters contain a database. The data in this database was first sourced from the optimum data for processing some formula expansion product obtained during testing through ceaseless adjusting and groping under precondition of a specific technical requirement.

Secondly, it was sourced from the formula composition analysis of the optimum data and the technical parameter analysis of the expansion product. For formula composition analysis, such as starch content, fat content and protein level in the formula, among them, how much content the vegetable protein and the animal protein account for respectively in the protein; for technical parameter analysis of the expansion product, such as expansion coefficient, gelatinization, discharging temperature and discharging water content etc., formed these data and the technological parameters chain into the “group data”, the formula of different material property formed accumulatively through testing had the different corresponding “group data”, in this way, formed a complete technological parameters database.

During application, when finding out a new formula, first found out a similar formula in the database through composition assaying analysis and obtained a proper technological parameters through data optimization technique to direct the production of the extruder under control of the technological parameter. In this way, fully avoided the non-human factor affect of the operator and kept the uniform quality of the expansion products durably.

EXTRUSION AND EXPANSION BY USING SUPERCRITICAL CARBON DIOXIDE (SCCO_2)

The traditional extrusion and expansion technique was of the steam expansion technique. The materials were expanded rapidly through steam vaporized under a certain pressure. The high temperature (130℃～170℃ or more higher), high pressure, low water content (13%～24%) and high shearing force would cause a certain loss of the heat sensitivity constituent (e.g. flavor agent, vitamin and amino acid etc.) in the food materials.

By improving the existing double-screw extruder, fill the supercritical carbon dioxide into the cooling section of the expansion chamber under pressure higher than that of barrel, mixed uniformly with materials. When the materials were extruded from the die, the materials were expanded under expansive action of the carbon dioxide for obtaining the even more uniform porous expanded structure.

The supercritical carbon dioxide applied in the food extrusion and expansion technique may be used in the processing under temperature lower than traditional extruding temperature based upon steam expansion. And the carbon dioxide is of an inert medium, almost no any destructive effect on various constituents in the food; thus, it may protect the sensitivity constituent, vitamin, flavor compounds and natural pigment constituent, and enables the products to have the better WSI and WAI values. At present, the application of this processing technique is at the research and development stage in the food industry of our country, but it has the very broad prospects for development.

CONCLUSION

During period of "11th Five-Year Plan", the food (feed) industry of our country will mainly break through the key technologies, such as food texture and structure recombination and property perfecting technology, biotechnology, quality and safety control technology. Along with application of the extruding equipment, the extrusion and expansion technique will be developed more rapidly.

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HOW DOES OIL ADDITION IN MAIN MIXER INFLUENCE PHYSICAL PROPERTIES OF TROUT FEED?

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ABSTRACT

The use of extrusion to produce all types of aquatic feeds is spreading rapidly throughout the world. Today, aquatic feeds are mostly produced in form of pellets by extrusion process, and their physical characteristics are dependable, among other factors, upon composition of extruded mixture and extrusion conditions.

The pellets' floating and sinking properties (settling velocity) are often the most critical functional characteristics, as the feed buoyancy impacts both the aquatic animal's nutrition, as well as the aquaculture environment. Floating/sinking properties are dependable of density of the pellets and density can be influenced by extrusion conditions.

Trout is a predatory fish which "catches" feed while it is slowly sinking in the water and for the trout, it is necessary to produce slow sinking pellets. Trout poorly digest starch, and main energy sources in trout feeds are fats and proteins. Thus, adding fats in the feed for trout is very important. However, large quantity of fats strongly influences secondary extrusion parameters (temperature, pressure, energy consumption, etc.). Therefore, the effects of oil addition on extrusion cooking conditions, and thereby on physical properties of trout feed were studied by using single-shaft extruder.

The aim of this experiment was to investigate possibility of varying physical properties of extruded product when oil was added in main mixer. A 4 X 3 X 2 factorial treatment design was used with changing concentration of fish oil (0, 3, 6 and 9 %), number of rotations of extruder main screw (90, 150 and 210 rpm) and die opening size (50 and 100 mm^2).

Addition of oil in the main mixer strongly influenced secondary extruder variables (temperature and pressure). Adding 3 % of oil in the main mixer and using the die with 50mm^2 of total openings' area caused high temperature decrease, in comparison with 0 % oil. When 6 and 9 % of oil is added, further temperature decrease was not so intensive. Temperature increased with increasing of screw speed, as it was expected. Comparing values for same oil concentration and screw speed and different die openings' area, it can be seen that temperatures obtained with 100 mm^2 die are slightly lower. Adding 3 % of oil did not caused so intensive temperature decrease, as it did with 50 mm^2 die. Addition of oil influenced pressure in extruder barrel by decreasing it. In contrary with temperature profile, higher screw speed resulted in lower pressure.

Size of die openings' area did not significantly influenced energy consumption during processing. Using of higher screw speeds induced higher temperature. High temperature of material and pressure drop at the exit of the die caused very intensive evaporation of

water from material. Water loss was higher when material was extruded at higher screw speeds and lower oil concentrations, and it was more intensive for 50mm^2 die as a result of development of higher temperatures when using this die, in comparison with 100 mm^2 die. Increasing the level of fat during extrusion caused an increase in the bulk density of the feed. This was possible due to the lubrication of the material inside of the extruder, which made it more difficult to impart mechanical energy into the product. Preventing of energy impart reduced starch gelatinization. As a result, added oil kept the material from expanding, and thus increased bulk density of the pellets. Addition of oil did not significantly ($p<0.05$) influenced settling velocity of product for screw speed of 180 rpm and for both dies used. For screw speed of 300 rpm settling velocity was significantly higher for oil concentration of 6 and 9 % when 50 mm^2 die was used, and for 9 % when 100 mm^2 die was used. For screw speed of 420 rpm, oil addition, regardless of oil concentration, significantly increased settling velocity, in comparison with material without oil added. Varying of oil concentration (3, 6 and 9 %) did not have influence on settling velocity of extruded product.
Keywords*: extrusion, pellets, physical characteristics, oil, trout*

INTRODUCTION

Extrusion can be defined as the process of forcing a food/feed material to flow under one or more of a variety conditions (i.e. mixing, heating and shear), trough a die which is designed to form and/or puff-dry the ingredients. In the extruder barrel the material is exposed to thermal and mechanical treatment, plasticizing and shaping the material from an initially granular powder to finished product [4]. Extrusion is a hydro-thermal process where many factors, such as barrel temperature, die geometry, extruder type, feed composition, feed moisture, feed particle size, feed rate, screw configuration and screw speed, can influence product quality [10].

Overview of extrusion process

Grinded ingredients are mixed to appropriate recipe and then transported to a holding bin above the extruder, which is of adequate volume to support the extruder operation for a minimum of five minutes. Essential to any extrusion operation are feed delivery systems which provide uniform flow at any desired extrusion rate.

Material from the delivery system is fed into the next section of the extruder, which is called the preconditioner [13]. The preconditioning step initiates the heating process by the addition of steam and water into the dry mash. The preconditioner supplies the extruder with uniformly mixed and hydrated material which improves stability of the extruding system as well as aids the development of certain final product characteristics. The main functions of a preconditioner include: 1) mixing of multiple ingredients such as fats, molasses and colors; 2) hydrating the dry mash; 3) precooking, which begins gelatinization of starches and denaturation of proteins; 4) thermal energy addition, generally in the form of steam [2].

In preconditioner the material is heated up to 80-90°C and moistened up to 22-28%. Preconditioning step improves extrusion process in many ways [14]. It increases extruder capacity, decreases wear of extruder components and adds time to extrusion process which allows for proper absorption of high moisture. When the three essential objectives (hydration, heating and mixing) of preconditioning prior to extrusion are adequately satisfied, several results should be expected. First, the raw material particles should be thoroughly hydrated to eliminate dry core present in the center of raw material particles prior to entering the extruder barrel. This leads to more efficient cooking of starch and protein. Complete hydration of raw material particles assist in heat penetration. Second, the raw material particles should be thoroughly heated to eliminate cool core present in the center of raw material particles. This, coupled with complete hydration, results in more complete starch gelatinization and protein denaturation. Sometimes, mixing of ingredients and preconditioning steps are conjoined in same equipment.

After preconditioning, the material is discharged into the extruder barrel where major transformations of raw preconditioned material occur. The types of the processes in the extruder barrel depend on the type of extruder. The inlet screw flighting is usually very deep and has a long pitch with flighting that are nearly vertical to maximize transport of the material into the processing zone of the barrel. Here free flowing material is converted into dough. In order to assist in blending water and steam with material, the compression ratio of the screw profile is increased and temperature and density of the moist dough is rapidly elevated. The screw pitch decreases and flight angle may also decrease to accomplish more mixing in this area. In the final cooking zone, the density is further increased as the combination of thermal and mechanical energy inputs plasticizes the material above its melt transition temperature. In the extruder barrel very high temperatures can be achieved, but the residence time of the feed at such elevated temperatures is very short (5-10 sec). This high temperature short time process maximizes the benefits of heating feed ingredients (improved digestibility, inactivation of antinutritional factors and pasteurization) while minimizing nutrient degradation.

Depending upon the design of the extruder, additional heating and cooling processes can be triggered in individual sections in the double jackets of the barrel (heating and cooling water or oil, steam addition). Direct supply of water or steam into the extruder barrel is possible in zones with low material pressure [7].

Maximal temperatures in extrusion of different feed materials are usually between 100 and 140°C and the pressure, depending of the product formulation, rises to 20 or even 70 bar [6].

The screw forces the material through the die, where the material is formed and expanded at the outlet of the die. The product is cut with rotating knife into the desired length. Die have two major functions. It provides restriction to product flow causing the extruder develop the required pressure and shear. In addition, it shapes extrudate as the product exits the extruder. The amount of expansion can be controlled by formula manipulation and open area in the die. The relative speed of the knives and the linear speed of the extrudate results in the desired product length [15].

During the extrusion process the temperature, moisture, pressure and shear forces act on the product during relatively short residence time and cause changes in product components, which can either have a positive or negative effect on the feed value. Extruding has the following beneficial effects on the feed mixture: 1) increased digestibility of components (starch modification, protein denaturation, fineness and solubility of fiber); 2) structuring and forming of individual components and formulations such as fish feed or texturing of high-protein components; 3) high water absorption ability; 4) different shapes of the product; 5) abrasion free pellets; 6) flavor enhancement; 7) destruction of antinutritional and toxic components (trypsin inhibitors, lecitins, glucosinolate); 8) inactivation of undesirable enzymes (urease, peroxidase, lipoxigenase); 9) destruction of microorganisms (bacteria, salmonella, yeasts), etc. However, changes in the extruder can also have some negative effects: 1) destruction of temperature sensitive vitamins and supplements (vitamins A, C, B_1, pigments, etc.); 2) inactivation of enzymes (amylase, phytase); 3) destruction of amino acids (lysine); 4) undesirable substances (Maillard, starch-lipid), etc [4].

Extrusion processing for aquaculture feeds

The use of extrusion to produce all types of aquatic feeds is spreading rapidly throughout the world [15]. Extrusion of aquatic feeds is a very broad topic, considering the number of different aquatic species being raised in the world today and the variety of feed formulations and product specifications [6]. In fish feed extrusion variable density of the extruded material, in particular, provides substantial advantage over simply manufactured pellets. In this way, the ability of the feed to sink in water can be specifically adapted to the eating habits of the fish, for example slowly sinking pellets for trout and salmon, with fat content up to 30%, or water-proof pellets for shrimps and other crustaceans [7].

The production of aquatic feeds requires far more knowledge and technical expertise than feed production for poultry, cattle or pig feed, due to the following reasons: (1) unlike land-living animals, fish have a very short digestive system and therefore they need an easy to digest feed; (2) the feed has to be highly digestible so that in case of an optimum feed utilization, the quantity of water polluting excreta produced is as low as possible; (3) form and size of the feed have to be adapted to the size of the fish; (4) the product density (sinking and floating properties) has to correspond to the animals' natural way of feed consumption, thus, water pollution by feeds material which is not consumed is avoided and the feed utilization (kg feed/fish) is improved [8].

Floating aquatic feeds have bulk density (determinated by measuring the mass of one liter sample) below 440 g/l for fresh water and below 480 g/l for sea water (3% salinity) [11]. They are expanded pellets varying in diameter from 1.5 to 10 mm in size. Typically floating feeds are extrusion cooked at moisture content of approximately 24 to 27% and at temperature of 125 to 140°C and expand upon exiting the die approximately 125 to 150% of the original die holes [6, 14]. In the production of sinking aquatic feeds, the operating conditions of the extruder are modified to yield a product with bulk density greater than 600 g/l for fresh water and greater than 640 g/l for sea water [11]. Less steam is added to the conditioning cylinder and water is added instead [15]. These products are generally 1.5 to 4 mm in diameter and predominantly are used for shrimp feeds. Sinking aquatic feeds are designed to feed slow eating bottom feeding species. As a result the major product specification is for the product to hold together in water for two to four hours so that it can be consumed. The moisture content necessary to produce these feeds is 22 to 25% and temperature is around 120°C. Slow sinking aquatic feeds are typically in the density range of 500 to 580 g/l for fresh water and in the range of 520-600 g/l for sea water [6].

In aquatic feed production, the pellets' floating and sinking properties are often the most critical functional characteristics as the feed buoyancy impacts both the aquatic animal's nutrition as well as the aquaculture environment. A feed's formulation plays a major role in product density but also modern extrusion technology provides many ways to control final product density [11]. Fish feeds are processed to various bulk densities depending on the species being cultured: floating (carp, tilapia, catfish), slow sinking (trout, salmon) and sinking (shrimp, river crab, cod) [15].
Trout is freshwater and saltwater fish belonging to the Salmonidae family. It is predatory fish which "catches" feed while it is slowly sinking in the water. Normally, this fish do not consume feed on the ground [8]. For the trout, it is necessary to produce slow sinking pellets. Trout poorly digest starch and main energy sources in trout feeds are fats and proteins. Thus, adding fats in the feed for trout is very important [1].
However, large quantity of fats strongly influences secondary extrusion parameters (temperature, pressure, energy consumption, etc.). Therefore, the effects of oil addition on extrusion cooking conditions and thereby on physical properties of trout feed were studied by using single-shaft extruder.

MATERIAL AND METHODS

Raw material formulation

Table 1 shows ingredient composition of dry mixture for trout. Mixture was formulated to meet or exceed all known nutrient requirements for trout, except fat, since fish oil was added in the dry mixture before conditioning process.

Table 1. Ingredient composition (g/kg) of experimental diet

Ingredient	
Fish meal	610
Soybean meal	120
Corn gluten	120
Wheat flour	65
Yeast	20
Sunflower meal	20
Soybean oil	20
Vitamin and mineral premix	25

Experimental design

A 4 X 3 X 2 factorial treatment design was used with changing concentration of fish oil (0, 3, 6 and 9 %), number of rotations of extruder main screw (180, 300 and 420 rpm) and die opening size (50 and 100 mm^2).

Conditioning

Complete mixture was conditioned in Muyang SLHSJ0.2A, China, double-shaft pedal mixer - steam conditioner, until material reached temperature of 80°C. Water was added directly into feed mash during conditioning, in order to achieve final moisture content (23,5 ± 0,5 %).

Extrusion

A single screw extruder, OEE 8, AMANDUS KAHL GmbH & Co. KG, Germany, with a length-to-diameter ratio of 8,5:1 and dies with 3 mm diameter openings and total openings' area of 50 and 100 mm^2 respectively, was used (Fig. 1). The speed of passage of material was 10 kg/h. Temperature sensor was inserted in the extruder barrel (T) and pressure sensor (P) was inserted to touch material.

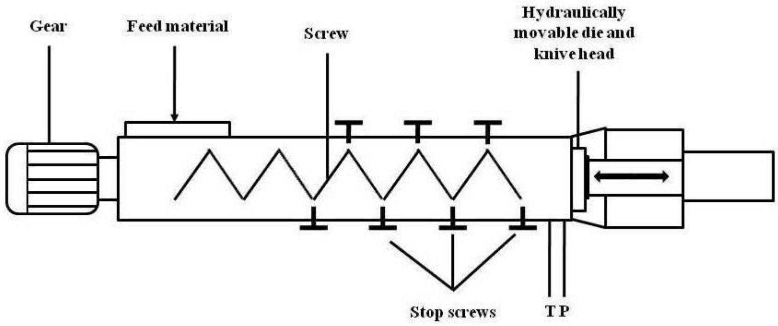

Figure 1. Single screw extruder diagram

Water loss

Moisture of material was measured with infrared moisture analyzer, Ohaus MB45, United States. Water loss was calculated as a change in moisture before and after extrusion process.

Bulk density

Bulk density was defined as the weight of an experimental sample in a 1 L vessel.

Expansion rate

The mean diameter of each experimental sample of pellets (a random sample of 15) was measured by using micrometer caliper. The expansion rate was calculated as follows: die diameter divided by mean sample diameter multiplied by 100.

Settling velocity

A 125 cm length of 12 cm diameter perspex tube was used for assessment of pellet settling velocity using fresh water as the test medium. Pellets (a random sample of 15) were gently introduced just below the water surface, and the settling velocities determined by timing the descent between two marks, 105 cm apart, the upper of which was 5 cm below the water surface (c.f. Robinson and Bailey, 1981). A distance of 15 cm from the bottom of the tube was found to be sufficient to avoid any bottom shear effect imposed by the tube bottom on pellet velocity. Pellets which came into contact with the wall of the tube, or those observed to have air bubbles entrained on their surface, were excluded from calculations.

Water holding capacity

Distilled water was added to the pellets to soak each pellet, and they were left for 1 h at room temperature. Then they were filtered through a 100 DIN mesh and left for 5 min. The water holding capacity (WHC) was calculated as the change in weight before and after soaking.

Data analysis

STATISTICA software version 9 (Statsoft, Tulsa, Oklahoma, USA) was used for analyzing variations (analysis of variance – ANOVA) and least significant differences (LSD). The level of significance was set at $P < 0.05$.
Second-order polynomial equation was used to determine the effect of fish oil and screw speed on settling velocity:

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum \sum b_{ij} x_i x_j + \varepsilon ,$$

Where Y represents the experimental response, b_0, b_i, b_{ii}, and b_{ij} are constants and regression coefficients of the model, and x_i and x_j are uncoded values of independent variables. Adequacy of predicted model was determinate by R^2. 3D graphs and contour plots were generated as a function of two factors using STATISTICA software version 9.

RESULTS AND DISCUSSION

In Table 2, influence of extrusion conditions on temperature and pressure in extruder barrel is shown. It can be seen that increase of oil content decreased temperature in extruder barrel. Adding 3 % of oil in the main mixer and using the die with 50mm^2 of total openings' area caused high temperature decrease in comparison with 0 % oil. When 6 and 9 % of oil is added, further temperature decrease was not so intensive. Comparing mean temperature value for 180, 300 and 420 rpm and using 50mm^2 die, it can be noticed that temperature increases with increasing of screw speed, as it was expected. Using 100mm^2 die, similar trend of the results for different oil concentrations and screw speeds can be observed. Comparing values for same oil concentration and screw speed and different die openings' area, it can be seen that temperatures obtained with 100mm^2 die are slightly lower. Adding 3 % of oil did not caused so intensive temperature decrease, as it did with 50mm^2 die.

Table 2. Influence of extrusion conditions on secondary extruder variables

Extrusion conditions		**Secondary extruder variables**			
Screw speed (rpm)	**Fish oil ($\%_{DM}$)**	**Temperature, $T_{50}^{(1)}$ (°C)**	**Temperature, $T_{100}^{(2)}$ (°C)**	**Pressure, $P_{50}^{(3)}$ (bar)**	**Pressure, $P_{100}^{(4)}$ (bar)**
180	0	100.0	93.2	5.0	3.0
	3	96.0	90	4.1	3.5
	6	94.1	88.5	4.0	3.0
	9	93.0	86.2	2.3	2.2
Mean value		95.8	89.5	3.8	2.9
300	0	110.2	103.8	2.8	2.5
	3	110.0	102.5	2.4	2.7
	6	106.5	101.8	2.5	2.5
	9	105.0	97.3	2.0	2.0
Mean value		107.9	101.3	2.4	2.4
420	0	124.0	109.9	2.1	2.6
	3	111.5	107.5	2.0	2.4
	6	110.9	106.2	2.2	2.0
	9	110.0	101.8	1.9	1.9
Mean value		114.1	106.3	2.0	2.2

(1)T_{50} - temperature in extruder barrel with 50mm^2 total die openings' area
(2)T_{100} - temperature in extruder barrel with 100mm^2 total die openings' area
(3)P_{50} - pressure in extruder barrel with 50mm^2 total die openings' area
(4)P_{100} - pressure in extruder barrel with 100mm^2 total die openings' area

Figures 1 and 2 are also showing influence of oil concentration and screw speed on extruder temperature profile. Comparing these Figures, it can be noticed that with using smaller die openings' area, and varying oil concentration and screw speed, higher temperature difference between treatments could be obtained.

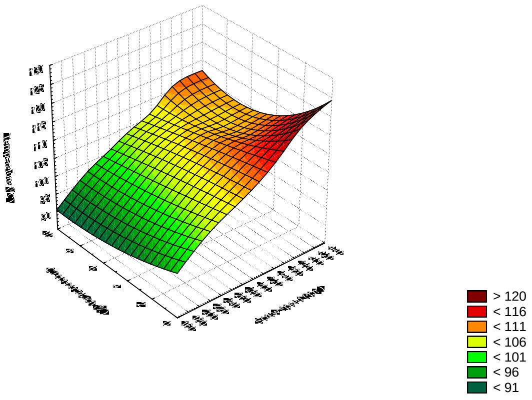

Figure 1. Influence of extrusion conditions on temperature (50 mm^2 die)

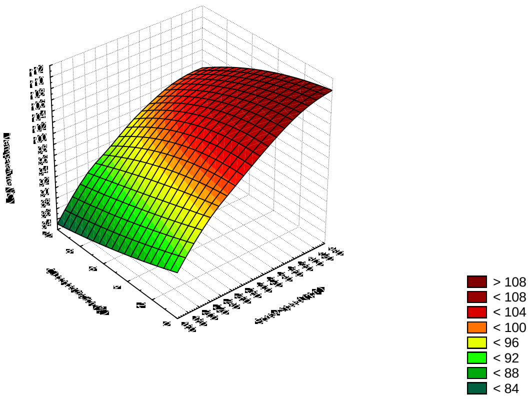

Figure 2. Influence of extrusion conditions on temperature (100 mm^2 die)

Addition of oil influenced pressure in extruder barrel by decreasing it. In contrary with temperature profile, higher screw speed resulted in lower pressure. Mean pressure value for screw speeds of 300 and 420 rpm was similar for both dies used. Also, when comparing mean pressure values for same screw speed but different dies, it can be seen that for 300 and 420 rpm almost same values were obtained.

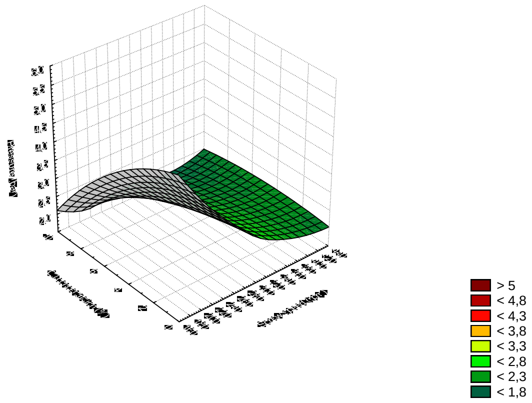

Figure 3. Influence of extrusion conditions on pressure (50 mm^2 die)

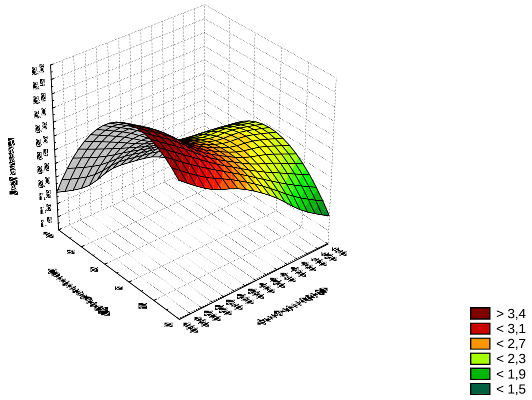

Figure 4. Influence of extrusion conditions on pressure (100 mm^2 die)

When looking influence of extruder parameters on extruder barrel pressure profile on Figures 3 and 4, it can be seen that usage of smaller die openings' area caused higher pressure difference for screw speed of 180 rpm.

Influence of oil addition on energy consumption in extrusion processing is shown in Table 3. As expected, addition of oil resulted in decreasing of energy consumption due to lower friction in extruder barrel. For 180 and 300 rpm, this decrease was not so high. For 420 rpm decrease was approximately 20 %, comparing values for 0 and 9 % added oil.

Table 3. Influence of extrusion conditions on energy consumption in extrusion process

Extrusion conditions		**Energy consumption**	
Screw speed (rpm)	**Fish oil ($\%_{DM}$)**	**Energy consumption, EC_{50}[(1)] (kWh/t)**	**Energy consumption, EC_{100}[(2)] (kWh/t)**
180	0	40.4	45.0
	3	39.0	42.6
	6	37.6	38.4
	9	37.1	34.1
Mean value		38.5	40.0
300	0	41.6	49.0
	3	40.7	44.5
	6	39.9	40.0
	9	39.2	35.0
Mean value		40.3	42.1
420	0	61.2	67.3
	3	60.8	66.0
	6	58.1	64.3
	9	40.0	51.0
Mean value		55.0	62.1

[(1)]EC_{50} – energy consumption in extrusion process with 50mm^2 total die openings' area
[(2)]EC_{100} - energy consumption in extrusion process with 100mm^2 total die openings' area

Size of die openings' area did not significantly influenced energy consumption during processing, as can be seen at Figures 5 and 6.

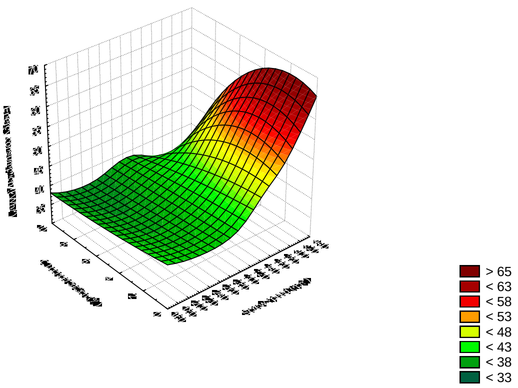

Figure 5. Influence of extrusion conditions on energy consumption in extrusion process (50 mm^2 die)

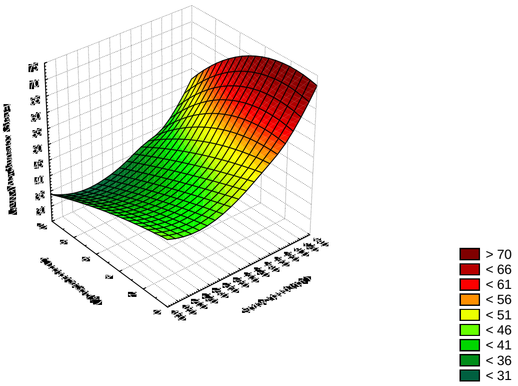

Figure 6. Influence of extrusion conditions on energy consumption in extrusion process (100 mm^2 die)

Influence of extrusion conditions on water loss of processed material at the exit of the die is presented in the Figures 7 (50mm^2) and 8 (100mm^2). As it has been described, using of higher screw speeds induced higher temperature. High temperature of material and pressure drop at the exit of the die causes very intensive evaporation of water from material. As it can be seen, when material was extruded at higher screw speeds and lower oil concentrations water loss was higher. Possible reason for that is that oil which covers surface of material particles prevents water transfer from inside of the particles to atmosphere. Water loss was more intensive for 50mm^2 die as a result of development of higher temperatures when using this die in comparison with 100mm^2 die.

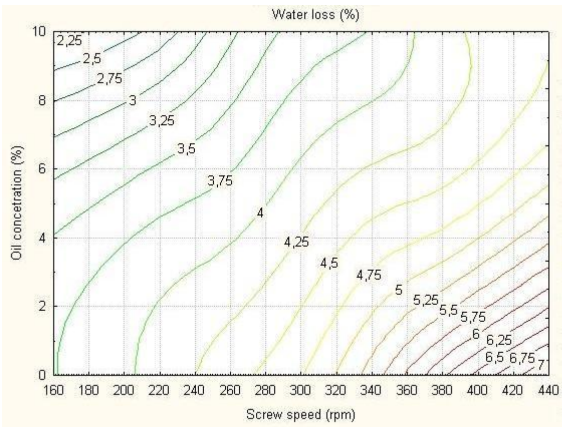

Figure 7. Influence of extrusion conditions on water loss of extruded product (50 mm^2 die)

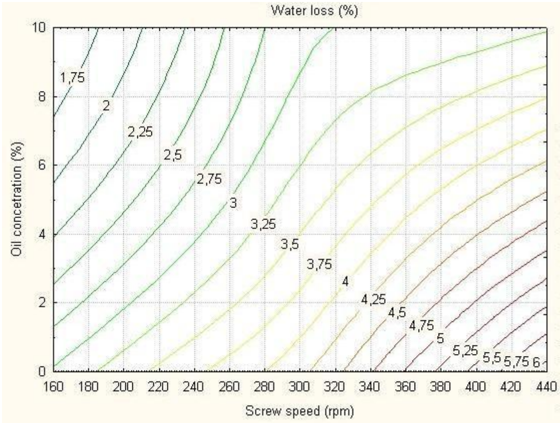

Figure 8. Influence of extrusion conditions on water loss of extruded product (100 mm^2 die)

Influence of oil addition and main screw speed on bulk density of extruded product is shown on Figures 9. and 10. Increasing the level of fat during extrusion caused an increase in the bulk density of the feed. This is possible due to the lubrication of the material inside of the extruder, which made it more difficult to impart mechanical energy into the product. Preventing of energy impart reduced starch gelatinization. As a result, added oil kept the material from expanding and thus increased bulk density of the pellets. Also, trout feed formula contains very small amount of starch component which is responsible for expansion of product. Therefore, bulk density of the product was generally higher.

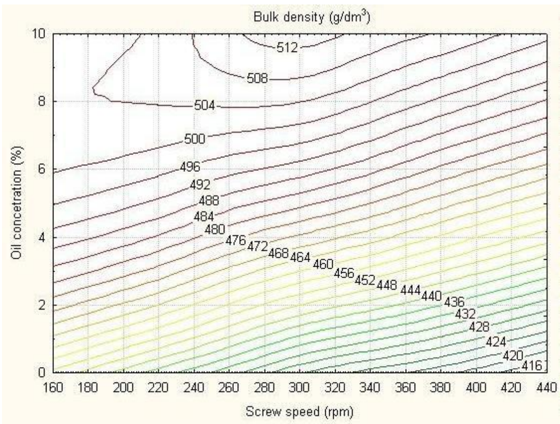

Figure 9. Influence of extrusion conditions on bulk density of extruded product (50 mm^2 die)

By looking results, it can be noticed that for more than 3 % added oil and for screw speeds of 180 and 300 rpm bulk density values were very close to each other. For those values is difficult to vary bulk density of the product. Increasing of screw speed to 420 rpm or decreasing of oil concentration to 3 % or less decreased bulk density. For these values curves at Figures 9. and 10. are more dense. That means that if oil is added higher energy inputs are needed for decreasing and varying bulk density of material.

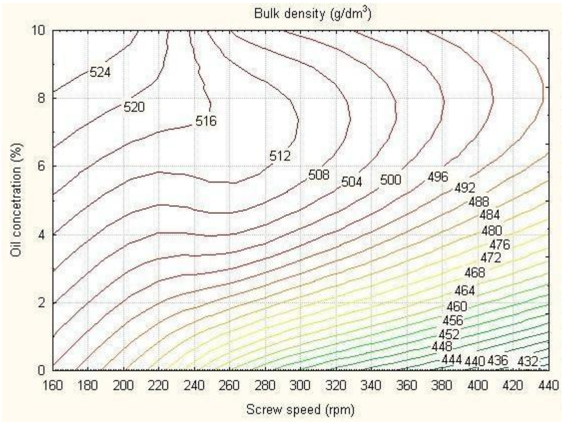

Figure 10. Influence of extrusion conditions on bulk density of extruded product (100 mm^2 die)

Additionally, diameter and expansion ratio of pellets were determined (Tab 4.). Results obtained for pellet diameter and expansion ratio have been confirming assumptions that increasing of oil concentration reduced friction in the barrel which was needed for expansion of the product. Also, for achieving of product expansion, even without added oil, high screw speeds are necessary. As it was case with bulk density, material extruded with more than 3 % of added oil and at main screw speed of 180 or 300 rpm had very similar values for expansion ratio and pellet diameter.

Table 4. Influence of extrusion conditions on pellet diameter and expansion ratio

Extrusion conditions		**Physical properties**			
Screw speed (rpm)	**Fish oil ($\%_{DM}$)**	**Pellet diameter, $PD_{50}^{(1)}$ (mm)**	**Pellet diameter, $PD_{100}^{(2)}$ (mm)**	**Expansion ratio, $ER_{50}^{(3)}$ (%)**	**Expansion ratio, $ER_{100}^{(4)}$ (%)**
180	0	3.03±0.06	2.97±0.13	0.89	-0.98
	3	3.01±0.05	2.97±0.08	0.31	-0.98
	6	3.01±0.07	2.90±0.10	0.33	-3.44
	9	2.95±0.06	2.89±0.06	-1.67	-3.67
Mean value		2.99	2.93	-0.04	-2.27
300	0	3.10±0.05	3.08±0.09	3.24	2.69
	3	3.06±0.03	3.04±0.06	1.96	1.31
	6	3.05±0.08	2.97±0.08	2.73	-1.11
	9	3.03±0.06	2.97±0.07	0.98	-1.11
Mean value		3.05	3.01	2.23	0.45
420	0	3.26±0.28	3.19±0.01	8.71	6.27
	3	3.17±0.08	3.12±0.09	5.71	3.89
	6	3.10±0.06	3.06±0.07	3.27	1.91
	9	3.05±0.08	3.03±0.06	1.71	0.89
Mean value		3.14	3.14	4.85	3.24

(1) PD_{50} – pellet diameter with 50mm² total die openings' area
(2) PD_{100} - pellet diameter with 100mm² total die openings' area
(3) ER_{50} – bulk density with 50mm² total die openings' area
(4) ER_{100} – bulk density with 100mm² total die openings' area

Influence of extrusion conditions on pellet settling velocity is shown in table 5. It can be seen that addition of oil did not significantly ($p<0.05$) influenced settling velocity of product for screw speed of 180 rpm and for both dies used. For screw speed of 300 rpm settling velocity was significantly higher for oil concentration of 6 and 9 % when 50 mm² die was used, and for 9 % when 100 mm² die was used. For screw speed of 420 rpm, oil addition, regardless of oil concentration, significantly increased settling velocity, in comparison with material without oil added. It can be noticed, that varying of oil concentration (3, 6 and 9 %) did not have influence on settling velocity of extruded product.

Table 5. Influence of extrusion conditions on pellet settling velocity

Extrusion conditions		**Physical properties**	
Screw speed (rpm)	**Fish oil ($\%_{DM}$)**	**Settling velocity, $SV_{50}^{(1)}$ (cm/s)**	**Settling velocity, $SV_{100}^{(2)}$ (cm/s)**
180	0	9.57 ± 0.67[a]	9.76 ± 0.38[a]
	3	9.56 ± 0.33[a]	9.94 ± 0.49[a]
	6	9.98 ± 0.60[a]	10.27 ± 0.45[a]
	9	10.22 ± 0.41[a]	10.39 ± 0.47[a]
Mean value		9.84	10.09
300	0	9.13 ± 0.67[a]	9.29 ± 0.44[a]
	3	9.52 ±0.53[ab]	9.92 ± 0.41[ab]
	6	9.93 ± 0.39[b]	9.94 ± 0.45[ab]
	9	9.99 ± 0.34[b]	10.14 ± 0.25[b]
Mean value		9.65	9.82
420	0	8.02 ± 0.80[a]	8.70 ± 0.70[a]
	3	9.14 ± 0.40[b]	9.58 ± 0.48[b]
	6	9.59 ± 0.41[b]	9.75 ± 0.46[b]
	9	9.78 ± 0.28[b]	9.93 ± 0.65[b]
Mean value		9.19	9.47

$^{(1)}SV_{50}$ – settling velocity in extrusion process with $50mm^2$ total die openings' area
$^{(2)}SV_{100}$ – settling velocity in extrusion process with $50mm^2$ total die openings' area
Results are mean ± standard deviation of 10 measurements for settling velocity.
[a] Means wit different letters in the same column of the same screw speed are significantly different at the 5% level.

Second-order polynomial equation was successfully used to determine the effect of fish oil and screw speed on settling velocity. Equation regression coefficients are shown in Table 6.

Table 6. Regression parameter coefficients of model used

Parameter	Regression parameter coefficients	
	Settling velocity, SV_{100} (cm/s)	Settling velocity, SV_{50} (cm/s)
Intercept	10,15192$^{(1)}$	9,575492$^{(1)}$
Fish oil (X_1)	0,12719$^{(1)}$	0,091328$^{(1)}$
Screw speed (X_2)	-0,00222$^{(1)}$	0,001371$^{(1)}$
Fish oil x fish oil (X_1^2)	-0,01106$^{(1)}$	-0,01106$^{(1)}$
Fish oil x screw speed (X_1 X_2)	0,00023$^{(2)}$	0,000532$^{(2)}$
Screw speed x screw speed (X_2^2)	-0,00000$^{(1)}$	-0,000011$^{(1)}$
R^2	0,95$^{(1)}$	0,93$^{(1)}$

$^{(1)}p < 0.05$
$^{(2)}p < 0.05$

CONCLUSIONS

Addition of oil in the main mixer strongly influenced secondary extruder variables (temperature and pressure) by reducing friction in the barrel. Using smaller die openings' area, and varying oil concentration and screw speed, higher temperature difference between treatments could be obtained. Addition of oil resulted in decreasing of energy consumption due to lower friction in extruder barrel. Lack of mechanical energy induced by friction resulted also in lower expansion of extruded product, and thus lower bulk density and higher settling velocity. By looking results it can be concluded that for increasing a expansion and thus bulk density, decreasing settling velocity, or varying one of those physical properties when more than 3 % oil is added high energy inputs are needed. Thus, for addition of oil in trout feed, when variation of physical properties of extruded product is needed, it is necessary to use coating systems.

ACKNOWLEDGEMENTS

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EFFECT OF EXTRUSION ON NUTRITIVE VALUE OF ANIMAL FEED

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ABSTRACT

Different thermal processes are used throughout the world as well as in our country for improving nutritional value of food and feed products intended for human and animal consumption. The effect of extrusion on the nutritive value of feed: soybean, rapeseed, corn, enriched corn meal and „wild forage fish“is shown in this paper. Technological parameters of extrusion process, quality of feed after extrusion and major transformations in feed structure occurring during thermal treatment are presented.
Keywords: *soybean, rapeseed, corn, enriched corn meal, sorghum, „wild forage fish“, extrusion, unease activity, trypsin inhibitor, NSI, glucosinolate*

INTRODUCTION

Food processing is an extremely important activity both in developed and non-developed countries. Due to rapid global population growth, severe food shortages could be faced. To prevent this, food and feed production must be increased through application of new technologies in biotechnology, that is, bio-industry [28]. Numerous technological processes aimed at improving nutritional value of food and feed products intended for human and animal consumption and efficiently utilization of primary and processed agricultural and food by-products have been developed worldwide.
Today, various heat treatment processes are used worldwide for cereals and other grain processing, such as toasting, extrusion, hydrothermal treatment, micronization, microwave heat treatment, dielectric heat treatment [58, 44, 31], however, according to the practical experience and literature data [45, 46, 47], extrusion and hydrothermal treatments are most commonly used processes in our country for extruded, i.e. hydrothermally treated products.
Properly applied heat treatment process has been shown to reduce anti-nutritional factors to an acceptable level, enhance digestibility of some nutrients (protein, oil, carbo hydrate), and improve sensory properties and microbiological quality of final product [26, 62]. Along with the antinutrient content reduction, thermolabile nutritive components must be preserved, therefore, process need to compromise these two demands.
Soybean processing into high protein and high energy feed involves application of heat treatment processes, namely– extrusion and hydro-thermal treatment. Advantage of this process, the final result of which is the full fat extruded soybean grits – soybean processed by dry or moist extrusion and heat treated soybean seeds, is that it offers

possibility for the production of quality product with improved hygienic and physico-chemical properties.

Besides cereals, as carbohydrate portion of a diet, animal feed must provide protein and fat of satisfactory biologic value. Soybean is the principal source of protein for the feed industry and is also considered a high energy feed due to its oil content. In the European Union, where intensive animal farming is practiced, 20 million tons of soybean meal and over 2 million tons of thermally treated soybean seed are used annually [6]. In our country, the use of feeds made from heat treated whole soybean is becoming more widespread in recent years. Whole soybeans contain approximately 38% protein and 20% and are of special value for young animals (piglets, calves, lambs, chickens) with higher dietary energy requirements [22]. With the use of heat treated soya– extruded full fat soya grits in the animal feed production technical issue related to the supplemental application of fat in feed mixtures is eliminated.

To be used in human and animal nutrition, soybean seed has to be subjected to thermal treatment to inactivate or reduce inhibitory substances contained in soybean seed, such as trypsin and chimotrypsin inhibitor [8], chemaglutinin [61], phytate [64], saponin ([59], antivitamin A, E, B_{12} [29], etc., and, consequently, improve nutritional value, hygienic safety and physico-chemical characteristics of soya products.

Extrusion is a technological process during which soybean is subjected to high temperature and high pressure and during which raw material is mechanically treated by shear forces (friction), that transform the structure of the initial material and create final product of different chemical composition, appearance, shape, etc. [53]. During extrusion, soybean seed undergoes numerous physico-chemical transformations and antinutritional factors are reduced (trypsin inhibitor by 97-98%) [60]. Protein fraction structure is also changed, as reflected in improved digestibility of protein, however, the process is responsible for the reduction in the content of some amino acids, like thermolabile lysine [2]. When soybean is exposed to excessive heat treating, or over-processing, the negative effects that reduce protein and essential amino acids content and give rise to undesirable reactions – Maillard reaction, lipid oxidation and others occur [43]. Furthermore, carbohydrate digestibility is increased during extrusion process [32], as reflected by the changes in the rheological properties of starch, i.e. starch swelling, solubility in cold water, decreased viscosity and partial or complete release of amylose and amylopectin from starch granules [32]. Starch gelatinization that takes place in the course of extrusion is an irreversible process, and when cooled, its volume is usually increased by 2 or 3 times.

Together with soya, rapeseed (*Brasicca* sp.) is an oilseed crop having huge potential from an energy and protein standpoint, and containing components of high nutritive value, notably proteins and oil, but it also contains antinutritional factors – erucic acid and glucosinolinates [49, 48, 50,55, 56]. Rapeseed oil contains erucic acid, a valuable raw material for manufacture of a wide array of industrial products such as plasticizers, surfactants, detergents, coatings polyesters [7]. Glucosinolinates, a group of over hundred organic anions containing sulphur and β-D-thioglucose residue, are found in rapeseed meal after oil extraction [10].

Although rapeseed is a good source of quality protein, its use in rations is limited by its fibre, phytic acid, glucosinolates, polyphenols content [30, 35, 37].

The use of rapeseed in compound feed is rather limited by its poor sensory properties because of high glucosinolate content– which is responsible for the pungent odour and biting taste as well as palatability, nutritional and health-related problems, particularly in non-ruminants [5, 14]. Glucosinolates and their hydrolysis products [41], have a goitrogenic effect on the thyroid function [23] that is, exert anti-thyroidal activity. For example, in rainbow trout fed a rapeseed meal-based diet, the disturbances in the hypothalamus-pituitary-thyroid axis have been reported [11]. Rapeseed-based diets with reduced glucosinolates content have been shown to improve weight gain and feed conversion ratio in pigs [5], that is, low-glucosinolate rapeseed diets have been reported to lower anti-thyroid activity and enhance biological value of the protein in rats [11]. Therefore, rapeseed may be included in ruminant rations at up to 20%, provided that glucosinolates content is not exceeding 20 μmol/g [35].

Problems caused by the antinutritional factors present in rapeseed can be overcome by selection and development of low-glucosinolate rapeseed varieties and application of technological processing methods (thermal treatment) leading to reduced glucosinolate and other anti-nutrient content.

Use of rapeseed which is after thermal treatment, i.e. extrusion, converted into a high-energy, high-protein feed leads to improved feed utilization efficiency and increased use of this feed in animal production [33].

Adequate energy level in complete feeds can be obtained through cereal supplementation, as the carbohydrate portion of the ration. Cereals and milling by-products are primary source of energy in animal feeding, and major ingredients in commercial feed.

Corn is the most commonly used grain in the animal feed production in our country due to its high energy content (16,2 MJ/kg), starch content, relatively high oil content and low fibre content. In addition to its excellent digestibility, corn is considered to have better flavour than other grains [6]. Rules on quality and other requirements to be met by animal feed specifies that, apart from corn and grains, wheat and corn bran, wheat and corn meal, corn germs, rye and rice bran and other milling products may be used in animal feeding systems [38].

Enriched corn meal is by-product of the corn milling industry containing fractions of endosperm, pericarp and germs. However, this type of feed have not been utilized to its fullest potential in the animal feed industry so far, and further research work is needed to provide more insight into nutritive value of this feed and confirm its use in the compound feed industry, on one hand, and the application of heat treatment processes (such as extrusion) should be introduced to improve its utilization efficiency, on the other hand should be introduced.

Thermal treatment is typically used to enhance nutritional, hygienic, physico-chemical and other properties of grains, i.e. to improve nutritive value of some ingredients, upgrade sensory characteristics (i.e. improves "mouthfeel" of treated corn), ensure the microbiological wholesomeness of final product [26, 62] and inactivate thermo-labile anti-nutrients.

Extrusion is a heat treatment which involves HT/ST principle of extrusion cooking (high temperature/short time), namely, the process in which material is exposed to high temperature (to 200 °C) for short time (to 2 minutes). Extrusion processing of corn,

which is the major raw material in the animal feed production [16, 57], as well as extrusion of corn dry milling, contribute to improved feed utilization efficiency [28, 52].
During extrusion, carbohydrate fraction of corn meal undergoes changes resulting in starch content decrease due to starch degradation and dextrin production. These changes result in *in vitro* and *in vivo* enhancement of starch digestibility, since starch gelatinization enables improved availability of starch degrading enzymes, and consequently, inactivation of amylase inhibitor [18].
During corn meal extrusion, content of total and reducing sugars is decreased as the result of Maillard reaction, considered as the least desirable reaction in food chemistry and involving sugar-protein interaction, primarily with the amino acid residues of lysine [13].
Due to short retention time of mass in the extruder (less than 30 s), level of preservation of nutritive grain components is relatively high [6], and, resultingly, only insignificant degradation of amino acids occurs during corn meal extrusion, in relation to untreated material, while protein digestibility is increased [18]. At the same time, thermal treatment assures increased oil digestibility of extrudates, although it is followed by the increased susceptibility to the lipid oxidation due to the increase of surface contact with air [36].
There is a growing demand for meat, milk and other animal farming products. Development of animal production is, however, impeded due to difficulties caused by continuous rise of feed prices and occasional shortages of protein feeds.
Greater use of inedible raw material of animal origin from agricultural and food production may help overcome such a situation. Hence, research efforts are focused on generation of protein feed of favourable chemical and nutritional characteristics from slaughter offal products and fish farming waste. Based on the research results of Vujkovic et al. [63], „wild forage fish“ accounts for as much as 27,66% of total caught fish, depending on the fish growing technique. Inedible fish products contain valuable nutritive ingredients, i.e. proteins, mono- and polyunsaturated fatty acids, mineral matter and vitamins in the form suitable for fish meal or protein feed production. It is also important to apply adequate technological processes, to preserve protein to a greater extent, while obtaining safe and wholesome product which is suitable for supplementation in feed mixtures [42].
Major problem in freshwater fish („wild forage fish“) processing is to eliminate bound water and fat content. Results of many researches indicate [42] that with the introduction of simple and cost-effective drying technology using vegetable carriers, feed meeting dietary requirements of animals for amino acids may be obtained. Additionally, fish processing using organic carriers, is simple, low cost and environmentally-friendly investment in comparison with separate technological treatments for water and fat separation.
Degradation of thermo-labile amino acids (cystine and cysteine) was reduced to minimum by the extrusion of pre-mixed raw material - vegetable carrier, i.e. full fat soya grits and „wild forage fish” at 90 ^{0}C.

MATERIALS AND METHODS

Extrusion of soybeans – dry process

Extrusion of soya was carried out in the machine manufactured by “Oprema zootehnička oprema” Ludbreg, Croatia, type M2, model 1000. Soybeans were pre-dried to moisture content of 10%, and cleaned of foreign material by means of air aspirators. Throughput capacity of the extruder was 1000 kg/h, rated power of electric motor 77 kW, and screw feeder driven by 1,5 kW electric motor. Extruder assembly consisted of four segments (extruder zones) and four screw flights with different pitch. Screw flight sections are mounted on the extruder drive shaft. Since the screw flight sections are segmented, a ring-like "shearlocks" and restriction units are placed between each section to control the pressure. Used shearlocks were marked 5 3/2”, 5 3/2”, 5 ½” and 5 ½”. Extruder head with nozzle was placed at the end of the flight section of screw. When screw flight sections, shearlocks and restriction units are mounted on the extruder drive shaft, segments are placed onto the extruder drive shaft and tightened in place. Digital thermometer is mounted in the last segment of the extruder and water and steam connections in the first segment.

Extrusion of soybeans - wet process with stream injection

Soya extrusion with steam conditioning was carried out in "Miltenz" device, type 501-SP (New Zealand), throughput capacity 500 kg/h. Extruded consisted of five heating segments (zones), main electric motor with nominal power of 37,5 kW, screw feeder driven by 1,5 kW electric motor and extrudate cutting device driven by 2,2 kW electric motor. Soybeans were treated using three segments. Conditioning of ground soybean was carried out with saturated steam at 5,5-6,0 bars.

Extrudate flow was regulated by die openings adjustment. Optimized opening diameter at the end of the extrusion process was ¾” (19 mm). Retention time in the extruder was constant at about 7 seconds. Retention time was determined by adding red colour into the ground material before entering the extruder, i.e. by measuring time needed for coloured extrudate to exit the extruder. Following the extrusion, final product was cooled to the room temperature.

Extrusion of rapeseed

Rapeseed and mixtures of rapeseed with other crops - corn, wheat, barley, triticale, alfalfa were used for extrusion (rapeseed : other crops – 30:70 and 50:50, i.e. corn : rapeseed : alfalfa – 60:30:10 and 40:50:10, respectively). Extrusion was carried out in the machine manufactured by "Oprema-zootehnička oprema", type M2, model 1000 extruder (Ludberg, Croatia), with four heating segments. Throughput capacity was 850-1000 kg/h, rated power of electric motor 75 kW, and screw feeder driven by 1,5 kW electric motor.

Rapeseed and mixtures of rapeseed with other crops were subjected to heat treatment using all 4 heating segments with "shearlocks" and restriction units placed between each section (segment) to control the pressure and temperature of the material subjected to extrusion and regulate flow through the extruder. Extruder head with nozzle was placed at the end of the flight section of screw. Extruder assembly consisted of four identical segments placed onto the extruder drive shaft and tightened in place when screw flight sections, shearlocks and restriction units were mounted on the extruder drive shaft. Working temperature measured in the head of extruder during extrusion was 125±1 °C, extruder capacity was 90%, current strength 85-90 A, and nozzle diameter 8 mm.

Extrusion of corn

Corn with moisture content of 12%, pre-ground in a hammer-mill, screen size Ø 5 mm, and then moistened for 6 hours to reach 18% moisture, was used for extrusion.
The extruder used had throughput capacity 900 kg/h, electric motor power 100 kW and screw feeder driven by 1,1 kW electric motor. Extrusion temperature was 90 and 95 ^{0}C.

Extrusion of enriched corn meal

For examining the effect of extruding on feed hygienization, extruded enriched corn meal (obtained by dry degermination process) with 14% moisture content, was moistened to reach 20% moisture and extruded. Extruding process was carried out in the extruder manufactured by "Metal-Matik", model 11-1000 (Beočin, Serbia), with four heating segments (zones). Throughput capacity of the extruder was 1000 kg/h. Electric motor with nominal power of 75 kW, screw feeder driven by 1,5 kW electric motor. Extrusion was performed at 105 °C.

Extrusion of sorghum

Sorghum was extruded in the extruder manufactured by "Metal matik" (Beočin, Serbia). Throughput capacity of extruder was 100 kg/h, extrusion temperature 98-103 ºC, with 4 segments and 4 screw flights and screen size Ø 4 mm i Ø 8 mm. Prior to extruding, sorghum was grounded in the hammer-mill and moistened to 20-23% moisture. For technological trials ground sorghum without additional moistening and supplemented with soybean at the ratios 70:30 and 50:50 (sorghum : soya) was used.

Extrusion of the feed made from "wild forage fish"

A high protein, good energy feed was made from „wild forage fish" and full fat soya grits pre-mixed at the ratio 1:2. Extrusion was carried out at 90 ^{o}C, in the Ukranian made extruder, type E-250, throughput capacity 1000 kg/h. Extruder consisted of four segments, die opening diameter ϕ10 mm and rated power of electric motor 37 Kw. Prior to extruding, wild forage fish material was grinded in the grinding machine („cutter"), and then mixed with full fat soya grits in the counter-current mixer.

Chemical methods for determining quality of soya, oilseed, corn, corn meal, sorghum and wild forage fish

Basic chemical composition (moisture content, crude protein, crude fat, crude fibre and mineral matter content) was determined according to A.O.A.C. method [3].

Starch and total reducing sugar content was determined in accordance with the Rules on the methods of sampling and carrying out chemical and physical analyses of grains, mill and bakery products, pasta and quick frozen pastry products [39].
Content of trypsin inhibitor in soybean seed and extruded full fat soya grits (dry extrusion and conditioning) was determined according to the method of Hamerstand at al. [21].
Urease activity in analyzed samples was determined according to the method prescribed by International ISO 5506 standard [25].
Nitrogen Solubility Index – NSI was determined according to A.O.C.S. method [1].
Amino acid composition of tested samples was determined on Biotronic LC 5001. Samples were hydrolized with 6 mol/dm^3 hydrochloric acid for 23 h at 110 °C. Cystine and methionine were previously oxidized with formic acid for 15 h at 2 °C [34].
Content of total glucosinolates was determined according to the Hungarian standard MSZ-08-1908-1989 which includes absorbency measurement of Pd-complex glucosinolates at 425 nm. Standard curve is designed by spectrophotometer series standard solution of synigrine (Sigma, S-1647) with Pd-reagent.

Microbiological analyses

Total number of micro-organisms, moulds, yeast as well as isolation and identification of *Salmonella* and sulphite reducing Clostridia were determined in accordance with the Rules on the Methods of Carrying out Microbiological Analyses and Super-analyses of Foodstuffs [40].
Presence of coagulase-positive staphylococci, Proteus species and Escherichia coli was determined by the internal laboratory method. Pour 50 ml of test sample into Erlenmeyer flask containing 450 ml of sterile nutrient broth. Homogenize sample and incubate at 37^{0}C for 24 h. Perform isolation and identification as specified in the Rules on the Methods of Carrying Out Microbiological Analyses and Super-analyses of Foodstuffs [40].

RESULTS AND DISCUSSION

Quality of feed made in the dry extrusion process (without steam) can be determined based on the results obtained for chemical composition and amino acid composition of soybean seeds before and extruded full fat soya grits after the treatment (Table 1).
Contrary to the soybean seeds, where proportion of amino acids in total protein content was 95,88%, certain losses in amino acid content occurred during production of extruded full fat soya grits and proportion of amino acids in total protein content dropped to 87,04%.
This reduction in the content of some amino acids was similar to already established decrease of amino acid levels during heat treatment of soya [20, 21]. Content of the limiting amino acid, lysine, in the feed was somewhat lower than reported in literature for thermally treated soybean, where it ranged from 5,5-6,5% in protein [40, 43]. This decrease is the result of the lower lysine content in soybean seed (6,10%) used for the production of feed in question and the application of more aggressive treatment in production of analyzed feed.

Recorded losses in lysine content caused by heat treatment can be explained by lipid-protein interaction and Maillard reaction taking place between NH_2-group of the lysine residues in the side-chain and the glucose or other reducing sugar present in the soybean [44].
Quality of final product, i.e. extruded full fat soya grits, can be determined based on the relevant data obtained during assessment of adequacy of applied heat treatment, shown in Table 2.

Table 1. Quality indicators of soybean seeds and extruded full fat soya grits

Quality indicators	**Soybean seed**		**Extruded full fat soya grits**	
Chemical composition	% in sample	% in DM*	% in sample	% in DM*
Moisture	10,06	-	4,67	-
Crude protein	37,48	41,67	39,40	41,33
Crude fat	19,27	21,26	20,26	21,25
Crude fibre	4,39	4,88	4,08	4,28
Mineral matter	4,63	5,15	4,81	5,05
Amino acid composition (% in protein)				
Asparaganinic acid	12,00		10,35	
Treonine	4,59		3,63	
Serine	5,02		5,00	
Glutaminic acid	14,73		13,84	
Proline	4,87		3,59	
Glycine	4,10		3,99	
Alanine	3,99		3,86	
Cystine	1,54		1,26	
Valine	5,14		3,76	
Asparaganinic acid	1,27		0,84	
Treonine	4,27		4,26	
Serine	7,20		7,13	
Glutaminic acid	4,49		4,21	
Proline	5,18		4,95	
Glycine	3,49		3,44	
Alanine	6,10		5,03	
Cystine	7,90		7,89	

*Fililipović et al., 2001
*DM – dry matter

Table 2. Quality indicators relevant to assessing adequacy of applied heat treatment

Quality parameter	**Soybeans**	**Extruded full fat soya grits**
Trypsin inhibitor (mg/g)	61,66	3,27
Urease activity (mgN/g/min at 30 ºC)	10,95	0,26
NSI (%)	65,82	25,64

*Fililipović et al., 2001

Major antinutritional factor in the soybean seed, i.e. thermolabile trypsin inhibitor, was significantly inactivated by extrusion process (94,70%). Van der Poel [61] indicates that the stream treatment (100 ºC > 15 min) reduces trypsin inhibitor content in soybean by 65-97%, and extrusion (145ºC, 16 s) by 78-98%. Gundel and Mátrai [20] suggested even lower levels to which trypsin inhibitor could be reduced (97-99% during extrusion). Nitrogen solubility index (NSI), yet another quality indicator used in thermal treatment optimization and quality control, was 65-75% in soybean seed [9, 44], but significantly lower in thermally treated products. Though data reported in the literature for optimum NSI values in thermally treated soya differ, data reported by Holmes [24] could be taken as a reference, according to which NSI level of 12,5% is considered too aggressive, while NSI level of 25,1% is considered as optimum in our country. Comparing these values with NSI values of extruded full fat soya grits (25,64%) it can be concluded that applied thermal treatment was optimum one.

Considering general agreement in literature data that trypsin inhibitor content of 5 mg/g or lower after any heat treatment is acceptable [22, 45, 53], it can be concluded that applied processing regimes were adequate and resulted in the final product of optimum quality. This statement could be additionally confirmed by the urease activity level (Table 2), being in agreement with data given in Table 3 [51] which are taken as reference values for determining optimum working parameters during thermal treatment of soybean.

Table 3. Urease activity levels obtained during different heat treatments of soybean

Heat-treated soybean products	**Urease activity (mgN/g/min)**
Over-treated	<0,05
Optimally treated	0,1-0,3
Below-optimum treated	0,3-0,5
Under treated	>0,5

*Fililipović et al., 2001

Quality of grinded soybean extruded in „Miltenz“ extruder (wet extrusion, with steam addition) and final product, i.e. extruded full fat soya grits is shown in Table 4.

Table 4. Quality indicators of soybean seeds and extruded full fat soya grits (extrusion with conditioning)

Indicators	Soybean seed	Extruded full fat soya grits
Moisture content, %	9,80	11,22
Crude ash, %	4,56	4,54
Crude fibre, %	5,26	5,11
Crude fat, %	20,19	20,05
Crude protein, %	35,40	35,27
Urease activity, mgN/g/min	8,00	0,22
NSI %	66,34	21,27
Trypsin inhibitor, mg/g	48,92	3,11

*Fililipović et al., 2001

Data shown in Table 4 are an indicative of soybean seed of an average quality established and maintained in our country in recent years [22, 28]. As the exudate quality primarily depends upon the quality of initial raw soybean seed and extruding temperature, it is very important to know the basic quality indicators of initial raw material, which have not changed significantly in our country for years [22, 60]. Major changes occurred in the antinutrients content, namely, trypsine inhibitor and urease activity, being in a positive correlation with mentioned antinutrients [51]. Higher antinutrient levels in raw soybean require application of more aggressive treatment regimes, and it is, therefore, desirable to have raw material of similar quality to obtain extrudate of standard quality with the application of the same technological parameters. If the quality of raw soybean substantially departs from the average soybean quality according to which optimization of the extrusion process took place, optimization should be conducted again.

When rapeseed is extruded alone its high oil content (41,07% in DM) prevents adequate heating and produces an oily pulp which is susceptible to lipid oxidation [54]. For this reason, rapeseed was extruded in combination with other feedstuffs and resultant product was of longer shelf life, suitable for storage and formulations with other feeds.

After dry extrusion process, reduction in total glucosinolate content ranged from 20-30%, with highest reduction recorded when extruding corn, rapeseed and alfalfa in the ratio 60: 30:10 (30,94%), and the lowest when extruded rapeseed and wheat in the ratio 50:50 (22,64%). Results are given in Table 5. Similar reductions in total glucosinolate content (19-23%) were reported by Smithard and Eyre [54], with the application of dry extrusion process (135 °C) in mixtures of rapeseed with either barley, rapeseed meal or sunflower meal, while reduction in glucosinolate content was only 19% when rapeseed alone was dry extruded [4].

Table 5. Glucosinolate content in rapeseed alone and combinations of rapeseed and other feedstuffs before and after extrusion

Sample	**Treatment**	**Glucosinolate (µmol/g DM)**	**Glucosinolate reduction (%)**
Rapeseed	ground	65,91	
Rapeseed	extruded	46,43	29,56
rapeseed+corn 30:70	ground	21,35	
rapeseed+corn 30:70	extruded	15,67	26,60
rapeseed+corn 50:50	ground	32,83	
rapeseed+corn 50:50	extruded	24,62	25,01
rapeseed +barley 30:70	ground	19,76	
rapeseed + barley 30:70	extruded	14,05	28,90
rapeseed+ barley 50:50	ground	33,57	
rapeseed+ barley 50:50	extruded	25,35	24,49
rapeseed+triticale 30:70	ground	23,34	
rapeseed+triticale 30:70	extruded	16,56	29,05
rapeseed+triticale 50:50	ground	36,73	
rapeseed+triticale 50:50	extruded	27,86	24,15
rapeseed+wheat 30:70	ground	19,80	
rapeseed+ wheat 30:70	extruded	15,25	22,98
rapeseed+ wheat 50:50	ground	41,70	
rapeseed+ wheat 50:50	extruded	32,26	22,64
corn+rapeseed+alfalfa 60:30:10	ground	18,65	
corn+rapeseed+alfalfa 60:30:10	extruded	12,88	30,94
corn+rapeseed+alfalfa 40:50:10	ground	35,22	
corn+rapeseed+alfalfa 40:50:10	extruded	25,60	27,31

Sakač Marijana et al., 2005

Chemical characteristics of corn and corn extruded at 90 and 95 ^{0}C are given in Table 6. During extrusion changes in the protein structure occur, thus leading to decrease in protein solubility [18]. Nitrogen solubility index (NSI) is one of quality indicators used in optimization of thermal treatment regime, as it reflects changes in the protein structure due to high pressure and temperature during extrusion process. Statistically significant difference between NSI values for corn and obtained extrudate, is yet another confirmation that corn proteins undergo structural changes during extrusion at 90 and 95^{0}C.

Table 6. Chemical composition of ground and extruded corn

Quality indicators	Corn	Corn extruded at 90^0C	Corn extruded at 95 ^{0}C
Crude protein	$9,25^c$	$9,07^b$	$8,97^a$
Mineral matter	$1,83^b$	$1,56^a$	$1,58^a$
Crude fibre	$3,45^c$	$2,47^a$	$2,80^b$
Crude fat	$4,80^c$	$2,08^a$	$2,66^b$
NSI	$13,11^b$	$6,06^a$	$5,88^a$
Starch	$70,90^c$	$67,06^b$	$64,98^a$
Total sugar	$1,00^a$	$3,99^b$	$4,12^b$
Reducing sugar	$0,40^a$	$0,42^a$	$0,45^a$

*Fililipović et al., 2009
Values are expressed as a mean value of five independent determinations.
Means in the same row sharing the same superscript letter are not significantly different

During extrusion, substantial physico-chemical changes take place in the carbohydrate fraction of corn, thus affecting starch digestibility and availability. Starch is gelatinized and degraded in the course of extrusion, and accessibility of enzymes to starch granules in the digestive tract is improved [12, 15, 64]. Starch content in extruded corn is significantly lower than in non-extruded corn, and, as the result, total and reducing sugars content is increased, thus contributing to the change of sensory parameters, namely, slightly sweet taste of extrudate.
Chemical composition of enriched corn meal and extruded enriched corn meal is given in Table 7.
During extrusion of enriched corn meal, substantial physico-chemical changes took place in the starch fraction of corn, and resulting in total sugar increase, starch content decrease and considerable change of organoleptic properties.

Table 7. Chemical composition of enriched corn meal and extruded enriched corn meal

Quality indicators , % in DM	Enriched corn meal	Extruded enriched corn meal
Crude protein	11,90	11,30
Crude fibre	4,36	4,48
Crude fat	9,14	8,90
Mineral matter	2,36	2,40
Starch	59,48	56,55
Total sugars	1,73	4,16

*Kormanjoš et al., 2007

Quality of untreated and extruded sorghum is shown in Table 8.

Table 8. Quality of untreated and extruded sorghum

Quality indicators (% in DM)	1	2	3	4	5	6
Moisture	27,98	15,09	14,48	9,57	14,97	9,11
Crude protein	13,62	13,01	22,78	22,04	23,92	26,29
Crude fat	6,80	6,17	5,17	6,57	6,04	8,32
Crude fibre	2,90	3,10	9,09	8,92	12,60	12,35
Mineral matter	3,32	3,26	3,18	3,78	3,54	4,41
Starch	57,37	56,90	45,03	43,38	41,24	27,52
Total sugar	3,39	2,67	5,57	5,37	4,12	5,92
Reducing sugar	0,40	0,21	0,560	0,60	1,40	0,39
Tannins	0,45	0,43	0,42	0,56	0,40	0,49

*Fililipović et al., 2003

1. Moistened and untreated sorghum
2. Extruded sorghum
3. Untreated sorghum mixed with soya in ratio 70:30
4. Extruded sorghum mixed with soya in ratio 70:30
5. Untreated sorghum mixed with soya in ratio 50:50
6. Extruded sorghum mixed with soya in ratio 50:50

Prior to extrusion, sorghum grain was ground and moistened to about 28% moisture content (Table 8), while soybeans were added to the ground, non-moist sorghum (30 and 50%) in order to elevate oil content and allow normal extrusion process. From the results presented in Table 8 it can be seen that the changes in the extruded sorghum occurred in starch content, as well as total and reducing sugar content, i.e. carbohydrate fraction. Changes in tannin content were insignificant, i.e. tannin content was reduced by 5% in relation to non-extruded sorghum. Extrusion cooking of sorghum grain at 30% soybean addition (Table 8, column 4) and 50% soybean addition (Table 8, column 6) did not bring about any significant changes in the tannin content, while some changes were detected in the carbohydrate fraction.
Chemical composition and microbiological analysis of „wild forage fish“ are presented in Table 9.
Chemical composition of „wild forage fish“ indicates to high water content (73,14%), high protein content (53,06%), fat (27,80%) and mineral matter content (10,75%) in dry matter. Results of microbiological analysis indicate that this raw material containing 20,000.000 bacteria and 5.000 moulds in 1 g, is not safe for use.

Table 9. Chemical composition and microbial count in "wild forage fish"

Chemical composition	**in sample (%)**	**in DM (%)**
Water	73,14	
Crude protein	14,41	53,06
Crude fat	7,55	27,80
Ash	2,92	10,75
NFE	0,95	3,50
Phosphorus	0,35	1,29
Calcium	0,98	3,61
Microbiological analysis		
Micro- organisms	in	number
Salmonella sp.	50 gr	0
Coagulase-positive staphylococci	50 gr	0
Sulphite reducing clostridia	1 gr	0
Proteus species	50 gr	0
Escherichia coli	50 gr	0
Total mould	1 gr	5000
Total yeast	1 gr	0
Total bacteria	1 gr	20 000 000

*Filipović et al., 2010

Chemical composition and microbiological analyses of extruded mixture of "wild forage fish" and soya grits are given in Table 10.
Upon extrusion of the mixture of "wild forage fish" and soya grits, a high energy, high protein feed was obtained containing only 70.100 bacteria and 300 moulds in 1g.

Table 10. Chemical composition and microbiological analysis of extruded mixture of "wild forage fish" and soya grits

Chemical composition	in sample (%)	in DM (%)
Water	21,28	
Crude protein	32,57	41,37
Crude fat	16,87	21,43
Crude fibre	6,53	8,30
Mineral matter	4,90	6,22
NFE	16,70	21,21
Phosphorus	0,37	0,47
Calcium	0,78	0,99
Microbiological analysis		
Micro-organisms	No. in	No.
Salmonella sp.	50 gr	0
Coagulase-positive staphylococci	50 gr	0
Sulphite reducing clostridia	1 gr	10
Proteus species	50 gr	0
Escherichia coli	50 gr	0
Total mould	1 gr	300
Total yeast	1 gr	0
Total bacteria	1 gr	70 100

*Filipović et al., 2010

Such a product can be used in the animal feed production, and with additional drying (at temperature not higher than 70 ^{o}C) to 13% moisture content can be safely stored for longer periods to be used for feeding all animal species and age groups.

CONCLUSION

- Extrusion of soybean grain intended for human and animal consumption is one of heat treatment processes, used to improve its nutritional, hygienic and physico-chemical properties, that is, to inactivate thermo-labile antinutrients, upgrade sensory properties and ensure product safety.
- Upon extrusion of corn, corn meal and sorghum, quality feed of improved nutritional value is obtained, with increased total and reducing sugar content due to changes in starch structure (gelatinization process), and resultingly, improved organoleptic properties of extrudate. Due to reduction of microbial counts during extrusion, these products are hygienically safe to be used for feeding all animal species and age groups and can be stored safely for longer periods. In extruded sorghum insignificant changes in tannin content were observed.

- Extruding of rapeseed with other feedstuffs (corn, wheat, triticale, alfalfa) resulted in the product of reduced glucosinolate content ranging from 20-30% in relation to untreated material. This feed is of satisfactory quality and can be in small quantities for broiler chicken feeding.
- Feed produced by the extrusion of „wild forage fish“ is a product with high protein, fat and mineral matter content, and of relevant nutritional value. It is hygienically safe and can be recommended for feeding all animal species and age groups. Due to increased moisture content, post-drying is required to allow safe storage and extended shelf life.

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SOYBEAN AND ITS PROCESSING PRODUCTS IN THE NUTRITION OF CALVES

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ABSTRACT

Soybean products, primarily soy protein concentrate and soy protein isolate are widely used as protein sources in milk replacers for calves. Substitution of 50% of milk protein with soybean proteins, decreases calves' daily gain and feed conversion ratio in the phase of liquid nutrition. Besides that, thermal and chemical inactivation of most of the antinutritional and antigenic components, intestinal histomorphological (reduction of villi length) and functional changes were registered at young calves fed milk replacers with soybean flour or soy protein concentrate, and to a lesser extent soy protein isolate. Soymilk is quality feed that can largely replace cows' milk in young calves' nutrition. Plant proteins should be used in milk replacers for calves after three weeks of age. Heat treatment of soybean reduces rumen degradability of protein and increases intestinal utilization efficiency. Using of heat-treated soybean as concentrate for calves, increases protein digestibility, increases content of rumen undegradable protein and fulfills needs in essential amino acids, and achieves high energy concentration of diets. Using of heat treated soybean in complete mixtures for calves increases feed conversion ratio, utilization of consumed nutrients and energy, and provides better average daily gains.
Keywords: *soybean, processing, calves, nutrition*

INTRODUCTION

Soybean and products of different technological processes of treating, in terms of intensive cattle production, are primary and necessary feed-source of dietary protein. Soybean and products of processing are particularly important feeds-sources of high-quality protein in young cattle nutrition. Beside of high protein content with favorable amino acids composition, soybean is rich in fat, phospholipids, trace elements and vitamins [41].

Products of soybean processing: heated soybean flour, soy protein concentrate, soy protein isolate, are increasingly used as protein sources in milk replacers for liquid phase of calves nutrition. Production performances of calves, primary daily gain and efficiency of feed utilization are often lower when calves were fed milk replacers where most of protein content (50% and more) are soybean proteins, relative to using milk replacers with complete protein content from milk-based feeds [35]. This effect depends on the numerous nutritional factors, including presence of antinutritional and antigenic factors in soybean-based feeds. Heat treatment of soybean (toasting, extruding, roasting and micronizing) as also chemical treatments: separation of soluble carbohydrates, by water or alcohol extraction (production of soy protein concentrate), protein precipitation (production of soy protein isolate), most of the antinutritional and antigenic factors are neutralized. Some protein fractions as glycinin and β-konglycinin staying in unchanged form, inducing immune reactions of calves, especially in intestine, leading to negative morphological and functional changes on intestinal mucosa, causing lower efficiency of feed utilization and other production performances of calves [22].

Heat treatment of soybean reduces rumen degradability of proteins and increases intestinal utilization efficiency. Considering that heating is common treatment for inactivation of antinutritional components in soybean, simultaneously this method of processing is applied for reducing of protein rumen degradability. Beside inactivation of antinutritional factors, this is the main reason for improving production performances of ruminants fed heated soybean [37].

Using of heated fullfat soybean in calves nutrition is subjected by nutritional value, positive effect on animal productivity and quality of animal production. Heat-treated soybean characterized with high content and protein quality (high proportion of rumen undegradable protein), and high fat content, affect positively on N balance and calves performances. Using heat-treated soybean in calves diets improves digestibility of crude protein (CP), increases the content of rumen undegradable protein, completely meeting the requirements in essential amino acids (AA), and high ration energy concentration. Using heated soybean in mixtures for calves, improves feed conversion, utilization of nutrients and energy, with better average daily gains [36].

NUTRITIONAL CHARACTERISTICS OF SOYBEAN AND SIGNIFICANCE OF HEAT TREATMENT

Protein and fat with portion of 60% are the main components of soybean. Carbohydrates makes about one third, including polysaccharides, stachyose, raffinose and saccharose. Phospholipids, sterols, minerals and other trace constituents make the rest.

Proteins form protein bodies with 2-20μm in radius, which remain after grinding of grain. Soybean proteins are characterized with high biological value, similar to animal proteins. According to amino acid structure, soybean protein is similar to egg protein. Soybean protein has heterogeneous structure, and consists of 88-95% of water-soluble fraction, where 8-24% are albumins, and 59-81% are globulins. Soybean protein further contains 3-7% of protein soluble in NaCl solution, and 2-5% of protein soluble in 0.2% solution of NaOH. Soybean globulin consists of α, β and γ-conglycinin and glycinin. High water solubility of protein provides high digestibility and nutritional value in animal nutrition. Although the soybean protein is excellent source of individual AA, content of AA with sulphur are insufficient.

Table 1. Chemical composition of soybean [28]

Item	Row soybean	Roasted soybean
DM, %	90.0	91.0
TDN	101.0	98.8
DE, Mcal/kg	4.77	4.72
ME, Mcal/kg	4.05	4.00
NEL, Mcal/kg	2.75	2.72
NEM, Mcal/kg	2.76	2.73
NEG, Mcal/kg	1.97	1.95
SP, %	39.2	43.0
NDICP, %	2.3	6.1
ADICP, %	0.6	2.0
Ether extract, %	19.2	19.0
NDF, %	19.5	22.1
ADF, %	13.1	14.7
Ash, %	5.9	5.0

NEL- Net energy for lactation
NEM- Net energy for maintance
NEG- Net energy for gain
NDICP- Neutral detergent insoluble crude protein
ADICP- Acid detergent insoluble crude protein

Soybean contents about 20% of fat located in small structures-spherosomes that are between protein bodies with radius of 0.1-0.5 μm. Soybean oil is characterized with high content of linoleic acid (51%) that is essential polyunsaturated fatty acid. Soybean oil also contents about 7% of linolenic acid that are polyunsaturated acid too, but more sensitive to auto oxidation compared to linoleic acid.

Table 2. Soybean oil fatty acids [12]

Fatty acid	Content, %	Average, %
Saturated		
Lauric	0.1	0.1
Myristic	<0.5	0.2
Palmitic	7-12	10.7
Stearic	2-5.5	3.9
Arachidic	<1.0	0.2
Behenic	<0.5	-
Unsaturated		
Palmitoleic	<0.5	0.3
Oleic	20-50	22.8
Linoleic	35-60	50.8
Linolenic	2-13	6.8
Eicosapentaenoic	<1.0	-

Carbohydrates of soybean are soluble sugars (9-12%), starch (3-9%), cellulose (3-6%) and pectin. Most of soybean carbohydrates are water-soluble.

Table 3. Soybean mineral content [28]

Item	Row soybean	Roasted soybean
Ash, %	5.9	5.0
Ca, %	0.32	0.26
P, %	0.60	0.64
Mg, %	0.25	0.25
K, %	1.99	1.99
Na, %	0.01	0.01
Cl, %	0.04	0.06
S, %	0.31	0.32
Co,mg/kg	-	-
Cu, mg/kg	13.0	15.0
I, mg/kg	-	-
Fe, mg/kg	148.0	142.0
Mn, mg/kg	29.0	29.0
Se, mg/kg	0.28	0.28
Zn, mg/kg	49.0	48.0
Mo, mg/kg	5.9	5.3

Antinutritional components of soybean are protease inhibitors, lectins, goitrogens, antivitamins, phytates, estrogens, saponins, factors of flatulence, antigens and lypoxigenase. Heat treatment of soybean is common method for inactivation of the most of antinutritional factors in row soybean. The basic mechanism of inactivation of antinutritional factors by heat treatment is their denaturation. The most of the antinutritional components in soybean are partially or completely inactivated by appropriate heat treatments as roasting, extruding, micronization, toasting and autoclaving are [11].

Proteases inhibitors of trypsin and chymotrypsin are the most studied antinutritional factors of soybean. Soybean contains two trypsin inhibitors: Kunitz and Bowman-Birk that are different according to composition, thermo stability and activity. These components inhibit intestinal activity of proteolytic enzymes. Portion of trypsin inhibitor is about 6% in total soybean protein [22]. Presence of trypsin inhibitor in row soybean causes different effects depend of species and age of animals, and of dietary content of soybean. Blocking intestinal activity of proteolytic enzymes significantly reduces utilization efficiency of dietary protein, and higher concentration of trypsin inhibitor can be lethal [4].

Lectins (chemagglutinins) make 1-3% of soybean proteins, characterized with ability to reversible binding carbohydrate fraction of glycoproteins in the surface of cell membranes. Binding the intestinal surface epitel cells (enterocytes), lectins interfere with mucosa surface-villi, reducing absorption efficiency of nutrients, primary reducing protein utilization, and increasing N excretion by feces and urine. It was determined that lectins inhibit hydrolases on villi surface and encourage intestinal colonization of coliforms. This causes great reduction of gain and in severe cases leads to exhausting of animals and mortality. Soybean lectins as trypsin inhibitor are easy degradable by heat treatment, and degradation is simultaneous with significant improving of soybean protein nutritive value.

Goitrogens inhibit incorporation of iodine in thyroxin precursors, lowering secretion. This component of soybean affects reduction of function and hypertrophy of thyreoidea, reducing animals' growth that is especially expressed in young animals.

Antivitamin effect with symptoms similar to deficit of vitamin D is assumed that is caused by phytic acid. It is possible that antivitamin effect is caused by tocoferol oxidase, as also and coenzyme that reduces effect of vitamin B_{12}.

Phytates are salts of phytic acid (inositol hexaphosphate acid) with metals as Ca, Mg, Fe, Zn, and Cu. These complex compounds are highly insoluble that significant reduces utilization of dietary phosphor and these minerals. It is well known that requirements in these elements are significant higher when soybean is included in ration, which is caused by phytic acid content. Heat treatment only partially reduces content of phytates, and satisfactory results can be achieved by enzymatic hydrolyze (using of enzyme phytase in mixtures). The utilization of phytates in ruminants are higher because of microbial hydrolyze in rumen.

Saponins are plant glycosides that hydrolyze to pentoses, hexoses, uronic acids and sapogenins. Saponins have a bitter taste, they are surface active compounds, hemolyse red blood cells, affect cell membrane permeability, and by that are toxic for animal tissues. These activities of saponins are present in soybean even after heat treatment. Soybean contains 0.5% of saponins. Saponins are hydrolyzed in digestive tract by bacterial enzyme activity.

Estrogens in soybean are mostly isoflavones.

Factors of flatulence in soybean are oligosaccharides with low molecular mass, contain α-galactosidic and β-glycosidic bonds, mainly raffinose and stachyose. These compounds cause bloat in ruminants.

Antigenic compounds of soybean induce specific antibodies synthesis, primarily at calves and pigs. These antigenic molecules are primarily proteins, glycoproteins, including proteases inhibitors, and lecithin. At predisposed animals, during repeated intake of antigenic molecules, allergic reaction is appeared with intestinal adverse effects. The most significant antigenic compounds are glycinin and β-conglycinin that together make 60% of soybean protein [22]. Glycinin and β-conglycinin are resistant to heat treatments, and treatment with 60-70% aqueous solution of ethanol at $80^{o}C$ for 2 h. Antigenic activity also does not appear in hydrolysates of soybean protein.

Lypoxigenase catalyzes lipid oxidation, and makes 2% of soybean proteins. The main cause of deteriorated aroma, flavor, taste and color of feeds with higher fat content is oxidation of lipids. Linoleic and linolenic acid are main substrate for lypoxigenase activity [44]. Lypoxigenase also catalyzes oxidation of vitamin E, C and carotene (typical antioxidant factors) additionally decreasing nutritional value of soybean products. During the process of lipid oxidation, peroxides are formed, which are transformed into less reactive compounds-hydroperoxides of fatty acids by reaction of isomerization and reduction. One of the main problems after lypoxigenase activity is forming of lipid-protein complex. Hydroperoxides and their secondary products react with proteins, causing destruction of their natural biological activity and toxicity for biological systems.

Advantage of using of soybean in ruminants' nutrition reflected in providing of high-quality protein is neutralized by extensive rumen microbial degradation of soybean protein. Soybean crude protein contains 10% of NPN with rate of ruminal degradation of 400 %/h, and 35% of soluble protein (B_1 fraction) with ruminal degradation of 100-200 %/h. Almost half of soybean crude protein is rapidly degraded to NH_3 by ruminal microflora. Insoluble fraction of protein-B_2 makes 51.4% of crude protein, with rate of ruminal degradation of 8-10%. About 86% of true protein (B_1+B_2 fraction) from soybean crude protein could be manipulated toward to increasing ruminal degradability resistance, and increasing of postruminal supplying in rumen undegradable protein and adequate amount of essential AA [33]. Heat treatment of soybean is used successfully for reduction of protein rumen degradability.

Heat treating of soybean decreases rumen degradability of protein and improves intestinal utilization. Fraction of rumen undegradable protein makes 31% of soybean crude protein. As heat treatment is common method for inactivation of antinutritional components in soybean, simultaneously it is used for reducing protein ruminal degradation. Beside of neutralization of antinutritional compounds it is the main cause of improved production performances of ruminants fed heat treated soybean [37].

Soybean meal, heat treated soybean (extruded, roasted, toasted), soybean cake and soybean expeller are the most common protein feeds-sources of RUP in rations for high yielding dairy cows. Soybean products are characterized with good tastefulness and optimal profile of intestinal available essential AA, the most similar to ruminal microbial protein. Soybean meal is characterized with high rumen degradability of protein-high RDP content (65-75%), while heat treated soybean features with lesser content of RDP (50-70%) as and soybean expeller (55%), [34].

Rumen degradability of soybean protein determined *in situ*, in row soybean and four soybean products were: row soybean-76.89%; roasted soybean for 30 min. at 60^{o}C-78.94%; soybean meal-68.53%; shelled soybean toasted for 35 min. at 95^o-105^{o}C-37.30%; shelled soybean toasted for 35 min. at 105^o-115^{o}C-27.80% [17].

Beside protection of protein from ruminal degradation, inadequate thermal processing can cause adverse changes on protein complex. If soybean as protein source is overheated, a digestive tract availability and utilization of AA (primarily lysine) are reduced. The influence primarily of high temperature, in feeds may cause reaction between aldehyde-groups of sugars and free amino-groups of amino acids from protein (Maillard reaction) where amino-sugar complex is formed, which is usually more resistant to digestive tract hydrolysis relative to normal peptides. Reversibility of this reaction is directly influenced by temperature and lasting of treatment. Reaction of free ε-group of lysine and aldehyde group of reducing sugars can significantly decrease nutritional value of soybean protein, considering that peptide chain with modified lysine is not subjected to hydrolytic effect of trypsin and is not utilizable. Low-molecular compounds that are formed by reaction between glucose and lysine inhibit N-aminopeptidases, reducing digestive tract protein absorption. Rate of reduction depends of presence of water, type and amount of reducing sugars, type of protein and temperature and lasting of heat treatment [18].

On high temperatures, beside reaction of ε-group of lysine with reducing sugars, occurs her reaction with carboxyl group of other AA (on break of peptide chain), and with sulphur from cysteine, additionally decreasing AA utilization.
Heat treatment causes denaturation of proteins and reduction of protein solubility. Protein solubility is used as indicator of adequacy of applied heat treatments [4]. In comparative studies of micronized, extruded and roasted soybean, the highest solubility of protein was registered in micronized soybean, intermediate in extruded, and the least content of soluble protein was determined in roasted soybean. This shows the advantage of treatments based on short time of heating and high temperature, compared to classic thermal processing.
Advantage of heat treated soybean is significantly improved flavor. Applied heat causes releasing of pleasant taste and aroma that favorably influence feed intake. Part of this improving is due to lypoxigenase inactivation, which is favorably for possibility of storage of soybean products.

EFFECTS OF USING SOYBEAN PRODUCTS IN PERIOD OF LIQUID NUTRITION OF CALVES

Milk replacers used in young calves' nutrition are classified as replacers contain entirely milk protein, and replacers contain protein from other feeds-sources of proteins. Milk replacers containing entirely milk protein are based on skim milk powder, whey protein concentrate, whey powder or delactosed whey. Toward to formulating economically acceptable milk replacers, especially in terms of increased using of milk replacers due to weaning calves at later age, the most common used alternative and low-cost sources of protein in milk replacers are soybean flour, soybean protein concentrate and soybean protein isolate that are characterized with high digestibility and utilization [2].

Table 4. Amino acid profile (%) of soybean, cow milk and calves' muscle tissue protein [22]

AA	Soybean	Cow milk	Muscle tissue
Threonine	3.7	4.6	4.9
Proline	5.7	10.1	5.1
Glycine	4.7	2.0	6.5
Alanine	4.8	3.5	7.0
Cystine	1.5	0.9	1.3
Methionine	1.5	2.6	2.8
Isoleucine	5.8	5.8	5.5
Lysine	6.7	8.5	9.5
Arginine	7.8	3.6	6.8
Essential AA	46.5	47.7	49.2
Nonessential AA	62.4	60.3	56.4

Defatted soybean flour is produced by oil extraction of ground and previously shelled soybean grains, followed with heat treatment and grinding. Soybean flour where oil was extracted using ethanol instead of hexane showed better results for using in milk replacers. Ethanol denatures antigenic proteins and reduces content of phenolic compounds that cause digestive disorders, decreasing of gain and increasing of mortality [13]. Fullfat soybean flour is produced by grinding and toasting of shelled soybean.

Soybean protein concentrate (SPC) is produced by separation of soluble carbohydrates from defatted soybean flour using alcoholic or isoelectric washing. Soybean protein concentrate contains minimum 65% of proteins in DM. Intestinal digestibility of SPC protein is 85% at calves, while digestibility of skim milk powder protein is 91% [26].

Soybean protein isolate contains the main soybean protein fraction with minimum 90% of CP in DM. It is produced using extraction of protein from defatted soybean flour, with subsequent precipitation-clotting of protein from extract, washing and drying.

Table 5. Chemical composition of soybean products (% DM) that are used in milk replacers [32]

Item	Soybean flour	Soybean protein concentrate	Soybean protein isolate
Crude protein	56.0	72.0	95.6
Ether extract	1.0	0.3	0.6
Sugars	16.0	1.0	-
Polysaccharides	15.0	20.0	0.5
Ash	6.0	5.0	3.3
Other components	6.0	1.0	-

Although soybean products are commonly used as protein sources in milk replacers, substitution of 50% of milk protein with soybean protein decreases average daily gain and feed efficiency of calves at period of liquid nutrition [22]. Plant proteins should be used in milk replacers for calves after third week of age [2]. Substitution of 50% of milk protein with soybean protein concentrate in milk replacers, at calves 1-14 days of age, decreased average daily gain by 32.5% and FCR by 33.3%. This milk replacers used for feeding calves until 42 days of age with, decreased average daily gain by 7.1% and feed conversion ratio by 5.9%. This pointing that calves at age later than two weeks are more tolerant on soybean protein [43]. This is according to negative effect on morphological and functional characteristics of intestinal mucosa (villi length and crypts depth) at young calves. Beside thermal and chemical inactivation of most antinutritional and antigenic components, intestinal histomorphological changes were registered (decreasing of villi length) at calves fed milk replacers with soybean flour or soybean protein concentrate [20], and this could be explained by abrasive effect of present fibers cellulose and hemicellulose. Series of other negative effects on enterocytes of intestinal mucosa were found at young calves: reducing capacity for protein synthesis, decreasing activity of digestive enzymes, reducing of absorption capacity, increasing of mucus secretion, immune activity and endogenous protein losses [15, 27]. Besides higher intestinal digestibility, soybean proteins are characterized with lower apparent digestibility, due to effect on increasing secretion of endogenous protein in intestinal mucosa and by that on higher losses of endogenous protein [26]. This could result from presence of resistant fractions of soybean protein or oligopeptides, and their interaction

with intestinal mucosa that affects increased secretion of endogenous protein. There is also possibility of effect of higher content of polysaccharides-cellulose and hemicellulose that intensify abrasion of mucosa and cell desquamation, affecting higher losses in endogenous protein too. Increasing amount of endogenous protein is partially result of increased extent of microbial protein synthesis in calves' intestine fed soybean protein concentrate or isolate.
Decreasing of daily gain by 18.3% and feed conversion by 14.5% were obtained, at Holstein calves 3-30 days of age, fed milk replacer where 60% of total protein was supplied from soybean [10].

Table 6. Effect of substitution of 60% of milk protein with soybean protein concentrate in milk replacer on production and morphological characteristics of young calves [10]

Item	Milk protein	Milk protein + Soybean protein concentrate
Initial BW, kg	42.4	41.1
Final BW, kg	52.1	49.3
Average daily gain, g/day	344	281
Feed conversion kg/kg of gain	1.81	2.13
Withers height, cm	82.4	80.8
Duodenum		
Villus height, µm	400	372
Crypt depth, µm	240	247
Jejunum		
Villus height, µm	713	506
Crypt depth, µm	300	209
Ileum		
Villus height, µm	532	458
Crypt depth, µm	352	301

Calves at age of 30-130 days fed milk replacer where hydrolyzed (by enzyme activity) soybean protein isolate supplied 56% of total protein, did not show significant differences in final BW, daily gain, feed efficiency, diet digestibility, morphological characteristics of small intestine mucosa, antibody titers, compared to calves fed standard milk replacer (21% CP, 20% fat), with completely milk protein. Feeding calves with milk replacer where 72% of protein was supplied from heated soybean flour, reduced final BW by 18%, daily gain by 27.3%, feed conversion by 34.4%, cold carcass weight by 21.3%, calves showed significantly lower dietary nutrients digestibility and N retention, and higher antibody titers specific for soybean antigenic proteins [21].

Table 7. Performances of calves fed milk replacer with completely milk protein (MP), milk replacer with 56% protein from hydrolyzed soybean protein isolate (HSPI), and milk replacer with 72% protein from heated soybean flour (HSBF), [21]

Item	MP	HSPI	HSBF
Initial BW, kg	53.9	53.4	53.4
Final BW, kg	165.6	156.9	135.8
Average daily gain, kg/day	1.23	1.14	0.89
Feed conversion, kg/kg of gain	1.60	1.68	2.15
Cold carcass weight, kg	103.6	99.9	81.5
Digestibility, %			
Dry matter, DM	95.5	93.7	81.3
Organic matter, OM	96.2	94.8	82.7
Nitrogen, N	94.4	91.5	68.6
Ether extract	92.0	89.0	84.1
Nitrogen free extract, N.F.E.	98.7	98.5	88.4
Ca	79.8	76.8	53.7
P	94.0	91.3	75.7
Retention, g/day			
N	38.0	35.8	30.1
Ca	19.3	18.1	13.6
P	11.2	11.4	9.2
Antibody titers in blood plasma, 74. day			
Against denatured proteins from HSPI	0	1.6	3.1
Against denatured proteins from SBF	1.4	1.0	9.3

In this researching, hydrolyzed soybean protein isolate did not show antibody activity of glycinin and β-conglycinin, while contents of these immunoreactive proteins were 3.94 and 3.61%, respectively. In untreated defatted soybean flour contents of glycinin and β-conglycinin with antigenic activity were 26.9 and 19.4%. Antitrypsin activity of HSPI was 3.1 TUI (Trypsin Units Inhibited)/mg CP, while this value for HSBF was 18.0 TUI/mg CP. In row soybean flour, antitrypsin activity was 87 TUI/mg CP.

Soybean protein concentrate and isolate are characterized with less than 2% of antitrypsin activity relative to row soybean and are free of immunoreactive glycinin and β-conglycinin [26].

Soybean protein concentrate and isolate can be used for substitution of 50% of milk protein in milk replacers. Until the age of three weeks, digestive proteolytic system of calves is able to digest nonmilk protein at lesser extent. Due to efficient diet utilization and optimal growth of calves, using of milk replacers with completely milk protein is recommended, until age of three weeks. At later age, calves can efficiently utilize milk replacers with partially substituted milk protein by other protein sources. Soybean proteins, in addition to lower digestibility, can induce allergic reaction and diarrhea. Milk replacers based on soybean proteins should be added with synthetic lysine and methionine for improving their AA profile [38].

Table 8. Intestinal apparent and true digestibility (%) of protein and AA of skim milk powder (SMP), soybean protein concentrate (SPC) soybean protein isolate (SPI), [26]

Item	SMP	SPC	SPI
Apparent digestibility			
Organic matter, OM	91.9	83.8	79.2
Crude protein, CP	90.6	85.2	72.7
Lysine	95.8	91.7	86.0
Cystine	79.5	75.1	54.0
Threonine	89.5	82.8	69.2
True digestibility			
Crude protein, CP	98.7	95.1	93.7
Lysine	99.4	97.3	96.7
Cystine	97.1	91.8	89.3
Threonine	98.6	94.4	92.9

Using of soybean proteins in milk replacers commonly affects adversely on production performances of calves, caused by impossibility of soybean proteins to coagulate in abomasum of calves, inducing of allergic reaction in gastrointestinal tract, morphohistological changes on intestinal villi, which reduce digestibility and absorption of AA. Average daily gain, digestibility of DM, AA, N and retention of N were increased when calves fed milk replacer where 50% of milk protein was substituted with heat treated and defatted soybean flour, added with synthetic AA: DL-methionine (0.13%), L-lysine (0.60%) and L-threonine (0.27%), compared with calves fed milk replacer with soybean flour, without synthetic AA [19].

Table 9. Production performances of calves fed milk replacer based on skim milk powder and whey powder (MP), milk replacer with soybean flour (SBF), and milk replacer with soybean flour with added synthetic AA (SBFAA), [19]

Item	MP	SBF	SBFAA
Intake DM, g/day	671.2	680.0	671.2
Intake N, g/day	22.5	22.8	22.5
Average daily gain, g/day	388.0	244.3	308.5
Digestibility DM, %	92.3	80.9	82.2
Digestibility N, %	84.9	66.7	68.4
Retention N, g/day	13.4	8.0	10.4

Substitution of 75% of milk protein in milk replacers for calves at age of 0-6 weeks, with soybean protein concentrate, soybean flour and additionally treated soybean flour (steaming on 60^{o}C for 1h whereas trypsin inhibitor activity was decreased to 1TUI), decreased average daily gain, diet digestibility, and N retention [7]. Considering only milk replacers based on soybean proteins, authors concluded that calves fed experimental treated soybean flour showed the best production performances, followed

with calves consumed milk replacer with soybean protein concentrate, and calves fed milk replacer with commercial soybean flour showed the poorest performances.
Soymilk can be efficiently used for substitution of part of fullfat milk (up to 50%) in diets for young calves, without negative effect on calves health, average daily gain and feed efficiency, while costs of weaning is decreased by 35% [14].

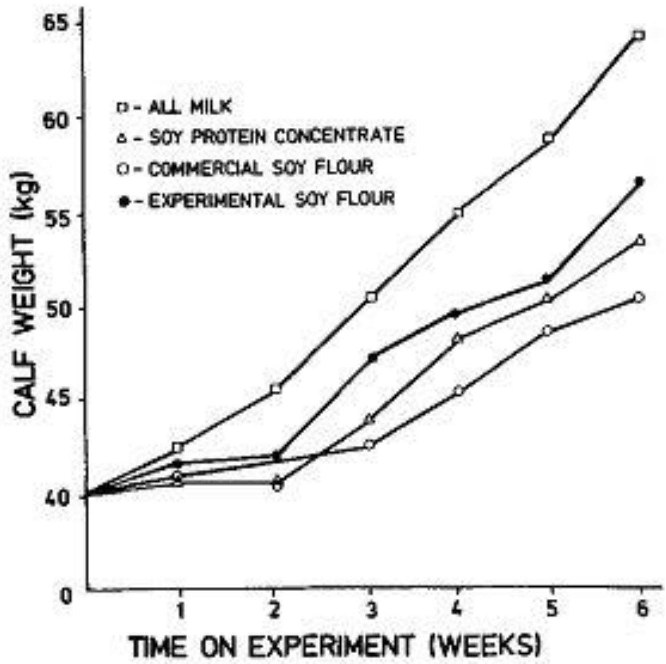

Figure 1. Body weights of calves fed different milk replacers [7]

Calves consumed soymilk, more rapid achieved concentrate intake of 900 g/day (parameter for weaning time).

Table 10. Effect of substitution of part (25 and 50%) of fullfat milk (M) with soymilk (SM), on production performances of calves [14]

Item	M	SM-25	SM-50
BW at 49. day, kg	68.3	68.0	65.3
Total gain, kg	26.4	26.4	23.8
Total DMI, kg	45.8	50.8	45.6
Feed conversion, kg of gain/kg feed DM	0.58	0.52	0.54
Age at 900 g/day starter intake, day	58.4	52.1	49.8
BW at 900 g/day starter intake, kg	71.4	64.4	61.1

SIGNIFICANCE OF USING OF HEAT TREATED SOYBEAN IN CALVES NUTRITION

Using of heat treated soybean in young cattle nutrition is according to his nutritional value, positive effect on reproduction performances, and quality of realized production. Effect of including soybean in diet for calves depends of dietary level, applied method of treating and exact production system.

Heat treated soybean contains 4% more metabolic energy than row soybean. Content of rumen undegradable protein in heat treated soybean is between 39 and 62%, depends of treating method. Heat treatment of soybean reduces content of soluble N and increases content of N fraction bind to fibers, relative to row soybean. This could be explain by Maillard reaction (amino-sugar complexes) that reduces solubility of N, partially these complexes retained in NDF and ADF fractions (trough out sequentially fractionation of fibers).

Table 11. Content of protein fractions in row and heat treated soybean [8]

Fraction	INRA (1988)		NRC (1996)		NRC (2001)	
	Row	Extruded	Row	Roasted	Row	Roasted
Metab. Energ., kJ/kg	14309	14393	15803	15803	16945	16736
Crude protein,%	35.4	35.4	36.3	38.5	35.3	39.1
Digestible prot., %CP	87.0	87.0	-	-	-	-
RDP, %CP	90.0	49.0	75.0	38.3	69.6-78.5	60.6-70.9
RUP, %CP	10.0	51.0	25.0	61.7	21.5-30.4	29.1-39.4
Soluble prot.,%CP	-	-	44.0	5.7	27.8	27.8
NPN,% soluble CP	-	-	22.7	100.0	-	-
NDFIP, %CP	-	-	4.0	23.6	5.87	14.20
ADFIP, %CP	-	-	3.0	7.29	1.53	4.74
B_1, k_d[1] (%/h)	-	-	200	150	-	-
B_2, k_d (%/h)	-	-	10.0	5.0	-	-
B_3, k_d (%/h)	-	-	0.20	0.18	-	-
Intestin. digest.,%/h	-	-	-	-	85.0	85.0
AA, % RUP						
Methionine	-	-	1.01	1.02	1.47	1.40
Lysine	-	-	5.36	5.77	5.98	5.98
Arginine	-	-	6.55	6.42	7.52	6.79
Threonine	-	-	3.52	3.56	3.96	3.80
Leucine	-	-	7.23	7.15	7.41	7.13
Isoleucine	-	-	4.65	4.61	4.42	4.22
Valine	-	-	5.09	4.91	-	-
Histidine	-	-	2.82	2.96	-	-
Phenylalanine	-	-	4.94	4.81	-	-

[1] k_d-Rate of ruminal degradation of CP fractions

Adequately heat treated soybean, improves calves' performances, compared with using soybean meal in starters for calves. Young calves require high concentration of energy and protein in ration. Increasing of energy content in mixture for calves by addition of animal or plant fats is related with decreasing of DM intake. Heat treated soybean that is characterized with high content of quality protein (with high proportion of rumen undegradable protein) and high level of oil, improves N balance and performances of calves [40].
Introduction of heat treatment of feeds increases possibility of their using and effect of utilization in calves nutrition. According to calves age, proportion of microbial protein that flows in small intestine from rumen is increased. However, only microbial protein cannot meet complete protein requirements of calves characterized with intensive growth. On the other hand, high level of dietary protein provides high daily gain, but not always efficiently utilization of protein. Including insoluble protein in diets for calves, which is rumen undegradable, provides efficiently protein utilization and sufficiently supplying of available AA [38].
Using of roasted soybean (138°C) in combination with roasted corn (135°C), improved production performances of Holstein calves (daily gain, feed conversion, energy utilization efficiency) at age of 1-8 weeks (weaned at 6 weeks) [1]. Ruminal concentration of NH_3 was higher at calves fed soybean meal, relative to calves consumed diets with roasted soybean-138 and 146° C (2.8, 1.3 and 1.6 mM, respectively) due to different contents of RDP (70, 55 and 48%, respectively). Blood urea concentration in calves at age of 8 weeks was higher for calves fed soybean meal (2.75, 2.31 and 2.58 mM, respectively), and these results can be explained with higher ruminal concentration of NH_3.
Using of extruded soybean (140°C) in mixture for weaned calves (60-120 days), improves efficiency of utilization of dietary DM, metabolic energy, dietary CP and biochemical blood parameters. This effect is more expressive when extruded soybean was used with heat treated (micronized) corn in mixture for weaned calves [36].

Table 12. Effects of using extruded soybean and micronized corn in mixture for weaned calves [36]

Item	SM	ES	ESMC
Initial BW, kg	62.5	64.6	65.5
Final BW, kg	121.0	121.6	123.2
DM intake, kg/day	2855.0	2755.6	2633.8
Feed conversion, kg/kg of gain	2.93	2.88	2.76
Utilization efficiency of ME MJ/kg of gain	35.92	35.77	33.96
Utilization efficiency of CP g/kg of gain	598.49	580.7	540.29
Glucose concentr. in blood serum, mmol/l	4.03	4.13	4.30
Urea concentr. in blood serum, mmol/l	3.44	3.13	2.81

SM-Mixture with soybean meal
ES-Mixture with extruded soybean
ESMC- Mixture with extruded soybean and micronized corn

Substitution of soybean meal with extruded soybean in diets for young cattle provides increasing of feed efficiency, followed with reducing of dietary DM intake, due to higher dietary energy concentration, lower level of methane production, and higher metabolic efficiency of fat retention.
Researching the effects of roasting temperature of soybean (99^o-163^{o}C) on production performances of Holstein calves at age of 1-10 weeks, authors [31] found that temperature interval 143^o-146^{o}C is optimal for this heat treatment, resulted in the highest daily gain, feed conversion, and dietary energy utilization.

Table 13. Production performances of calves fed in mixture roasted soybean at different temperatures [31]

Applied temperature	Average daily gain kg	Feed conversion kg of gain/kg of feed	Energy utilization Mcal/kg of gain
99^{o}C	0.55	0.35	10.02
127^{o}C	0.61	0.37	9.51
143^{o}C	0.69	0.38	9.28
146^{o}C	0.60	0.36	9.34
163^{o}C	0.40	0.33	9.98

Authors concluded that requirements of young calves in rumen undegradable protein are high, which can be supplied by adequate temperature of heat treatment of soybean (143^o-146^{o}C, with RUP content of 50-60%), while overheating causes forming of indigestible compounds that affecting lower feed efficiency.
Using of heated soybean in mixtures for calves can reduce dietary starch concentration and enable formulating of diets with high energy concentration, with avoiding of ruminal acidosis appearance. Favorable effect of using of soybean is greater when concentrated diets for calves are applied, due to lower interaction with fibers digestibility. However, it is recommended that portion of soybean in calves' rations should be limited at 20%, due to avoiding adverse effect on rumen digestibility and tastefulness of diets [24].
Inclusion of fullfat soybean in calves' diets (20% in DM) as also addition of soybean oil causes increasing of carcasses fat content by 7%, and carcass weight by 3%. Fullfat soybean as also soybean fat in diets for calves, increase content of fatty acids with more than 18 C atoms, especially unsaturated fatty acids with accompanying decreasing of portion of fatty acids with less than 16 C atoms. Simultaneously reducing content of intramuscular fat (portion of 15% extruded soybean in calves' diet, reduces fat content in *musculus longisimus dorsi* by 11.7%). This is result of decreasing of *de novo* synthesis of fatty acids with short and medium chains in muscles [6].
In experiment with Holstein calves (1-12 weeks), higher daily gains were found at calves fed mixture with extruded soybean meal relative to calves consumed commercial soybean meal (0.76 and 0.71 kg/day), dietary DM intake was also improved (1.43 and 1.32 kg/day), [23]. This was explained as a result of increased content of RUP.
Beside the total protein requirements in young cattle nutrition (as also other category of cattle), portion of dietary RUP content should be considered [18]. With higher portion of dietary RUP, daily gain of calves is increased, especially at age of 90-120 days when animals are entirely adapted to completely dry feed nutrition. In addition, it was found

that higher dietary content of RUP improved DM, energy and protein intake, as also efficiency of utilization for BW gain, and increased N retention. Simultaneously, ruminal pH and content of acetic acid were increased, with lower content propionic acid. There were no effects of higher dietary RUP content on digestibility of DM, OM, CP and NFE, as also on biochemical parameters of blood (concentration of glucose, urea and total protein).
Using of extruded soybean, instead of soybean meal, especially in combination with heat treated corn in mixtures for weaned calves (60-120. days), improves feed digestibility (110. day), [39].

Table 14. Effect of using extruded soybean and micronized corn in mixture for weaned calves on feed digestibility (%), [39]

Nutrient	SM	ES	ESMC
Dry matter	76.09	77.25	79.73
Organic matter	78.33	78.06	81.91
Crude protein	71.51	72.14	76.25
Crude fiber	53.95	52.75	50.90
Ether extract	88.66	87.36	85.77
NFE	83.35	84.50	89.57

SM-Mixture with soybean meal
ES-Mixture with extruded soybean
ESMC- Mixture with extruded soybean and micronized corn

At *in vitro* conditions it was obtained that releasing of free fatty acids from substrate: soybean meal + soybean oil, extruded soybean, row soybean and roasted soybean (at 132^o, 146^o and 163^o), achieved maximum after 4, 6 and 12 h (row and roasted soybean) of incubation. As roasting temperature is higher, extent and rate of releasing of free fatty acids are reduced. Fatty acids from roasted soybean were significantly lower exposed to biohydrogenization process relative to other treatments, even relative to row soybean. This is due to some processes of heat treatment (extruding) that release oil from micelles located intracellular in soybean grain, cause more rapid oil releasing in rumen. In addition, it was determined that soybean meal + soybean oil and extruded soybean were characterized with lower digestibility of NDF and ADF fractions of fibers, relative to roasted and row soybean, which is caused by rapidly releasing of free fatty acids and their depressive effect on fiber digestibility in rumen [30].
Increasing content of RUP in diets for Holstein calves: the first period at age of 0-12 weeks, with 33, 37 and 46% of dietary RUP content; and the second period at age of 14-25 weeks, with 30, 34 and 38% of dietary RUP, improves feed efficiency, especially at later age [42]. Due to microbial degradation of dietary protein, it is common that duodenal flow of RUP and AA is inadequate, causing protein insufficiency for rapid growth of calves. Positive correlation was registered between dietary content of RUP and AA available for intestinal absorption.
In 9-weeks experiment with female Holstein calves (age of 3 months, 150 kg), average daily gain and DM intake were higher at calves fed extruded soybean meal, relative to commercial soybean meal, whereas calves consumed mixture based on barley and

extruded soybean meal showed higher daily gain, relative to calves fed mixture based on corn and extruded soybean meal [5].

Table 15. Production performances of calves fed mixtures based on corn or barley, and soybean meal or extruded soybean meal [5]

Item	CSM	CESM	BSM	BESM
Initial BW, kg	148.5	149.3	143.2	155.1
Final BW, kg	219.0	220.4	209.5	232.4
Average daily gain, kg/day	1.12	1.13	1.05	1.23
DM intake, kg/day	5.9	6.1	5.2	6.7
DM intake /BW, %	3.30	3.31	3.03	3.59
Feed conversion, kg of gain/kg of feed	0.20	0.20	0.21	0.19

CSM-Mixture based on corn and soybean meal
CESM- Mixture based on corn and extruded soybean meal
BSM- Mixture based on barley and soybean meal
BESM- Mixture based on barley and extruded soybean meal

Calves consumed diet with higher content of RUP (improved quality and amount of intestinal available protein) has increased N retention per kilo of metabolic mass, and more efficiently N utilization, compared with calves with higher dietary concentration of RDP (affects on increasing ruminal absorption of NH_3 and urine urea concentration), [40].
At contrary, in assay with steers (initial BW of 240 kg) was found that using mixture based on soybean meal (44% CP) increased utilization and retention of N, compared with using row or extruded soybean [16].

Table 16. Metabolism of N at steers consumed different soybean products [16]

Item	Soybean meal	Row soybean	Extruded soybean
Consumed N, g/day	121.9	114.8	122.1
Absorbed N, g/day	76.9	67.4	72.3
N retention, g/day	36.5	29.1	31.8
% of consumed N	29.8	25.3	26.1
% absorbed N	47.1	43.0	44.0
Ruminal ammonia N, mM	7.0	7.2	6.9
Blood serum urea concentr., mM	5.8	6.3	6.1

Intestinal digestibility of AA in row and extruded soybean were 76 and 86%, while in soybean meal was 93%. Intestinal digestibilities of ration AA for these three treatments were 68, 73and 88%, respectively. Although nonenzymatic reactions that cause protein denaturation in heat treated feeds reduce AA availability for ruminal microflora, also commonly reduce intestinal availability of AA, too.
Holstein calves fed mixture with roasted soybean, showed lower dietary DM intake by 5.5%, but also higher feed efficiency by 7%, relative to control diet [25].

Using of extruded soybean in rations for steers did not affect average daily gain, but improved feed conversion, compared with rations based on row soybean or soybean meal [3].
In experiment with female calves (initial BW of 101 kg), authors [9] concluded that increasing of dietary concentration of RUP (using heat treated soybean meal, instead of commercial soybean meal) in mixtures, increased excretion of N by feces (35.8 and 29.7 g/day). This pointing that treatment applied in purpose to reduce rumen degradation of protein in soybean meal, also can reduce intestinal digestibility of protein. There were no differences between intestinal digestibility of treated and untreated soybean meal (79 and 81%), determined *in vitro*. Total tract digestibility of N was higher at calves fed mixture with higher content of RDP (untreated soybean meal, 72.2 and 67.2%). Retention of N was not affected by protein degradability in rumen.
In researching with Holstein steers authors [29] reported that using of extruded instead of row soybean decreased ruminal concentration of ammonia N (18.2 and 19.8 mg/100ml), as also decreasing of rumen concentration of NH_3 with higher temperature of extruding: 20.7, 17.8 and 16.1 mg/ml, for temperature of extruding 116, 138 and160^oC, respectively. There were no differences between treatments in total amount of N flowed to duodenum, as also in amount of bacterial N flowed to duodenum. Portion of bacterial in total nitrogen reached duodenum was 64% at steers fed mixture with row soybean, while it was 62, 66 and 61% at steers consumed mixtures based on extruded soybean at 116, 138 and 160^oC. This can be explained by fact that ruminal concentration of ammonia N above 5 mg/100 ml does not limit microbial protein synthesis. Proportion of absorbed N in small intestine relative to total available N was higher at steers consumed extruded soybean relative to treatment with row soybean, and increased with extruding temperature. Intestinal absorption of lysine was higher by 23% at steers fed extruded relative to row soybean (98.7 and 80.3 g/day).

CONCLUSION

Using of soybean products in calves' nutrition has according to their nutritional value, positive effects on production performances, and quality of realized production. Effect of including soybean products in diet for calves depends of dietary level and applied method of processing. Soybean products, primarily soy protein concentrate and soy protein isolate are widely used as protein sources in milk replacers for calves. Soybean proteins should be used in milk replacers for calves after three weeks of age, at the level of up to 50% of total protein content. Heat treatment of soybean reduces rumen degradability of protein and increases intestinal utilization efficiency. Using of heat-treated soybean in diets for calves, increases protein digestibility, increases content of rumen undegradable protein and fulfills the needs in essential amino acids, and achieves high energy concentration of diets. Using of heat treated soybean in complete mixtures for calves increases feed conversion ratio, utilization of consumed nutrients and energy, and provides better average daily gains.

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EXTRUDED AND POPPED AMARANTH GRAIN

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ABSTRACT

Amaranth was an important food crop for the American civilizations of the past. Grain of Amaranth has similar characteristics to those of the cereal grains and is often called a pseudocereal. Absence of gluten and relatively high content of squalene and amino-acid lysine make the amaranth grain an atractive ingredient in creating functional food. The small size of the seeds and their oil content of approximately 8% allow extrusion without grinding or adding additional water. By selecting the proper screw configuration along with a range of barrel temperatures and screw speeds, extruded products with varying degrees of expansion can be obtained. Popping of Amaranth grain is the most common mean of amaranth processing to produce snack foods. The interest in amaranth grain is based on its popping capacity, the characteristics of the starch, the nutritional value and the potential use of popped grain as an ingredient in snack food. Popped amaranth grain has pleasant specific taste and can be used as a separate snack, addition to muesli, cake decoration or as raw material for further processing. Extruded and popped foods based on grain amaranth are often sold in organic-food stores in the sections for gluten-free products.

Use of Amaranth grain

Production of amaranth as a grain reached a zenith during the Mayan and Aztec period of Central America, when amaranth grain was a staple cereal crop. Their production and use declined significantly, however, coinciding with the collapse of the Indian cultures following the Spanish conquest [17]. On ceremonial occasions, amaranth grain was ground and shaped with human blood into figures representing gods or reverted animals and eaten as part of religious rites. When Cortez conquered the area in 1519 he banned the native religions and prohibited amaranth cultivation as a means of eliminated the established worship rituals. Thus amaranth gained the rare distinction of being one of the few plant food species in history eliminated from popular cultivation as a result of a legislative fiat [43].

A growing number of studies have investigated the application of Amaranth as pseudo cereals in the production of nutrient rich products. Investigations performed on non - traditional cultures started when the world was faced with the change of technological conditions of production. The need for the plants with highly adaptable potential even in unfavorable climate conditions paid the world's scientific public attention to *Amaranthus sp.* [5]. *Amaranthus* L. species possesses more than 60 species out of which the greatest is the number of wild growing ones. Possibility of growing *Amarantus sp.* in a temperature continental climate under the precipitation regime of the Danube River basin, at region of Vojvodina, has started in 1994. A survey on the yield and chemical composition of Amaranth grown (*A. cruentus, A. mantegazzianus, A. caudatus*) has reported it was relatively high yield and high nutrition value [7, 9].

Grain of Amaranth has similar characteristics to those of the cereal grains and is often called a pseudocereal. In botanical terms, amaranth, is not true cereals, it is a dicotyledonous plants as opposed to most cereals (e.g. wheat, rice, barley) which are monocotyledonous. They are referred to as pseudocereals, as their seeds resemble in function and composition those of the true cereals. Amaranth seeds are small (1-1.5 mm diameter), they are lenticular in shape and weigh per seed is 0.6/1.3 mg. The grain structure of amaranth is differs significantly from cereals such as maize and wheat. In amaranth seeds, the embryo or germ, which is circular in shape, surrounds the starch-rich perisperm and together with the seed coat represent the bran fraction, which is relatively rich in fat and protein [17].

Absence of gluten and relatively high content of squalene and amino-acid lysine make the amaranth grain an atractive ingredient in creating functional food [11,43]. Results from a number of recent studies have highlighted the need for an improvement in the nutritional quality of cereal based gluten-free products. Several gluten-free grains exist, such as the pseudocereals amaranth is characterized by an excellent nutrient profile. Thus, an increasing trend in research is focusing on it use in the formulation of high quality, healthy gluten-free products such as bread and pasta. However, commercialization of these products is still quite limited. The availability of palatable pseudocereal -containing gluten-free products would represent significant advance towards ensuring an adequate intake of nutrients in subjects with celiac disease [1].

During a few just passed decades, *Amaranthus* sp, owing to its good nutritive values, represent subject of interest for scientific - professional public [46]. Grain have several applications in food production and can be processed for instance be expanded, extruded or milled. Expanded and extruded seeds have a pleasant, specific taste and can be used as a separate snack, muesli ingredient, cake decoration or as a raw material for futher processing. Amaranth flour obtained by whole or popped seed grinding may be used as wheat flour replacement (to 20%) in tortillas and extruded products, as well as maize replacement in corn-based foods to improve the product quality [11,16].

It is possible to grind Amaranth grain it to the granulation of grits and flour, and as such it can be a component of different bakery or confectionary formulations [16,28].

Nutritional components of Amaranth grain

Protein content in amaranth is generally higher than in common cereals such as wheat. The amaranth seed protein is rich in lysine in which cereal grains are usually deficient Among the notable nutritional attributes of amaranth grain is its high protein content (130–206 g/kg) with a better balance of amino acids and a particularly high lysine (49–61 g/kg protein) and sulphur containing amino acids (41 to 45 g/kg protein) contents. [19,27]. In the determining the protein content of amaranth by Kjeldahl nitrogen procedure, some researchers have used the factor 6.25 and some 5.85 [16].

Table 1. shows the results of the basic chemical composition of Amaranth grain.

Table 1: Chemical composition of amaranth grain

Grain	Protein (%)	Fat (%)	Total starch (%)	Ash (%)	References
Amaranth	16,5 ± 0,3	5,7 ± 0,3	61,4 ± 0,8	2,8 ± 0,0	Alvarez-Jubete [1]
Amaranthus cruentus	16,96	5,88	66,52	3,79	Bodroža-Solarov et al. [8]
Amaranth (comercial collection)	17,55	7,71		2,8	Becker et al. [2]

Amaranth contains 58–66% starch with a low gelatization temperature and granule size varying between 1 and 3.5 µm, depending on variety [45].The amylose form ranges from 0 to 22% of total starch, the balance being the branched/chain form, amylopectin [48].
Grains contain 6 to 10% percent of oil, found mostly within the germ, which is high in unsaturated oils (76%), especially in linoleic acid [12,24]. Amaranth oil is reported to contain high concentrations of tocotrienols, rare forms of vitamin E that inhibit key regulatory enzyme in cholesterol biosynthesis [20]. Also, it was found that amaranth oil contains larger amounts of isoprenoid squalene than other common vegetable oils. Squalene is a known obligatory biological precursor of sterols and its content in the seed increase the nutritional importance of amaranth grain. Squalene increases the oxygen supply to the cells of the human body. It seems that this oxygen carrying function plays a key role in lowering LDL blood cholesterol, enhancing the immune system and even preventing cancer [20].
It is generally accepted that the consumption of food naturally rich in dietary fiber is beneficial to the maintenance of health. The content of amaranth grain total dietary fiber was high (16.37 %). The content of amaranth fiber is higher than the values for wheat, oats, triticale, and sorghum, but lower than those for barley and rye [40].
Amaranth grain contains high amounts of minerals, especially calcium and magnesium [4]. Also, amaranth seed has high level of dry matter, mineral and fat content [47].They are characterized by high concentrations of calcium, phosphorus, iron, potassium, zinc, vitamins E and B complex, and a low level of antinutritional factors [45].
Antioxidant activity with the DPPH method for the raw amaranth of the two varieties was 410.0 mmol trolox/g sample for Centenario and 398.1 mmol trolox/g sample for Oscar Blanco [40].
Antinutrients, such as trypsin inhibitors and tannins, are at such low levels that do not present a nutritional hazard [16,20].

Extrusion of Amaranth grain

Thermal treatment of cereals is used for the improvement of their nutritive, hygienic, physico-chemical and other characteristics. Extrusion cooking is a popular food-processing technique, especially for cereals. It has many advantages: versatility, high efficiency, low cost and good product quality. Extrusion conditions (high shear, elevated temperature, and low moisture) may cause compositional and nutritional changes in the end product [40].

Extrusion capacity, processing and equipment

Basic parameters that influence the extrusion process are moisture content, properties of materials, temperature, pressure and number of revolutions of screw [25].
The different equipment types, extrusion temperature and water content of amaranth grain were shown in Table 2.

Table 2: Different equipment types and temperature of amaranth extrusion

Types of extruders	Water content (%)	Temperature (°C)	Reference
Single screw extruder having the following parameters:254.5 rpm, resident time 10–13 s, manufactured by Jarcon del Peru, Huancayo, Peru		180	Repo-Carrasco-Valencia et al. [40].
Brady single-screw extruder - Model 2160		150-160	Sanchez-Marroquin et al. [42].
Haake rheocord reomex 252 HAAKE RHEOCORD REOMEX 252 extruder with 4:1 compression ratio and L/D ratio of 20:1	12,14,16,18	100,150, 190	Bodroža-Solarov et al. [6].
Laboratory Brabender, 20 DN extruder, 4:1	16	160	Bodroža-Solarov et al. [10].
Single screw extruder E60 manufactured by Sever, Subotica	18	120	Bodroža-Solarov et al. [14].
10 DN Brabender extruder (Duisburg, Germany), with a3:1 compression ratio screw at 173 rpm using a 3mmdiameter die.		150–175–200	Gonzalez et al. [26]

Adjusting of moisture content in extrusion process enables controlling of extrusion conditions. Moisture content of raw material prior to extruding is limited by minimal content which is necessary for emulsifying, denaturation and homogenization, as well as by maximal values at which occur textural changes in final products or insufficient expanding [32].
The small size of the seeds and their oil content of approximately 8% allow extrusion without grinding or adding additional water. By selecting the proper screw configuration along with a range of barrel temperatures and screw speeds, extruded products with varying degrees of expansion can be obtained [16].
In our studies, we investigated pellets which were produced by extrusion using a single screw "E60" (“Sever” Subotica) extruder at 110^0 C and humidity of 18% [15].

Physical characteristics, starch structure, chemical composition and sensory properties of extruded products of amaranth grain

Extrusion cooking is a popular food-processing technique, especially for cereals. Some beneficial nutritional effects of extrusion are the increased starch and protein digestibility, and destruction of anti-nutritional factors, for example trypsin inhibitors of soybeans. However, nutritional damage (e.g. loss of available lysine) may also occur during extrusion when very high temperature and shear forces are used. Modification in particle size, solubility and chemical structure of various fiber components may occur and cause changes in their bacterial degradation in the intestine and in their physiological properties. Extrusion cooking may also cause a shift from insoluble fiber to soluble fiber [40].

Extrusion process is accompanied by the changes of the carbohydrate complex namely by the reduction of the molecular weight of starch affected by degradation of starch into dextrin [41].

It is a well-known fact that starch subjected to heating may undergo degradation if its temperature rises over 250 C. Water absorption of puffed and extruded cereal products may be interpreted on the basis of starch-water-protein interactions which affect the solid phase structure of processed material. Water absorption has been generally attributed to the dispersion of starch in excess water. This dispersion is increased by the degree of starch damage due to gelatization and process-induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules. Among other factors affecting water absorption there are: type of proteins, degree of their denaturation and amount of fiber present in processed cereal material [36].

In our experiments, carried out on a single-screw extruder at medium temperature (110˚C) and humidity of 18%, extrusion of Amaranth grain and grits decreased the moisture and starch content, while the protein content remained constant**.** The thermal treatment improved the microbiological status of the product when compared to that of non-treated ones [15].

The Fig.1 shows the change in chemical composition of raw and extruded amaranth grain.

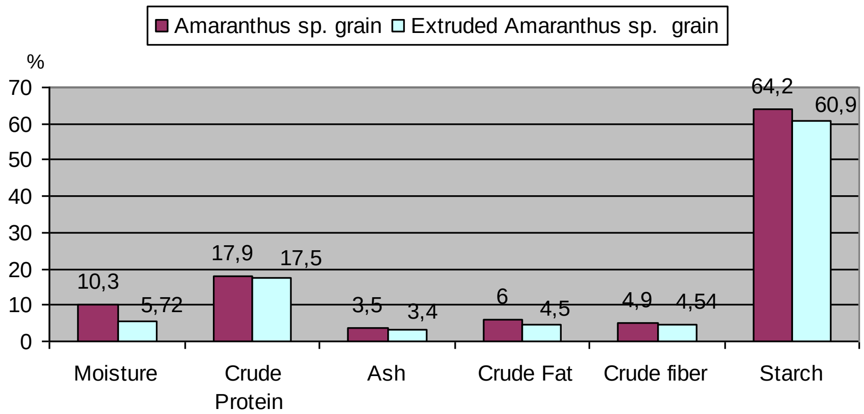
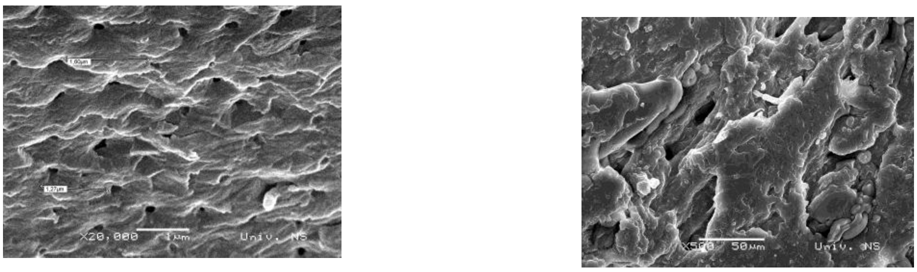


Fig 1. Chemical composition of grain and extruded Amaranth grain [15]

The content of total and insoluble dietary fiber decreased during the extrusion process. In amaranth variety Centenario, the content of soluble dietary fiber increased from 2.5 to 3.1% during the extrusion process. The content of phytic acid in amaranth was 0.3% for both varieties, and the content of total phenolic compounds was 98.7 and 112.9 mg /100 g of sample, for Centenario and Oscar Blanco, respectively [40]. The content of total phenolics, phytic acid and the antioxidant activity decreased in both varieties during the extrusion process. The in vitro digestibility of protein and starch was improved after the extrusion process in both varieties, demonstrating potential for nutritional applications [40].
Thermal processing of grain (cooking, toasting) inactivates heat labile antinutrients [4].
The center of A. *cruentus* seed is referred to as perisperm. The perisperm contains starch in the form of amilopectin. Perisperm cells contain small polyhedral granules which are very tightly packed with little or no matrix material holding them together and visual changes of the A. *cruentus* starch during extrusion processing on different temperature condition were observed by using Scanning Electron Microscope (Fig. 2) [6].



(a) Perisperm of raw material *(b) Perisperm after extrusion at 100^{0}C*

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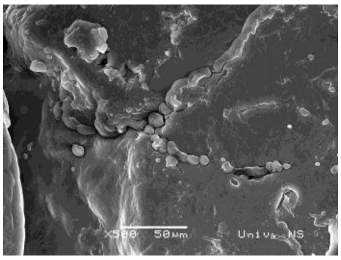
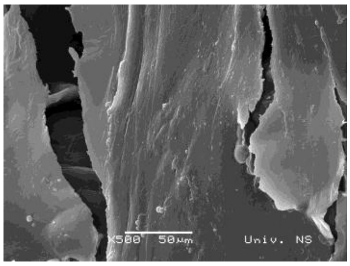


(c) *Perisperm after Extrusion at 150^0C,*

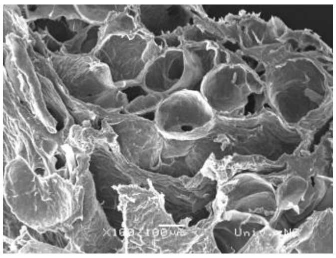


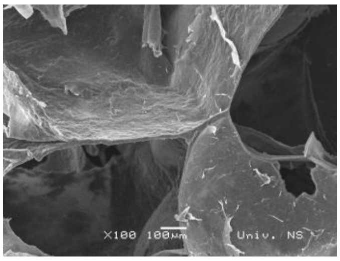
(d) *Perisperm after Extrusion at 190^0C*

Fig.2. Scanning electron micrographs of perisperm of raw A.cruenus seed and after extrusion at 100^0C, 150^0C, 190^0C

Addition of amaranth grits to extrusion blend proportionally reduced extrusion index and increased density of extrudates, due to its reduced expansion properties compared to corn. Reduced expansion resulted in a denser product with smaller air cell diameters Dried amaranth 50: maize 50 extrudates contained a greater number of cells with smaller air cell diameters than the corn meal control (Fig.3.) [21].

A





B

Fig.3. Scanning electron micrographs
of amaranth 50 : maize 50 extrudate cross-section at A (100x, bar = 100µm)
100% corn extrudate at B (100x, bar = 100µm)

Extrudates produced by extrusion of *Amaranthus* sp. grits with different moisture contents have lower taste acceptability scores, lower expansion degrees, and higher densities and hardnesses if compared with the standard corn grits extrudate. Future investigation need to be oriented to possibilities of implementation of technology o aromatization additives, which probably will increase taste acceptability scores. Optimal value of moisture content of *Amaranthus* sp. grits for extruding is 20%. The extrudate which was obtained from *Amaranthus* sp. grits with moisture content of 20% had the lowest density, highest expansion degree and the lowest hardness which resulted in the highest score for taste acceptability, compared with extrudates obtained from grits with lower or with higher moisture contents [14].
Snack-like products were obtained by extrusion-cooking of corn-amaranth grits blends containing 20 or 50% amaranth grain. The obtained products had different texture, color and taste. The product with 20% amaranth grain had pleasant and specific taste and good porosity. The product with 50% amaranth grain had higher density, poor melting and specific taste. Higher content of amaranth grits in blends increased the snacks density, decreased expansion, increased hardness and darkened the color [10].
Products and processing of extrudates from mixtures of *Amaranthus* sp. kernels with grits of diverse cereals were investigated by a number of authors [16, 41].
Amaranth, quinoa and buckwheat were also used by Schoenlechner, Jurackova, and Berghofer [44] to produce gluten-free pasta. By means of an experimental design, they determined the optimal levels of the three pseudocereal flours, albumen, emulsifiers, and enzymes to obtain a high quality pseudocereal-containing gluten-free pasta product [44].
It is difficult to produce expanded products by extrusion cooking of amaranth grain alone, due to its high fat content (6-8% in whole grain). Fat provides a powerful lubricant effect in extrusion cooking and reduced product expansion [6]. Flips of 100% corn grits have the highest expansion (4.03) and lowest density (0.095 g/cm^3), which provides demanded crispy structure during eating. Blend of 50% corn and 50% amaranth grits resulted in a decreased expansion index(1.83) compared to control 100% corn grits by 2.2 times, but in increased density (0.346g/cm^3) by 3.6 times. When part of the corn grits is replaced with amaranth grits viscosity of gels decreases compared to pure corn grits. Also, extrusion process partially damages starch granules, thus obtained gels of extruded products have lower viscosity than the initial grits [6].

There are a lot of extruded products on the market. Extruded foods based on grain amaranth are often sold in organic-food stores usually in the sections for gluten-free products. (Fig. 4).

Fig. 4: Extruded amaranth product on market [50]

Popping of Amaranth grain

The interest in amaranth grain is based on its popping capacity, the characteristics of the starch, the nutritional value and the potential of use of popped grain as an ingredient in snack food.

Popping capacity and equipment

The different equipment types and popping temperature of amaranth grain were shown in Table 3.

Table 3: Different equipment types and popping temperature

Types of popping equipment	Temperature of popping (°C)	Reference
Fluidized bed, laboratory-scale experimental stand located at the Department of Machines and Applications for Food Industry, Technical University in Bialystok, Poland	180-350	Zapotoczny et al. [51]
West Bend Poppery II hot air Corn Popper (The west Bend Co, Wisconsin, USA)	200-240	Lara and Ruales et al. [33]
Pilot-scale fluidized bed equipment	150–175–200	Gonzalez et al. [26]
Aluminum hot plate	200	Bodroža-Solarov et al. [8]
Expander LGUN	220	Bodroža-Solarov et al. [5]

Grain puffing in a stream of hot air is one of well-known methods of low-moisture cereals production. Numerous studies have been conducted on the puffing of amaranth seeds in a fluidized bed at air temperature varying between 180 and 350 °C, and air velocity ranging from 0.6 to 1.3 m/s [51].

Lara [33] studied the possibility of using a household corn popper for the popping of amaranth grain. The process conditions with the lowest popping capacity are 200°C, 14 g load and 16% of grain moisture.

Bodroža-Solarov et al. [5] studied the possibility of processing *A.cruentus* grain using an expander LGUN with pressure of 11,5 atmosphere.

The results obtained show that the quality of puffed amaranth seeds is strongly affected by both the final temperature of the material and duration of the process. The positive effects of amaranth seed puffing in hot air on the product quality include higher water and fat-holding capacity of puffed seed flour, as observed by Singhal and Kulkarni [45].

Konopko [31] studied heat and mass transfer during puffing of amaranth seeds in a pneumatic conveyer. He found that jet expansion of amaranth seeds occurs after 3.5 s of heating at a temperature of 290 °C and after 1.5 s at 370 °C. He demonstrated that the temperature of a single seed rose during puffing from the initial value of 20°C to 185°C.

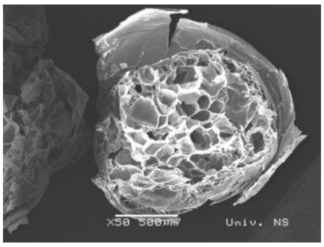
In spite of the relatively short duration of heating, puffed amaranth seeds may exhibit different properties depending on the time of puffing and air temperature applied.
The results of a study conducted by Zapotoczny et al. [51] demonstrate that puffing at 290 °C allows obtaining a product characterized by better color, geometric and fat absorption characteristics, compared with raw material and seeds puffed at temperatures exceeding 300 °C. Nevertheless, resistance to compression of puffed amaranth seeds is relatively low, in comparison with the resistance to compression of raw material, so despite the lower value of water absorption observed for amaranth seeds puffed at 290 °C, this temperature can be considered optimum for amaranth seed puffing.

Physical characteristic, starch structure, chemical composition and sensory properties of popped products of amaranth grain

Gonzalez [26] concluded that flours obtained from samples heated by fluidized bed gave aqueous dispersions with high consistencies when cooked, and they had low solubility in water and preserved parts of the starch crystalline structure. Flours obtained from extrusion-heated samples gave very high solubility in water but had lower consistency of the aqueous dispersions when cooked, and they showed a complete loss of the crystalline and granular structure. By applying each of the two heating processes, it was possible to modify, according to selected targets, the amaranth starch-rich fraction, what would allow to obtain pre-cooked amaranth flours with a wide range of hydration and rheological properties. Taking the results obtained in this work into account we can make the following remarks: most of the changes caused by both processes can be explained on the basis of changes on the starch crystalline structure and the degree of the granule integrity damage. Popping causes high degree of granule disruption and almost a complete loss of crystallinity. These effects are explained considering the values of the following properties: very high solubility, intermediate level of initial consistency, absence of amylographic peak, low retrogradation consistency and low values of both elastic module.
Popping produces the optimum increase in the protein efficiency ratio and minimum loss of available lysine. Popped amaranth grain has pleasant specific taste and can be used as a separate snack, addition to muesli, cake decoration or as raw material for further processing [16].
The unique nutritive composition of amaranth seed makes it attractive for use as a blending food source to increase the biological value of processed foods [46].
The mechanical properties of foods are key parameters for the evaluation of consumer acceptance of texture. The above observations indicate that amaranth seeds processed at 290 °C are characterized by acceptable color, physical, functional and mechanical properties. The water absorption of seeds puffed at 290 °C was slightly worse than the water absorption of seeds puffed at 330 and 370 °C [51].
Pedersen et al. [37] proved that amaranth seed puffing in hot air increases dietary fiber content of seeds. Beside the optimum increase in the protein efficiency ratio and minimum loss of available lysine, thermal treatment of popped amaranth grains gelatinizes starch that could affect the water absorption, crumb quality, taste and the over-all acceptation of the bread. The aim of this investigation is the contribution of

popped amaranth grains to the improvement of the nutritional value of bread as well as to assess the sensory properties of supplemented wheat breads.
Bodroža-Solarov [8] concluded that the addition of amaranth popped grains increased significantly ash, protein and crude fiber content and decreased the starch content of the breads compared to the control wheat bread. Higher doses of popped grains increased fat and reducing sugar content of the breads.

Fig. 5. Scaning electron micrographs of popped Amaranthus sp. grain (L GUN) (magnification x 50).



During storage were observed differences in the shelf lives of the expanded *Amaranthus* sp. seeds in dependence of barrier properties of the applied packaging materials. Popped amaranth seeds are products characterized with low moisture content (2.7 %) and low water activity (0.4) and as such, they are susceptible to adverse changes in sensory properties due to lipid oxidations since these processes tend to increase at low Aw values. Also, products with water activities around 0.4 are in the risk of development of photooxidative changes. There were no systematic moisture and water activity differences among samples packaged in met PE/PET and PET/Al/PE materials during 5 months of storage. However, samples stored in PE and PET/PE increased the moisture content and water activity value especially after 15 and 20 weeks of storage [13].
Rancid odor was first noted after 15 weeks of storage especially in samples packaged in lower barrier materials while the flavor was not particularly intense. The development of rancid odor seems to correlate with the increase of hexanal content higher than 5 ppm which is in consistency with the observations of Fritch and Gale [23].
Rancid odor was more pronounced in samples packaged in lower barrier packaging materials during storage. These materials transmitted light indicating that light induced oxidative changes in the samples. According to Mortensen et al. [34], in food with high fat and moisture content, light induced severe odor changes in packaged samples with different ratios of residual oxygen in head-space. Rancid taste developed during the last 5 weeks of storage and was more intensive for lower barrier materials while in other samples the off-flavor was not particularly intense [13].
Popping of Amaranth grain is the most common mean of amaranth processing to produce snacks foods such as: ”alegrias” from Mexico, “turos” from Peru and “Alboroto from Guatemala and “laddoos” from India. In such products, popped grain is agglomerated with honey and molasses syrups [16].
The mineral composition data [8], showed that the addition of popped amaranth grain significantly increased the content of zinc, manganese, magnesium, and calcium in the bread. Zinc content increased by 42.6-74.6%, manganese content by 51.7-90.8%, magnesium content by 75.7-88.0% and calcium content by 57-171% for supplementation levels from 10% to 20% of popped amaranth grain, respectively. When expressed in terms of Dietary Reference Intakes [28], for adult males and females, a daily portion

(300 g) of bread supplemented with 20% popped amaranth seed can meet 4.4% of DRIs for Ca, 18.9% and 24.9% of DRIs for Mg, 63.3% and 80.9% of DRIs for Mn, and 22.9% and 31.5% of DRIs for Zn, for males and females, respectively.
The mineral composition of breads supplemented with popped amaranth grain was shown in Table 4. [8].

Table 4: Mineral composition of breads supplemented with popped amaranth grain

Bread	**Mineral composition (mg/kg)**							
	Zn	**Cu**	**Fe**	**Mn**	**Na**	**K**	**Mg**	**Ca**
Control	7.21^{a}	4.09^{a}	51.47^{a}	3.81^{a}	3003.25^{a}	1600.30^{a}	137.80^{a}	80.79^{a}
20% amaranth	12.59^{c}	4.57^{a}	65.43^{a}	7.27^{c}	3056.93^{a}	1581.81^{a}	396.90^{c}	219.04^{c}

Mean values in the same column followed with different letters are significantly different ($p<0.05$).

So far, uses of amaranth starch in food preparation of custards, pastes, and salad dressings have been published by Stallknecht and Schulz-Schaffer [46] as well as incorporation of amaranth flour in tea cookies and bakery products [28].

Fig 6: Popped amaranth product on market [29].

There are a lot of amaranth grain popped products on the market. Popped foods based on grain amaranth are often sold in organic food stores in the sections for gluten-free products (Fig 6).

CONCLUSIONS

Amaranth has been increasingly researched as nutritious ingredient in gluten-free formulations. Some of the most attractive features of these seeds include their high quality protein and the presence of abundant quantities of fiber and minerals such as calcium and iron.
Extrusion of Amaranth grain and grits decreased the moisture and starch content, while the protein content remained constant**.** The thermal treatment improved the microbiological status of the product when compared to that of non-treated ones. The small size of the seeds and their oil content allow extrusion without grinding or adding additional water.

Popping of Amaranth grain is the most common mean of amaranth processing to produce snacks foods. Popped amaranth grain has pleasant specific taste and can be used as a separate snack, addition to muesli, cake decoration or as raw material for further processing. In such products, popped grain is often agglomerated with honey and molasses syrups.

However, availability of these products in the market is still quite limited. More research is necessary to fully exploit the functionality of these seeds as gluten-free ingredients in the production of palatable products which are also nutritionally balanced.

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THE INFLUENCE OF BARLEY EXTRUSION ON THE NUTRITIVE VALUE IN BROILER FATTENING

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ABSTRACT

The experiment was conducted to study the effect of extruded vs. unprocessed barley in the diet (400 g/g) on the performance of broiler chickens. Two experimental diets were as follows: B - unprocessed barley; and ExB - extruded barley. The diets were fed as pellets. Extruded barley compared to unextruded gave higher soluble fibre (28 vs. 36 g/kg) and lower insoluble (190 vs. 163 g/kg) and total (219 vs. 200 g/kg) dietary fibre values. Extrusion increased extract viscosity (1.3 vs. 3.7 cP) and water binding capacity (1.6 vs. 2.2 ml/g DM) of the barley. During the first week, birds fed extruded barley in the diet increased water consumption ($P \leq 0.05$). A significant depression in feed efficiency (day 7-21), feed AME, and in fat and protein utilisation was observed when extruded barley was included in the diet. Extrusion reduced the AME content of barley by 0.82 MJ/kg DM.
***Keywords**: barley, extrusion, nutritive value, chicken*

INTRODUCTION

Extrusion cooking is a process where a feed or diet, converted to a semi-fluid state by applying high pressure, shear forces and heat, is extruded through a die nozzle or nose cone by a screw(s). Additional heat or moisture may be added to the material at different stages of extrusion. The physical and chemical changes caused by extrusion cooking of a given diet are determined largely by the type of extruder and the extrusion cooking conditions.

Extruders can be found in a variety of sizes and types, but in general they consist of a fixed metal barrel through which material is transported. The barrel contains one or two screws which convey the food material from the feed end of the barrel to the die, which determines the final product shape. Heat may be applied to the barrel, but heat due to friction may be sufficient to cook the material. The temperature reached by the food/feed during cooking extrusion can be quite high (200°C) but the residence time at these elevated temperatures is very short (5 to 10 sec). The dimensions and geometry of the barrel, the screw compression ratio and positions of elements on modular screws are additional variables which affect shear and pressure within the extruder. The pressure within the barrel increases due to a restriction at the discharge of the barrel. The speed of screw rotation also affects the degree of shear developed and the length of residence time within the extruder. The viscous dissipation of mechanical energy is typically large in the metering section (the portion of the screw nearest the discharge of the extruder) so that the temperature increases rapidly. Discharge pressures typically vary between 30 and 60 atm. At these elevated pressures, flashing of moisture does not occur within the confines of the barrel because the pressure exceeds the vapour pressure of water at the extrusion temperature. As the food exits the die, steam is flashed due to pressure differential.

The steam acts as the leavening agent, stretching the still-plastic material. Expansion occurs both longitudinally and radially, and hardening may occur within seconds. In extrusion practice, „expansion“ is used to describe the events that lead to the formation of puffed, low-density cellular materials from a hot, gelatinised mass of starch which is forced under pressure through a restricted opening into the atmosphere. Starch plays an important role in extrusion cooking of cereals being a major component of the extrudate matrix and a key element responsible for expansion.

Intense mechanical shearing in the extruder disorganises the original structure of the material. The high shear rates tend to align long molecules in food constituents giving rise to cross-linking or restructuring resulting in the extruded foods unique texture. Scanning electron microscopic observations showed that the cell walls of extruded products were thinner and their surfaces rougher than those of the raw material (Aoe 1989). Several characteristics of the raw material influence the final product. These have been summarised by Phillips (1988) and include chemical composition, prior thermal history, particle size and moisture level. Beneficial effects include the destrucion of anti-nutritional factors and the modification of starch. However, heat-labile vitamins may be lost and Maillard products may be formed from protein-sugar reactions, and formation of amylose-lipid complexes may decrease utilisation of fat.

Influence of extrusion on the nutritive value has been investigated until now almost exclusively in respect of human nutrition. It is well documented that changes in polysaccharide complex (starch and fibre) are most important from the nutritional standpoint. Heating starch-rich foods or feedstuffs with a high moisture content will lead to a gelatinisation of starch. Cooking of starch is known to increase the susceptibility to amylase hydrolysis, mainly due to hydration of starch granules and partial solubilisation of its molecules. The increased buffer extract viscosity of the feed after extrusion and pelleting is primarily a consequence of increased starch solubilisation. However, enzyme-resistant starch can also be formed during thermal processing (Englyst et al. 1982). This fraction is resistant to amylases unless solubilised in alkali, and is believed to be formed by retrogradation process with the formation of strong intermolecular hydrogen bonds in the amylose fraction (Englyst et al. 1983, Siljeström and Asp, 1985).

Extrusion cooking may change the content, composition, and physiological effects of dietary fibres (as well as starch) in various ways. First, starch could undergo modification and form enzyme resistant fractions, which acts *in vivo* as dietary fibre (Björck et al. 1986). Second, degradation of dietary fibre to low molecular weight fragments would diminish its content. Third, macromolecule degradation of fibre may increase the solubility and change the physiological effects of the fibre fraction.

A lot of investigations were published on influence of pelleting on feed nutritive value for broiler. Despite the growing practice of feed processing at temperatures higher than conventional pelleting (i.e. extrusion), there are a few reports on its effect on nutritive value of cereal grains or whole feed mixtures for young chicks. Extrusion cooking, being a recent practice in poultry feed manufacturing, has received considerably less attention than pelleting in this respect. Considering that the dietary fibres and, especially, the soluble fraction, are recognised as the major depressive factor in barley diets, it can be hypothesised that changes in physicochemical and physiological properties of fibres due to processing may affect feed nutritive value and interfere with the NSP-splitting enzymes added to the diet. No investigations concerning the influence of feed extrusion on nutrient utilisation in mature poultry have been as yet reported.

Despite the growing practice of heat treatment of poultry diets, there are a few reports on its effect on nutritive value of cereal grains or whole feed mixtures. Heat treatment of barley such as autoclaving and steaming resulted in lower weight gain and a poorer feed efficiency compared with untreated cereals in broiler diets (Burnett 1962; Herstad and McNab 1975; Thomke and Hellberg 1976). In other cases, the heating of barley (100 and 120°C) improved the weight gain, or was without effect (Herstad and McNab 1975). Earlier studies showed that extrusion of a whole diet may impair feed utilisation and energy metabolisability in broiler chicks (Pfirter et al. 1993). During extrusion, the raw material is subjected to intense mechanical shearing through the action of the rotating screws, which disorganises original structure. Extrusion cooking could affect dietary fibre, both in terms of quantity and physiological properties. Considering importance of NSPs in diet for young chick, it is to expect that changes in chemical and physical properties of dietary fibre due to processing might have an influence on nutritive value of high fibre diets. The purpose of the studies presented here was to asses the effect of barley extrusion on its nutritive value for broiler chickens.

MATERIAL AND METHODS

Raw barley at 13% moisture content was ground (1 mm) through a hammer mill. One half of the ground barley was extruded in the single screw extruder under the following conditions: feed rate 480 kg/h, screw speed 540 rpm, temperature of the product in a barrel just before the die 120-130 C, pressure 80 bar, water added 23% of dry solid feed rate. Although barley meal remained in the extruder barrel for total 20 sec, it was exposed to the highest temperature for only few seconds (in the last part of the barrel). The temperature of the extruded barley immediately after leaving the die was 77-79°C. The cooled and dried extruded barley was hammer-milled before feed mixing. All feed mixtures were steam-preconditioned at 70°C and pelleted (3 mm).

Two dietary treatments (Table 1) were tested. Barley was included to the basal diet at the level of 400 g/kg. The test diets were as follows: B - unprocessed barley and ExB - extruded barley; Each diet was fed to three replicates (cages) of eight male birds between 7 and 39 days of age.

For metabolism studies, excrements from each cage were collected during three (broiler) or four (laying hens) consecutive days. The excreta were collected in the morning and frozen everyday (-20°C). For analysis, frozen samples were thawed over night, homogenised, dried for 48 hours at 60°C, and ground (0.5 mm). Energy, organic matter, fat and nitrogen utilisation, as well as fibre degradability were estimated by means of the indicator method as described by Prabucki et al. (1975), using 4 N-HCl insoluble ash (AIA) as indicator. Celite 545 (acid-washed diatomaceous earth;) was added to the diet to increase the level of AIA and reduce variability in the analysis, when determining the indicator level in the feed. Celite 545 is a nutritionally inert substance.

The β-glucan content in barley, feed and excreta was determined enzymatically (McCleary and Glennie-Holmes 1985) following ethanol extraction (50% v/v) to remove oligosaccharides and free sugars. To determine inactivation of native barley β-glucanase

during extrusion, the β-glucan content was determined for the unprocessed and extruded barley prior to and after incubation (37°C, 30 min), and freeze drying. The β-glucan degradation during incubation was attributed to endogenous β-glucanase. Aqueous extraction of ethanol-extracted barley samples was done by stirring 1 g sample with 50 ml distilled water for 30 min at 37°C. The suspension was centrifuged at 3000x*g* at room temperature for 15 min and the supernatant collected. This extraction was carried out three times and the soluble fraction filtered (glass filter G2) and freeze-dried.
The viscosity of feed extracts was determined as follows: five g of raw or extruded ground barley or 10 g of ground feed (0.25 mm screen) was extracted with 37.5 ml phosphate buffer (pH = 6.0) at 40°C for 30 min, centrifuged, and filtrated (Schott Glass Filter No.1). Viscosity was determined using a Brookfield cone-plate viscometer (model LVTDVCP-II+, cone 40; Brookfield Engineering Laboratories Inc., Stoughton, MA, U.S.A.) at 25°C and shear rate 450 s^{-1}. Water binding capacity of barley and feed was determined according to Caprez (1986) by incubating 3 g of ground sample (0.25 mm screen) with 30 ml of distilled water at room temperature for 24 hours. After centrifugation (4000 x *g*, 10 min) the supernatant was carefully removed. Water binding capacity was expressed as g of water per g of dry residue.

Table 1. Feedstuff composition of the experimental diets (g/kg)

	B[1]	**ExB**
Ingredients		
Barley[2] *unprocessed*	396.9	...
Barley *extruded*	...	396.9
Maize	187.4	187.4
Soybean meal (43)	277.8	277.8
Fish meal	27.8	27.8
Meat and bone meal	30.4	30.4
Fat	54.6	54.6
DL-methionine	2.2	2.2
Lysine HCl	1.0	1.0
$CaCO_3$	5.0	5.0
Na-bicarbonate	0.8	0.8
NaCl	1.0	1.0
Vitamin/Mineral Premix3	5.0	5.0
Celite	10.1	10.1

[1]Calculated composition (g kg -1): AME (MJ) 12.5; crude protein 208.4; methionine 5.7; lysine 12.2; calcium 7.4; phosphorus 6.2.

[2] barley containing 47 g kg-1 β-glucan

[3]One kilogram of feed contains: vitamin A, 10 000 IU; vitamin D3, 2 500 IU, vitamin E, 30 mg; vitamin K3, 2.5 mg; vitamin B1, 1 mg ; vitamin B2, 3.5 mg; vitamin B6, 4 mg; vitamin B12, 0.015 mg; biotin 0.1 mg; Ca-pantothenat, 20 mg; I, 0.5 mg; Se, 0.15 mg; niacin, 30 mg; folic acid, 0.5 mg; choline, 100 mg; betaine, 100 mg; Cu, 5 mg; Fe, 20 mg; Zn, 35 mg; Mn, 80 mg; Lasalocid, 90 mg.

RESULTS AND DISCUSSION

Chemical and physical characteristics of the extruded barley

Extrusion fragmented and solubilised dietary fibre, as indicated by remarkable changes in fibre fractions of the barley (Table 2). The soluble: insoluble fibre ratio changes resulted from increased soluble fibre ($P≤0.05$), and decreased insoluble fibre ($P≤0.001$). Solubilisation and fragmentation of insoluble fibre would explain this observation. In unprocessed barley, soluble fibre accounted for only 13% of the total, whereas in extruded barley it was 18%. Slight increase in soluble fibre content has been previously reported for processed cereal products: from 1.3 to 2.0% for wheat whole meal (Varo et al. 1983) and from 1.1-1.4% for white flour (Siljeström et al. 1986).

Total dietary fibre content was lower in extruded barley compared to raw barley ($P≤0.01$; Table 2) as a consequence of the reduced insoluble fibre fraction. A similar decrease in total dietary fibre in some cereals, as a result of fragmentation under severe extrusion conditions was also shown by Ralet et al.(1990) and Dysseler et al. (1990). Asp et al. (1986) also reported that fibre fragments produced during processing do not precipitate in the analysis. Other authors reported no change (Varo et al. 1983; Siljeström et al. 1986) or a slight increase (Björck et al. 1984) in the total dietary fibre after extrusion. Increased ethanol extract yield (Table 2) is indicative for polysaccharide fragmentation, and increased water solubility for additional polysaccharide solubilisation. Considering that fibre fragmentation could account for only a 2% increase in ethanol extract yield (see decrease in total fibre), the majority must originate from starch.

Table 2. Chemical and physical characteristics of raw and extruded barley (g/kg DM)

	Untreated barley	**Extruded barley**
Dietary fibre (n=4)		
insoluble	190.3 ± 1.8	163.3 ± 3.0***
soluble	28.4 ± 5.7	36.2 ± .6*
total[1]	218.8 ± 7.0	199.6 ± 3.5**
Ethanol (50% v/v) soluble fraction (n=3)	109.6 ± 2.8	198.5 ± 7.4***
Water soluble fraction[2] (n=7)	78.1 ± 1.8	161.9 ± 2.5***
β- Glucan (n=4)	47.0 ± .8	45.7 ± 1.9
β- Glucan after incubation[3] (n=3)	34.7 ± .5	41.1 ± 1.7**
Viscosity (n=3)(cP)	1.33 ± .0	3.74 ± .3***
Water binding capacity (n=4) (g/g DM)	1.59 ± .1	2.22 ± .1***

[1]Total dietary fibre = insoluble DF + soluble DF,
[2]Water soluble fraction of ethanol-extracted barley
[3]Ground barley was incubated at 37°C for 30 min and subsequently freeze-dried
***p<0.001, **p<0.01

Extrusion greatly increased the viscosity of barley extract (Table 2), due to starch gelatinisation and increased solubility of dietary fibre. Extruded barley increased the viscosity of the entire diet considerably (treatment ExB; Table 3). The water binding capacity of the extruded barley (Table 2) was higher than in raw barley, probably because the extrusion treatment disrupted structures and created pores in the cell walls that water can penetrate. In addition, enhanced soluble fibre concentration will also increase water binding capacity by forming a network, in which water molecules can be entrapped. The content of β-glucan was not changed due to extrusion (Table 2). After incubation of raw and extruded barley, a greater reduction in β-glucan occurred in unprocessed grain, indicating a destruction of endogenous β-glucanase by extrusion.

Table 3. Determined chemical and physical characteristics of the experimental diets (g/kg DM)

	Untreated barley	**Extruded barley**
Ash	71.1	73.2
Crude protein	239.2	244.1
Ether extract	88.5	85.6
Crude fibre	42.4	46.6
Gross energy (MJ)	19.7	19.7
β-Glucan	16.3	15.9
Viscosity (cP)	1.59	3.79
Water binding capacity (g/g feed)	2.29	2.31

Influence of the extruded barley on chick performance

A significant depression in feed efficiency occurred on extruded barley compared to the corresponding raw barley diet ($P \leq 0.05$, Table 4). The factorial analysis showed the negative influence of extrusion on feed efficiency during the first two weeks ($P=0.06$). In spite of poorer feed efficiency, the weight gain of the chickens was not depressed. Despite the higher viscosity of the extruded barley diet (Table 3), the birds were able to slightly increase feed intake, and overcome reduced feed utilisation.

Table 4. Effect of barley form on growth performance of broiler chickens

		B	**ExB**	% change
Daily weight gain (g)				
Days	7-21	43.0	43.3*	*+0.07*
	7-39	57.4	57.5	*+0.17*
Daily feed intake (g)				
Days	7-21	64	66*	*+3.12*
	7-39	104	110*	*+5.77*
Feed efficiency (kg/kg)				
Days	7-21	1.490	1.529*	*-2.62*
	7-39	1.817	1.920*	*-5.67*

*p<0.05

Table 5. Water intake per bird and excreta dry matter content between 7th and 28th day of life.

		B	ExB
Water intake (ml/day)			
Days	7-14	119	141^{**}
	14-21	206	229^{*}
	21-28	279	296
Ratio water: feed (ml/g)			
Days	7-14	2.6	3.0^{**}
	14-21	2.5	2.7^{*}
	21-28	2.3	2.3
Excreta DM[1] (g/kg)		283	263

[1] Average value for three collection periods (week 2, 3 and 4)
**p<0.01, *p<0.05

Inclusion of extruded vs. unprocessed barley reduced the AME content of the diet by 0.32 MJ/kg DM ($P \leq 0.05$). Accordingly, AME of barley was reduced by 0.82 MJ/kg due to extrusion. Herstad and McNab (1975) reported that heating barley at 120°C for 1 hour reduced the AME content of barley by only 0.21 MJ/kg (90% DM basis), implying that processing conditions during extrusion in the present work were more severe and therefore impaired barley nutritive value to a greater extent. The AME intake was not depressed by inclusion of extruded barley in the diet (Table 6), and the birds were able to maintain growth comparable to those fed the untreated barley diet. Utilisation of fat was especially depressed with extruded barley probably because increased viscosity of the diet (Table 3) made the diffusion of larger particles as fat micelles in the intestine particularly difficult. High negative influence of barley β-glucans on digestibility of added fat was reported earlier (Edney et al. 1989).

Table 6. Treatment effects on apparent metabolisable energy content of the experimental diets, nitrogen and fat utilisation and β-glucan degradability.

	B	ExB	% change
AME[1,2] feed (MJ/kg DM)	14.327	13.998^{*}	*-2.3*
AME intake (MJ/day)	1.043	1.057	*+1.3*
Fat utilisation[2]	0.904	0.864*	*-4.4*
Nitrogen utilisation[2]	0.562	0.528^{*}	*-6.0*
Nitrogen retention[3] (g/day)	1.56	1.55	*-0.6*
β-glucan degradability[4]	0.520	0.550	*+5.8*

[1]AME (Apparent metabolisable energy) = feed gross energy x energy metabolisability coeff. [m (E)]
[2]Average of three collection periods (in the 2nd, 3rd and 4th week of life),
[3]Nitrogen retention = feed intake x N in feed x N utilisation coefficient.
[4]Measured in the 3rd week of life
*$p<0.05$

Extruded barley significantly increased water consumption during the first week of the experiment (Table 5), both absolutely and expressed as the ratio of water-to-feed consumed ($P \leq 0.05$). This was attributable to the enhanced water binding capacity and viscosity of extruded barley. The difference in water consumption between the extruded and raw barley diet declined rapidly with age: in the first and second week the birds fed extruded barley drank 15% and 8% more water, respectively, whereas in the third week no difference was observed. The highest water intake of the birds fed extruded barley coincided with the lowest DM content of excreta (Table 5).

Enhanced degradability of β-glucan in the diet with extruded barley may be attributed to a higher porosity of cell walls and higher fibre solubility. In general, soluble fibre is more easily fermented than insoluble (Nyman and Asp 1982). In an experiment with rats, Björck et al. (1984) showed that the dietary fibre in extruded wheat floor was more extensively degraded than in the raw material. A depression in growth and feed efficiency was observed with chicks fed heat treated barley (Burnett 1962; Thomke and Hellberg 1976). Herstad and McNab (1975) found that autoclaved barley reduced DM digestibility of the whole diet. A depression in barley nutritive value due to extrusion, seems to be a result of additional fibre solubilisation. A doubling of polysaccharide concentration increases viscosity 10-fold (Morris 1990), hence even a small increase in fibre solubility may substantially increase viscosity. The negative effect of additional fibre solubilisation was intensified by simultaneous destruction of endogenous β-glucanase, thus preventing viscosity reduction otherwise seen in unprocessed barley (Gohl et al. 1978). The cell wall destruction due to extrusion would expect to improve nutrient availability of the barley. However, this positive effect was predominated by the negative effect of fibre solubilisation and increased viscosity which impaired digestibility of the entire diet.

As compared with ruminants, little is known about the role of micro-organisms in the digestive tract of poultry. Most of available information has come from *in vitro* studies on isolated strains and thus may not truly reflect the *in vivo* situation (Mead, 1993). The populations present vary from one part of the tract to another and their composition is affected by factors such as host age, diet and the use of antibiotics. In the poultry the two main sites of bacterial activity are the crop and caecum. Within the crop (pH=4-5) the predominant organisms are lactobacilli. The lactobacilli are capable of controlling populations of *E. coli* in the crop and their effects are bacteriostatic (Fuller, 1977). The proventriculus and gizzard present an inhospitable environment to micro-organisms. Nevertheless, Lactobacillus populations of up to 10^8 per g of contents has been reported (Smith, 1965). In the duodenum and ileum facultative anaerobes (*Streptococcus*, *Staphylococcus*, *Lactobacillus* and *E. coli*) as well as obligate anaerobes (*Eubacterium*, *Propionibacterium*, *Clostridium* etc.) are present (Mead, 1993). In chickens the caeca provide the most stable environment for microbial proliferation of any part of alimentary tract (microbial counts up to 10^{11} g/wet contents). Bacterial populations in the caeca and short colon are dominated by obligate anaerobes. In mature bird most micro-organisms are saccharolytic in nature i.e. able to ferment glucose (Mead, 1993). However, of particular interest is the apparent absence of any significant cellulolytic activity (Barnes et al. 1972). Starch may be utilised by some species (i.e. *B. vulgatus*), and some budding bacteria were found to be able to utilise arabinoxylan (Croucher, 1980).

The important factor for bacterial colonisation of bird's intestinal tract is peristalsis. The contents of the gastrointestinal tract are continually being passed towards the vent. Therefore, in order for micro-organisms to colonise the gut it must either multiply at a rate faster than the rate at which it is being removed by peristalsis or else it must attach to the epithelial surface (Fuller 1984). There is ample evidence that viscous polysaccharides can increase the residence time of digesta (Gohl and Gohl 1977), which may result in increased bacterial colonisation of intestine. The presence of unabsorbed nutrients additionally promote prolific bacterial growth in the middle and lower part of the gut (Salih et al. 1990).

Fat digestibility especially can be diminished in chickens given barley and rye diets (Classen et al. 1985; Salih et al. 1990). Dietary addition of soluble pentosans to the chicks diet progressively decreases fat retention (Fengler and Marquardt 1988). The solubilized polysaccharides increase viscosity and form a network, reducing thereby the nutrient diffusion rates in the intestine. Fats, present as large conglomerates in the gut lumen would be disproportionately susceptible to such a situation than smaller particles. Beside this physical obstruction, as direct effect of increased viscosity, fat malabsorption is additionally potentiated by microbial deconjugation of bile acids in the gut (Campbell et al. 1983b; Feighner and Dashkevicz 1988). Such an activity in the intestine of chicks is normally present, but aggravated in case of high viscosity diets. As mentioned earlier, retard transit of high viscosity digesta enables microbial proliferation, resulting in an intensified bile acids modification and insufficiency at the intestinal level (Campbell et al. 1983c). Abnormalities of bile acid metabolism as cause of impaired fat digestibility is indicated by correction, to some degree, by dietary supplementation with conjugated bile salt, sodium taurocholate (Campbell et al. 1983a; Fengler et al. 1988). The bacterial species most often implicated in the antibiotic response of chicks is *Streptococcus faecalis* and *Streptococcus faecium* (Fuller et al. 1979).

Chicks fed rye or barley have higher intestinal microbial counts (Wagner and Thomas 1978) and give a greater response to antibiotics (Fernandez et al. 1973; Day and Thomas 1980) or germ-free environment (Campbell et al. 1983a) than observed for other cereals. A microbial involvement in the depression of nutrient retention caused by including high levels of barley or rye in the diet has been indicated from observations that growth rate, nutrient retention and bone mineralisation can be improved with antibiotics (MacAuliffe et al. 1976; Marquardt et al. 1979; Cave et al. 1990; Elwinger and Teglöf 1991). Especially fat digestion and rachitogenic effects (Antoniou and Marquardt 1982; Patel and McGinnis 1976; Patel et al. 1980) respond to antibiotic supplementation. Addition of NSP-splitting enzymes lowers gut viscosity (Teitge et al. 1991; Bedford and Classen 1992), promotes feed passage rate and reduces microbial counts in the chicken intestine (Salih et al. 1991; Almirall and Esteve-Garcia 1994). Thereby enzymes influence the conditions in the gut and indirectly its microbial status. In this respect dietary enzyme preparations may interact with antimicrobial feed additives when supplemented to high-fibre diets for poultry.

CONCLUSION

In the experiment the effect of extrusion (120-130°C) on barley nutritive was studied. Extruded barley compared to unextruded gave higher soluble fibre (28 vs. 36 g/kg) and lower insoluble (190 vs. 163 g/kg) as well as total (219 vs. 200 g/kg) dietary fibre values. A significant depression in feed efficiency, feed AME, fat and nitrogen utilisation, as well as increased water consumption ($P \leq 0.05$) were observed when extruded barley was included in the broiler diet. Extrusion reduced the AME content of barley by 0.82 MJ/kg DM.

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THE DEVELOPMENT OF A NEW ASSORTMENT OF FOOD AND FEED BY THE APPLICATION OF MICRONISATION AND EXTRUSION

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ABSTRACT

The production of food of a high nutritive value and safety in sufficient amounts is one of the main characteristics of contemporary agriculture and food industry. The second half of the previous century brought awareness on a need to return to natural sources of food and high biological values that food has for a human organism. Permanent stress and adverse effects of deleterious food and environments affected contemporary men and made them facing the utilisation of materials and components of the natural origin in all spheres of life, and especially in a domain of the food production, nutrition and disease prevention.
Based on the newest trends in the global food science and technology, the objective of this study was to present the most important results obtained on the development of the new assortment of food and feed by the application of modern technical and technological procedures of processing of field crops at the Maize Research Institute, Zemun Polje. The application of processing technologies, such as micronisation and extrusion, is indeed one of the most important alternatives in making a new assortment of a high nutritive food that can meet high requirements of modern nutrition. Due to combining different field crops, first of all cereals, and legumes and due to their adequate technological processing, our studies resulted in products that indicate high possibilities of using these technologies. Beside the reduction of antinutritional substances by the application of micronisation and extrusion, better digestibility and partial sterilisation were largely obtained. This is of particular importance in the nutrition of the most sanative categories of consumers and animals.
The aim of the present study is to attract attention to this very important sector of the contemporary science and technology that is full of actual and great challenges.
Keywords: *field crops, micronisation, extrusion, food and feed*

INTRODUCTION

Essential changes have been occurring in the development of agriculture and the food production. These changes have been in agreement with scientific information, technical and technological innovations and the development of the society as a whole. One of the priority goals of the contemporary science is certainly the food production improvement, providing food safety and high quality, as well as, general paying attention to food importance and effects of food on health, which is a component part of a struggle for the health maintenance and improvement and diseases prevention. The first decade of the 21st century was designated by paying full, actual and fundamental importance to food and effects on human life and health. This is reflected in its multiple roles and functions that it provides (http://www.fshn.hs.iastate.edu/). According to predictions of many researchers in world's known centres, 21st century will be an age of food and health.

The issue permanently present in plant food research is how to increase a nutritive value of field crops, that is, how to use their nutritive values in the best way, how to make them more accessible and therefore more utilisable.

Overall studies aimed at the improvement of the field crops utilisation have been carried out for several decades only in one scientific institution, Maize Research Institute, Zemun Polje. These studies encompass three main disciplines of the field crops utilisation: grain and silage quality and the development of products. Co-workers of the Department of Technology published over 400 scientific papers and books of proceedings and abstracts, several studies, elaborates and books related to these three disciplines. They are also prize-winners [1, 2, 6, 9, 17, 18]. Published papers present in detail results of this long-term scientific and research work on creating a new assortment of biologically valuable food of high quality and ecologically safe products [8, 20, 21, 22, 25, 26, 27]. The objective of this study was to aim research at the development of a new assortment of maize- and other filed crops-based food and feed by the application of modern technical and technological procedures of processing, micronisation and extrusion, with a low input of energetic resources, water, labour and chemicals adapted to the utilisation in a place of raw material production. There are several aims of processing maize, soya bean and other field crops by the application of micronisation-flaking and extrusion-cooking by friction, methods that are based on the principle of high temperature - short time: to improve taste and edibility, to eliminate undesirable ingredients, to increase digestibility, to decontaminate pollutants and to perform selective pasteurisation. In the beginning of 1980s, i.e. 1990s, when a microniser, i.e an extruder were introduced into the experimental plant of the Department of Technology of the Maize Research Institute, Zemun Polje, more intensive scientific and research work on the development of a new assortment of field crop-based feed and food began. Certainly, these modern procedures of processing of agricultural products have been significantly presented and given their full contribution to challenges that our food and feed industries faced. The ecological principle of the production of biologically valuable food has been gaining in its importance. Therefore, a wise natural wealth management, biodiversity conservation and nature self-renewability, a rational consumption and saving of energy and natural resources, especially, non-renewable ones, recycling of so-called pure technology, the employment of environmental protection measures have also been gaining in their importance. And all these for satisfying needs of today's and future generations. A future concept of modern nutrition of people and animals cannot avoid this fact.

As a result of scientific and research studies carried out at the Maize Research Institute, Zemun Polje, technologies of the production and the development of new micronised and extruded products were established. As already mentioned, many scientific papers dealing with these issues were published. The aim of this study is to directly describe and collectively present previous long-term results of the application of contemporary technical and technological procedures of processing and new assortments of ZP food and feed based on maize, soya bean and other field crops, as well as, to envisage the state and prospective of this field development.

MICRONISATION

Micronisation is a patented process that uses a part of a spectrum of infrared rays of the wavelength of 3.4 to 1.8 microns. This micron size wavelength has found to be highly efficient in achieving a necessary temperature in a very short time (http://www.micronizing.com). Infrared rays, of the stated wavelengths, occur in a generator composed of a set of radiators with a specially designed perforated ceramic tiles of temperatures between 750 and 900°C, which are achieved by combustion of 30-35m^3 of natural gas. Absorbed rays make the constituent molecule of grain to vibrate that leads to sudden increase in the internal temperature and rise in water vapour pressure [5]. Different materials have different capacities to absorb infrared rays and convert them into heat. In cereal grains, internal temperature between 90 and 100°C is achieved in 50 seconds. Due to this, internal cooking grain swells and breaks. Heavy rollers are used to roll such heated grain into thin, elastic and lasting flakes of increased nutritive values, improved palatability, enhanced flavour, attractive appearance and colour. Besides, micronising technology reduces the moisture content by 30-40%, increases 3-4 times particle area, increases 3-4 times swelling power (water absorption per a gram of dry matter), solubility of carbohydrates and increases 1.5-3 times starch digestion. In soya bean grain (or generally in legumes) the same technology reduces the content of protease inhibitors (trypsin inhibitor, hemagglutinin, lipoxygenase, urease) by70-90% [11]. The final product of micronisation of grained products are thin, elastic and lasting flakes of increased nutritive values, improved palatability, enhanced flavour. Micro flora from a surface of fresh grain is reduced in such flakes. Such properties of micronised products provide their wide application in both, direct marketing and baker's trade, industry of animal feed, beer and infant foods.

The technological procedure of micronisation encompassrs the following operations: grain cleaning, wetting or conditioning, thermal radiation, rolling, cooling and packing of finished products [6].

Cleaning of fresh grain. As in any other processing, cleaning is performed to remove foreign admixtures, fractions and dust. A grain size uniformity is desirable, as grains of different sizes are differently exposed to thermal radiation.

Grain wetting. One of essential goals of the micronisation application is to cause changes in starch, i.e. to obtain a desirable degree of gelatinisation under which disturbance of the organised structure of starch granules occurs whereby its crystalline structure is lost. This change requires the presence of certain amount of moisture in grain. It was determined that the optimum moisture for this procedure ranges from 18% and 22%. Wetting is not so simple, as it is necessary that each kernel has approximately the same moisture percentage. It is well known fact that it is easier to precisely take away moisture from grain than to add it precisely. In recent times, new devices have been introduced for precise wetting.

Radiation - thermal treatment. Conditioned or wet grain is dispatched in the following way:

- infrared/thermal ray generator is switched on,

- belt conveyor is started up to transfer grain
- vibrating feeder is adjusted to dose grain mass that will be heated,
- time, i.e. the speed of grain mass transfer under the infrared rays is set up.

As a rule, cereals are exposed to infrared-thermal rays about 50 seconds but in some cases it can be corrected depending on the species and conditioned grains.
Rolling of grain. Rays absorbed in grain (that is transferred by the belt conveyor) cause vibration of the constituent molecule of grain. The grain content is cooked within the coat-pericarp and internal temperature ranges from 90°C to 110°C. Hot grains, which are soft and swollen, are passed between two heavy and specially riffled rolls (each of 1000 kg). The rolls immediately make individual flakes of a great area in which the greatest part of starch granules is broken, whereby starch is largely adjusted to a fast activity of enzymes of digestibility.
Cooling. After rolling the surface of hot flakes is several times greater than the initial grain surface. Flakes come off rolls and fall down onto the reversible belt conveyor that is adjusted to their cooling. A fan, installed above the belt conveyer, accelerates evaporation and conveys vapour and a part of gases over a cyclone into the atmosphere, and cooled flakes (15-20°C) reach the packaging system.
All stated operations: radiation, rolling, cooling up to packing continually last 3-4 minutes.

EXTRUSION

Extrusion is another technological process that is based on the principle high temperature - short time. The basic phenomenon of extrusion is cooking under pressure. Extrusion cooking can be done by the introduction of steam superheated by electric heater or particle friction. Extruders are designed according to a dominant function and changes that are wanted to be achieved in the processing material. Dry extrusion uses, as a source of energy, heat that occurs by friction of the processed material using lubrication with fatty low melting ingredients or water [7, 6]. Extruder presents a simultaneous pump that transfers, mixes, tears, cuts, expands, kneads and forms the material under pressure and temperature or even better, a band spiral in a reactor for physical, chemical and biochemical reactions. Changes in grain occur for a very short time (20-30 s) at high temperatures without presence of oxygen and without Brown reaction. The exposure to a high temperature for a short time does not damage amino acids, vitamins, fatty acids and metabolic energy. Expanding effects are achieved by surface expanding of the extrudate, which is particularly important for gelatinisation and disruption of starch granules, springing out of oil drops from oil and the increase of the crude fibres volume and their digestibility. Dehydration effects occur from the moment when the material exits the extruder, when free from the pressure, it evaporates and loses heat. Extrusion cooking was performed at the temperature of 125-140°C for 25-35 seconds.
A great number of processing experiments were performed in our studies included grain products of different physical properties and various chemical compositions. Such studies point out to the possibility to obtain a new assortment of food and feed of high nutritive and biological values, good stability and durability.
A heat treatment of soya bean by extrusion enhances nutritive value of proteins in calf feeding. These experiments proved that the application of the extrusion technology as a

procedure for the inactivation of antinutritional substances in fresh soya bean grain had full nutritive and economic justification [15].

THE APPLICATION OF MICRONISATION AND EXTRUSION PROCESSES

The aim of the study was to make products of high nutritive and biological values that can be used as individual components of food or semi-ready-made food. These products were made by the application of micronisation and extrusion technological processes from different cereals and various maize hybrids and crops that biologically supplemented maize (soya bean, peas, broad bean, etc.) without damaging proteins, amino acids, vitamins, fibres and fats.

Micronisation and flaking of grains of wheat, husked barely, triticale, peas, broad bean, soya bean, maize, maize endosperm and maize germ was carried out. At the same time, dry cooking of the same cereals and legumes was done by friction in a special extruder. Average and sub-samples were drawn from obtained products (flakes and extrudates) and then chemical and biochemical composition, as well as, technological quality were determined and changes occurred during these processes were compared with the initial raw material.

The most significant changes in cereal grain thermally treated occur in starch as starch makes two thirds of a grain weight that as fresh has no palatability and edibility. It is known that starch macromolecules that succumb many processes of transformation under thermal and mechanic effects result in different physical structures and properties [14, 33]. If starch is heated in the presence of water, the structure of starch granules is disrupted and granules lose their double-helical structure and Maltese cross occurs. This phenomenon, known as gelatinisation, occurs within the temperature range from 62 to 80°C for dent maize starch, 63 to 72°C for waxy maize starch and 52 to 85°C for wheat starch [31]. Accordingly, each type of starch has a characteristic temperature range within which gelatinisation occurs. Due to these reasons, applied procedures of processing differently affect taste, edibility and nutritive value. During thermal and mechanical processes, starch macromolecules degrade, i.e. their molecular weight is reduced, by which their physical, chemical and functional properties are changed (energy content, digestibility, viscosity, water binding capacity, swelling capacity, gelatinisation, retrogradation, fermentability, etc). Heating of starch in water causes disruption of hydrogen bonds between polymers, thereby weakening the granule. It is assumed that the initial swelling occurs in the amorphous regions of granules where hydrogen bonds are less numerous and the polymers are more susceptible to dissolution. The structure of granules becomes weaker, granules absorb water and swell. Depending on conditions of the applied process, different degrees of structural disruption exist [32]. Cooling of the system causes retrogradation, that is reassociation of starch molecules resulting in the formation of crystalline aggregates and a starch gel [16]. Although amylopectin can retrograde upon cooling, linear amylase macromolecules have a greater tendency to reassociate and form hydrogen bonds than "tumbleweed-like" amylopectin molecules. In such a way, the content of resistant starch (RS) can be increased in the starch material [13]. Depending on needs of different consumers, types and categories of animals, the task is to produce food by combining different raw materials that

biologically supplement and their nutritive values by the application of appropriate technological processing treatments. If conventionally processed, starch is cooked and gelatinised in the presence of a great amount of water. Grain is hydrated from the surface towards inner parts, although often many starch granules remain unchanged. During the process of extrusion the grain content is exposed to cutting, mixing, compression, heating (in the presence of a minimum amount of water) and to passing through openings under high pressure. Starch granules exposed to these conditions gelatinise and form homogenous mass. A short time that the material is in the extruder is not optimum for total gelatinisation of all starch granules. In the process of micronisation, grains absorb infrared rays and gelatinisation is done from the centre to the periphery of the starch granule. Due to these reasons, combining processes of micronisation and extrusion in practice give good results.
Performed studies encompassed numerous plant and processing experiments with grains of maize of different and specific physical traits and various chemical composition, as well as, a great number of laboratory tests and analyses. These studies point out to the possibility of making a new assortment of biologically valuable food and feed. Under *in vitro* conditions, the effect of a high micronisation temperature on digestibility of dry matter of grain of two ZP genotypes with specific traits was determined, as well as, changes in other very important nutritive components of maize grain [30]. Obtained results are presented in Table 1.

Table 1. Digestibility and nutritive quality of maize grain and flakes

Hybrid	ZP 633		ZP Rumenka	
	Fresh grain	Micronisation 145^{o}C	Fresh grain	Micronisation 145^{o}C
Oil (%)	4.52	3.94	6.27	4.28
Proteins (%)	11.85	11.70	14.40	11.35
Crude fibres (%)	2.30	2.17	2.64	2.05
Starch (%)	72.15	70.90	67.30	66.20
Soluble carbohydrates (%)	0.65	0.91	0.25	0.11
Digestibility (%)	83.90	86.50	81.67	83.76

According to obtained results it can be concluded that the application of the micronisation process in both observed maize genotypes led to the increase of the digestibility coefficient in relation to digestibility of dry matter of fresh grain. The changes in the content of soluble carbohydrates and the reduction in the content of starch and crude fibres under effects of high temperatures caused the increase in digestibility of maize flakes. The same studies encompassed the determination of effects of high temperatures on *in vitro* digestibility of dry matter of soya bean grain (Figure 1).

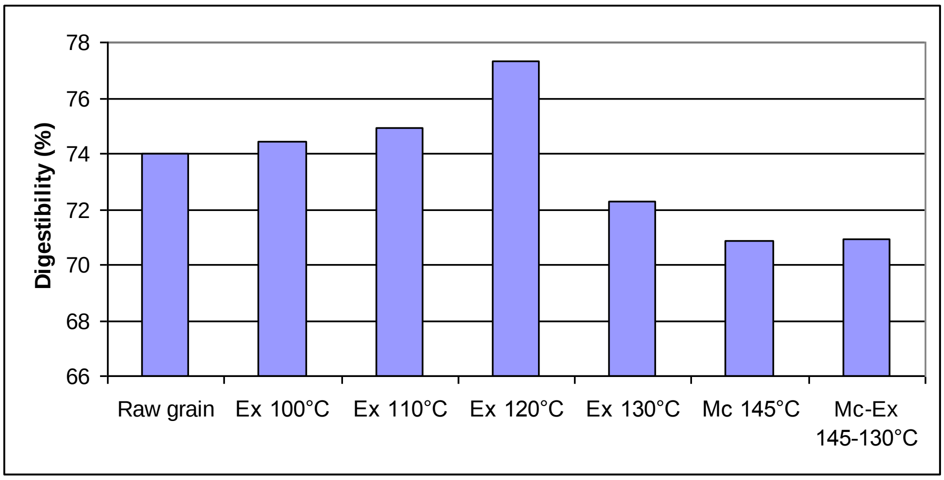

Figure 1. Effects of high temperatures on digestibility of soybean products

It was concluded that the extrusion process more significantly affected the increase in digestibility of soya bean grain dry matter. On the other hand, the micronisation process had a completely opposite effect on soya bean grain digestibility. Depending on needs of different types and categories of animals, the task is to produce feed by combining raw materials that biologically supplement and their nutritive values by the application of appropriate technological processing treatments. Therefore, the aim of these studies is to observe the effect of high temperatures during the micronisation processes on changes in biochemical contents of grain of different cereals and legumes. In addition to maize and soya bean grain, wheat, barley and field pea grains were micronised at the temperature of 145°C. The basic chemical content (starch, proteins, oil, crude fibres and ash) and the content of soluble proteins, trypsin inhibitor, urease, resistant starch and dry matter digestibility were analysed in fresh grain and flakes obtained after the treatment with infrared rays. Changes in the basic chemical content in flakes of cereals and legumes cannot be attributed to effects of high temperatures during the micronisation process. High temperatures affect the decrease in the content of water soluble proteins in cereal and legume grains, as well as, the decrease of the content and activities of observed antinutritional substances. Digestibility of legume grains was decreased under high temperatures by approximately 3%, while digestibility of maize and wheat grains was increased. High micronisation temperatures did not affect enzymatic hydrolysis of cereal starch, while a significant effect on the decrease of the content of resistant starch was observed in field pea [29].

Upon the determination of physico-chemical traits and technological and functional qualities, in accordance to the defined processing regime, experimental amounts of micronised and extruded products were made and tested in some other research and manufacturing organisations. Farinological, extenzographic, maturographic and amylographic parameters of flour, to which different amounts of micronised and extruded products were added, were studied at the Department of Carbohydrate Foods Technology, Faculty of Technology in Novi Sad. Obtained results point out that micronised flakes and extruded cereals can be very efficiently used in the production of bread and bakery products of high quality. Excellent results were achieved at the MPI "15 septembar" in Valjevo and MS ČIN-Komerc Novi Banovci, where a special kind of bread with the addition of flour made of micronised flakes was made and was favourable evaluated by consumers [23, 24].

Moreover, the objective of our newest studies is the application of the extrusion process as an economic procedure for the production of resistant starches that are defined as a type of starches that are not digested in the small intestine, but can be degraded (fermented) in the large intestine. This topic is today very actual and attractive and of an enormous practical importance in the food industry [13, 16].

PRODUCTS OF THE MICRONISATION AND EXTRUSION PROCESSES - PRODUCTS OF BIOLOGICALLY VALUABLE FOOD AND FEED

As already stated, the goal of this study was to present previously obtained results and achievements and to discuss prospective of the future development of a new assortment of food and feed by the processing of field crops by micronisation and extrusion at the Maize Research Institute, Zemun Polje. Technologies of the production and development of new micronised and extruded products were developed as a result of scientific and research work. Co-workers at the Department of Technology of the Maize Research Institute, Zemun Polje have published many scientnific papers within this field [3, 4, 10, 12, 19, 24, 25, 28].

Several new semi-finished plant products of the specific composition, designated as ENBEL-18, GRASO-25, BOSO-28 and PASO-25, have been developed. The stated products were made out of the combination of maize, soya bean, pea, French bean, broad bean and husked barely in an appropriate ratio, after which they were extruded and formed into flakes or granules and presented a semi-finished ration with qualitatively balanced ratio of amino acids, fatty acids and other nutritive components. Although made products are of exceptionally attractive taste, further work shall be done to improve both, taste and appearance and modew of packing.

A new and unique product MIKRO-EX SOJA was obtained from the whole soya bean grain by the combination of the processes of micronisation and extrusion. This product is characterised with the following chemical composition: moisture (4-7%), proteins (36-39%), oil (19-21%), urease activity (0.4g/g/min) and a pronounced low content of antinutritional substances such as trypsin inhibitors, hemaglutinin, urease and lipoxygenase. The product was commercialised as a protein energy supplement to feed. Obtain scientific and professional results within this field were confirmed trough the cooperation with institutions established in this field such as ACB Corporation, Institute for Animal Husbandry, AIC Zemun, UNIP Valjevo, Superprotein Zrenjanin, ACB Inshre, Sig, PD Zaječar and others.

When technological and physico-chemical analyses were completed, greater experimental amounts of these products were made and used for nutritive tests in feeding different types and categories of domestic animals, that is effects of micronisation and extrusion of soya bean on production results in broiler breeding, production of eggs and milk, as well as, calf rearing were determined. Obtained results unambiguously show that

the application of micronisation and extrusion, as methods of feed processing, was completely justified [15].
In addition, the following feed products specific in their nutritive values and different from other products in the local markets were developed at the Maize Research Institute, Zemun Polje, by the combination of modern technological procedures of processing and the principles of the production of healthy foods: ZP complete feed intended for weaning piglets to piglets of 25kg, ZP complete feed for laying hens and ZP complete feed for chicks.
Starting form previously achieved scientific and professional results, potential possibilities, state of and requirements by the market, and recommendations of food scientists, who insist on a greater participation of whole cereal grains in food, new ZP products, such as ZP flour of micronised maize grain, have been made. These products are, in fact, new mill products, i.e. three different types of whole-grain flour made of micronised maize of specially selected ZP genotypes with red, yellow and white kernels. These products composed of all valuable components of maize grain are unique on the national market and present a good base for spreading a spectrum of baked goods of high quality. The ZP technology of micronised maize flour production is not only unique, but also provides certain technological advantages in production of maize bread and bakery products. The micronisation technology is a technological procedure of thermal grain treatment at high temperatures for a short time by which grain traits are changed and its digestibility is improved. Red whole-grain maize flour has improved nutritive properties due to a greater content of proteins, anthocyanins and insoluble fibres. Yellow whole-grain maize flour has improved nutritive properties due to a greater content of proteins, carotenes, oil of high quality and insoluble fibres. Furthermore, white whole-grain maize flour has improved nutritive properties due to a greater content of proteins, oil of high quality and insoluble fibres.
The production of a new assortment of bakery products based on micronised grain of genotypes ZP Rumenka and ZP 633 was organised. The grain of the selected ZP maize genotypes was exposed to the thermal treatment of micronisation, dry thermal treatment with infrared rays at the temperature of 140°C in a short period of time of 50 seconds [5]. Results on the chemical composition of flour made from micronised grains of four observed ZP maize genotypes are presented in Table 2.

Table 2. Chemical composition of flour made from micronised ZP maize genotypes and used in the bread production [20]

ZP Genotype	Proteins (%)	Oil (%)	Starch (%)	Crude fibre (%)	Ash (%)
ZP 551b	12.27^{a}	4.32^{a}	68.54^{c}	2.55^{a}	1.26^{a}
ZP 633	11.70^{b}	3.94^{b}	69.44^{bc}	2.17^{a}	1.35^{a}
ZP 677	9.02^{c}	3.76^{b}	73.28^{a}	2.16^{a}	0.96^{b}
BG ZP Rumenka	11.35^{b}	4.28^{a}	69.79^{b}	2.05^{a}	1.28^{a}
LSD 0,05	0.513	0.225	0.957	0.578	0.101
CV (%)	1.44	1.67	0.40	8.10	0.56

a,b,c-statistical significance of means, CV – coefficient of variation

Bread with 20% micronised maize grain contains all biologically valuable ingredients of maize grain and it is similar by its sensory properties to products of white flour. Micronised flour contributes to prolonged freshness of bread, hence it provides a longer duration of a product, while specific taste of maize gives special properties to bread and spreads a spectrum of high quality bakery products. Moreover, bread with the addition of micronised grain of ZP Rumenka is characterised with a red colour of the kernel cover due to the presence of anthocyanin, while bread with the addition of micronised grain of the genotype ZP 633 has an attractive yellow colour due to the presence of β-carotenes, as important natural antioxidants. Quality of products packed into thermo-shrinking foils was identical seven days after baking to quality of non-packed three-day old products, without addition of preserving agents in the spring period and bread did not show signs of mouldiness and fuzziness. Obtained results on quality of bread with the addition of micronised maize show that bread is of high quality, ages more slowly and has modified nutritive properties that are especially pronounced when genotypes with the increased content of proteins and germs were used [23, 24].
There is also a ZP concentrate for the bread production with all valuable ingredients of maize grain. Whole-grain flour of micronised red- and yellow-seeded ZP genotypes is the base for the production of both, this concentrate and bread. These products are unique on the national market and have the improved content of necessary nutritive components (proteins, oil, carbohydrates, fibres, vitamins, anthocyanins, β-carotene and minerals). Corn bread is the newest ZP product belonging to highly valuable food with all biologically valuable ingredients of maize flour. It has properties of traditional, i.e. national food. These and previously described ZP products of maize-based highly valuable food present functional food as their regular consumption provides certain health advantages and impacts prevention of some contemporary illnesses.

CONCLUSION

Great changes in food and feed led to the utilisation of a new assortment of feed and food of high nutritive values. For that purpose, the application of modern processing technologies, such as extrusion and micronisation, is recommended, as food of higher quality, better taste and digestibility that can satisfy high nutritive demands by various consumers, such as the most sensitive category of the human population and the most productive animals, can be made from existing resources.
Experience and results gained at the Maize Research Institute, Zemun Polje, are of the exceptional importance and they can be widely applied in production practice, which would accelerate the development of small- and medium-scale companies for processing of maize, soya bean and other filed crops. This will result in even more intensive use of field crops, the most important naturally renewable raw materials in our region.
The implementation of such projects within the field of the development of a new assortment of food and feed by the application of modern technical and technological procedures of field crop processing is very important and of great significance for today and future generations. Therefore this implementation should continue in future.

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QUALITY OF CORN EXTRUDATES AND EXTRUDATES FROM SELECTED CORN PRODUCTS

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ABSTRACT

Food production worldwide is one of the major challenges of the modern life. Therefore, novel technology processes are applying to increase the nutritional value of raw materials, food and feed. One sophisticated technological process for improving nutritional value and quality of raw materials is extrusion.
Heat treating of cereals is used for improving their nutritional, hygiene, physico-chemical and other properties, i.e. it increases the nutrient value of some nutrients, improve sensory properties (i.e. increasing, "sweetness" of extruded product), provides the microbiological safety of the products and inactivate possibly present thermo-labile nutrients. This paper presents the technical-technological parameter of the process, physico-chemical composition and microbiological safety of raw materials before and after extrusion.
***Keywords**: extrusion, corn, corn meal, buckwheat*

INTRODUCTION

Heat treating of cereals is used for improving their nutritional, hygiene, physico-chemical and other properties, i.e. it increases the nutrient value of some nutrients, improve sensory properties (i.e. increasing, "sweetness" of extruded product), provides the microbiological safety of the products [23, 36] and inactivate possibly present thermo-labile nutrients. The commonly used heat treatments for processing of cereals, such as corn, are extrusion, micronization, hydrothermal treatment, toasting and other processes. Extrusion leads to changes in the carbohydrate complex of corn, i.e. the decrease in starch content due to its degradation to dextrin. These changes cause an increase in vitro and in vivo digestibility of starch, because starch gelatinization providing increase of substrate content for enzymes which can digest starch, also, leads to inactivation of inhibitors of α-amylase [2, 7, 16]. In addition, it was found that extrusion improve water absorption of extruded products and other physico-chemical characteristics. Moreover, extruded product became microbiologically safe [12, 15, 17, 18].
For centuries, buckwheat (Fagopyrum esculentum Moench) is well known raw material for bakery goods production, due to large amounts of protein, starch and vitamins. The protein of buckwheat consists of wellbalanced amino acid with high biological value [21, 34]. It posses particular flavour – cereal nutty-like in freshly harvested and freshly milled buckwheat or bland with a rancid tone in old buckwheat [22].

Due to nutritional properties which are mentioned above as well as beneficial effect on human health, large number of researchers tried to carry out the application of buckwheat flour in food industry. Chillo et al. [6] examined the possibility of addition of buckwheat flour to semolina for spaghetti production, while Lin et al. [28] partly replaced wheat flour with buckwheat flour during bread production. Bilgicli [3] tried to use buckwheat flour in tarhana processing.
In the domestic production of food corn is one of the most used raw material in feed production, because of high energy value (16.2 MJ / kg), starch content, relatively high oil content and low levels of cellulose. It is believed that corn, besides the best digestibility, has the best taste in comparison to the other cereals [2]. Because of the previously mentioned properties, research was carried out on the use of extruded corn as raw materials for bakery production [13].
In this paper were presented the technological parameters of the extrusion, as well as physico-chemical properties of raw materials before and after extrusion.

MATERIAL AND METHODS

Extrusion of raw materials was carried out at industrial type of extruder and achieved temperatures were different. Mixture (90% corn (sample one): 10% light buckwheat flour) is extruded at a temperature of 115 and 150 °C; corn (sample two) at temperatures 90 and 95 °C, and enriched corn meal at a temperature of 95 °C. Moisture content of all samples was adjusted to 18% before extrusion to allow extrusion at control temperature regime, since Venou et al. [35] recommended cca 20% moisture content for wheat and corn extrusion.
Basic chemical composition (water, crude protein, crude fat, crude cellulose and minerals content) of raw materials and extruded products were determined according to AOAC Official Methods [28]. Starch, total sugar and reducing sugar content were determined according to Regulation of methods of physical and chemical analysis for quality control of grain, milling and bakery products, pasta and quickly frozen dough [29], while calcium, phosphorous, β-carotene and test weight according to Regulation of sampling and methods for performing physical, chemical and microbiological analysis of feed [30].
Nitrogen solubility index is determined by the method of AOCS [27].
Particle size distribution was tested according to internal method with DIN sieves. The total number of microorganisms, yeasts and molds, as well as the separation and identification of Salmonella and sulphytoreducing Clostridia was examined according to Regulation of methods for microbiological analysis and super-analysis of food [31].
Presence of Coagulase positive staphylococy, Proteus species and Escherichia coli was determined according to modified method from Regulation of methods for microbiological analysis and super-analysis of food [31]. Modification is concerning sample preparation: 50 g of sample was weight into e-flask and incubated in 450 ml of sterile media at 37 °C for 24h. Isolation and identification was examinated according to Regulation which is mentioned above.
Mean values of examined quality parameters, which were calculated on dry matter, were tested by ANOVA, whereas differences among individual mean values were determined

by Duncan test at significance level of 0.05. Softver STATISTICA 7.0 i 8.0 were used for statistical calculation.

RESULTS AND DISCUSSION

Particle size distribution of whole-milled corn and light buckwheat flour, which were raw materials for extrusion mixture, was shown in table 1. Reaching the optimal particle size distribution is prerequisite for appropriate carrying out of extrusion procedure. It is essential that added water was distributed quickly and equaly into raw material during condition process, which is happened before extrusion to achieve optimal thermal treatment [18]. Matz [26] stated the importance of particle size distribution for extrusion and production of expanded snack products. Crunchy structure of extrudates demand particles with higher diameter (for example: 80% residue on U.S. sieve 60) whereas finer texture of extrudates needs particles with lower diameter (for example: 65% residue on U.S. sieve 20) [20, 32].

Chemico-nutritional composition of whole-milled corn, light buckwheat flour, mixture prepared for extrusion and extrudates was shown in table 2. During extrusion process water content was lowered to the level that provides long shelf life of extrudate (Table 2). Since buckwheat starch has higher amylose content (46%) [34] which can limit expansion during extrusion, mixture of whole-milled corn and light buckwheat flour (9:1) was used for extrusion. Protein content and starch content of light buckwheat flour were on the level that Chillo et al. [6] cited, whereas crude fat content was lower. Also, buckwheat posess other nutritive properties, it is well known that this plant is a source of rutin, quercetin, and kaempferol-3-rutinoside. Buckwheat contains more rutin than most of other plants, which exibits antioxidative, antihemorrhagic and blood vessel protecting properties [21].

Table 1. Particle size distribution of whole-milled corn and light buckwheat flour [37]

Sieve mash Ø (mm)	Sieve overtails (%)	
	Whole-milled corn	Light buckwheat flour
2.00	19.1	-
1.25	25.9	-
1.00	9.9	-
0.63	13.6	0.2
0.25	19.9	8.5
0.125	11.5	32.6
0.63	0.1	46.8
Bottom	-	11.9

The extrusion process leads to statistically significant changes, since table F value was 19.247 and the F values for crude protein, crude fat, starch, total sugar and reducing sugar content were 26639.33; 2978.630; 923401.9; 1760.353 and 364.4511, respectively. Starch content of extrudate obtained at 150 °C was significantly lower than those of extrudate obtained at 115 °C and nontreated mixture for extrusion (Table 3). Consequently, increase in total sugar content was statistically significant in both extrudates in compared to raw materials, also, extrudate produced at 150 °C have higer total sugar content than extrudate produced at 115 °C (Table 3). Reducing sugar content of extrudate extruded at 150 °C was statistically significant smaler in comparison with nontreated mixture for extrusion (Table 3). Also, extrudate produced at 115 °C had decrease in reducing sugar content, however it was not statistically significant (Table 3). The changes in protein content were not statistically significant.

Table 2. Chemical composition of extruded products and raw materials [37]

Quality characteristic	Whole-milled corn (%)	Light buckwheat flour (%)	Mixture (90% whole-milled corn: 10% light buckwheat flour)	Extruded mixture at 115 °C	Extruded mixture at 150 °C
Moisture	17.32	11.70	16.76	13.30	9.63
Crude proteins	7.44	11.38	7.83	8.44	8.50
Crude fat	3.44	2.71	3.37	3.40	2.92
Starch	62.12	69.16	62.82	65.87	66.90
Total sugars	1.44	1.48	1.44	2.16	3.60
Reducing sugars	0.96	0.59	0.92	0.86	0.48

Statistically significant decrease in crude fat content was detected after extrusion procedure at 150 ºC compared to non-treated mixture for extrusion. The reason for this reduction could be applied method for crude fat determination which does not contain phase of hydrolysis. It may be expected that extrudates could be susceptibled to lipid oxidation due to increase contact surface with air. Camire and Dougherty [5] state that the pronounced sensitivity the lipid oxidation process of extruded products are caused by low moisture content of extruded products and increased surface which is in contact with air as well as poor inactivation of lipoxygenases .

Table 3. Chemical composition of Chemical composition of extruded products and raw materials in dry matter [37]

Quality characteristics	Whole-milled corn (%)	Light buckwheat flour (%)	Mixture (90% whole-milled corn: 10% light buckwheat flour)	Extruded mixture at 115 °C	Extruded mixture at 150 °C
Crude proteins	9.00[a]	12.89[c]	9.41[ab]	9.73[b]	9.41[ab]
Crude fat	4.16[a]	3.07[b]	4.04[a]	3.92[ac]	3.23[bc]
Starch	75.13[a]	78.32[d]	75.47[ab]	75.97[b]	74.03[c]
Total sugars	1.74[a]	1.68[a]	1.73[a]	2.49[b]	3.98[c]
Reducing sugars	1.16[a]	0.67[bc]	1.11[a]	0.99[ac]	0.53[b]

The values were expressed as mean value of three independent measurment.
Mean values of examinated quality parameters calculated on dry matter labeled by the same letter in raw were not statistically significant difference ($p<0.05$).

Particle size distribution of corn, which is extruded, is shown in table 4.

Table 4. Particle size distribution of milled corn [11]

Sieve opening (Ø, mm)	Sieve overtails (%)
2.00	14.9
1.25	15.4
1.00	8.1
0.63	18.5
0.25	34.8
0.125	8.3
0.063	-
Bottom	-

Chemical and nutritional profile of corn can be determined by examining the quality parameters which are presented in Table 5. The extrusion process leads to statistically significant changes, since table F value was 19.247 and the F values for crude protein, crude ash, crude fiber, crude fat, NSI, starch, total sugar and reducing sugar content were 3545.3; 28600.33; 82555.220; 364.2411; 52411.33; 2204.45 3465.33 and 29600.33, respectively.
Table 5 shows the chemical properties of corn extruded at temperature 90 and 95 °C. During the extrusion process the structure of proteins have been changed which often leads to decrease in protein solubility [16, 18]. Nitrogen solubility index (NSI) is one of the parameters which is used in optimized heat regime, because it reflects changes the

structure of proteins caused by high pressure and temperature during the extrusion process. According to states of Holmes [19] in assessing the adequacy of treatment and product quality - NSI level of 12.5% is considered to be the result of application too high temperature, and the level of 17-25% NSI is a result of the optimal heat treatment. NSI values for corn in comparison to obtain extruded products were significantly statistically different, confirming that during extrusion at temperatures of 90 and 95 ° C came to structural changes in corn proteins, followed by statistically significant differences in crude protein content (table 5). Namely, the extrusion of corn results in the decrease in the crude protein content, and decrease in total and reducing sugar content (table 5), probably as a result of the Maillard's reaction, one of the undesirable reaction in food chemistry, which include the interaction between sugars and proteins, primarily lysine amino acid residues [8].

Extrusion grinded corn resulted in statistically significant changes of crude fat content of extruded products in compared to untreated corn, the reduction of crude fat was about 57% at 90 °C, i.e. and about 45% at 95 °C (Table 6). A similar degree of reduction of crude fat of about 60% were found by Venou et al. [35] after corn extrusion at 115-125 °C. Another reason for this crude fat reduction is mentioned above.

Tabela 5. Chemical composition of milled corn and extruded corn at 90 and 95 °C in dry matter [11]

Quality characteristic	Corn (%)	Extruded corn at 90 °C	Extruded corn at 95 °C
Crude proteins	9.25^c	9.07^b	8.97^a
Crude ash	1.83^b	1.56^a	1.58^a
Crude fiber	3.45^c	2.47^a	2.80^b
Crude fat	4.80^c	2.08^a	2.66^a
NSI	15.91^c	6.66^a	6.21^a
Starch	70.90^c	67.06^b	64.98^a
Total sugar	1.00^a	3.99^b	4.12^b
Reducing sugar	0.40^a	0.42^a	0.45^a

The values were expressed as mean value of five independent measurment.
Mean values of examinated quality parameters calculated on dry matter labeled by the same letter in raw were not statistically significant difference (P<0.05).

During the extrusion at carbohydrate complex of corn occurred significant physico-chemical changes, which affect to the digestibility of starch. The starch content in extruded corn was significantly lower in comparison to non-treated corn, which have influence on increase in the content of total and reducing sugars (table 6), which could be reason for gaining sweet taste of extruded product.

Table 6 shows microbiological profile of corn before and after extrusion. Commonly, detected molds are belonging to Aspergillus, Pencilium, Fusarium, Mucor etc. [1]. Prior to extrusion 63 000 molds were present in corn and due to extrusion the count was only 55 per 1g. Total number of microorganisms also significantly decreased after corn extrusion. Sulphytoreducing clostridia were not detected in both corn samples. Similar data were found by Kormanjoš et al. [24]. Even though extrusion temperature are relatively low and duration is short (6-10 s), a significant decrease in total number of microorganisms is evident, probably due to very high pressure, 30-40 bar, table 6.

Table 6. Content of microorganismsin corn and extruded corn [11]

Microorganism	Number In	Non-treated corn	Extruded corn
Salmonella sp.	50 g	0	0
Coagulasa positive *Staphylococcus*	50 g	0	0
Sulphytoreducing *Clostridia*	1 g	0	0
Proteus	50 g	0	0
Echerichia coli	50 g	0	0
Total number of molds	1 g	63 000	55
Total number of yeasts	1 g	45 000	0
Total number of microorganisms	1 g	1 200 000	310

Enriched corn meal produced by Bühler degermined technology represents a novel protein-energy feed in the feed industry, because it is characterized by elevated levels of crude protein and fat (table 7) in comparison to corn meal produced by standard process. Protein content of enriched corn meal is higher 25% than corn grain (8.5% crude protein content).

The essential feature of this feed is its increased energy (4%) caused by increasing oil content, as a result of presence of corn flour and germ. Corn, as a primary energy nutrient in feed industry and the most commonly used grain in composition of finished feed mixture has energy content 16.2 MJ/kg, while enriched corn meal is 16.87 MJ/kg. Nutritive value of enriched corn meal contributes to the presence of tocopherols, especially α-tocopherol as the main constituent of liposolubile vitamin E, but also one of very powerful antioxidants [4], and β-carotene, pro-vitamin A, which also characterized the antioxidant activity [9].

Table 7. Physical and chemical characteristics of enriched corn meal and extruded enriched corn meal (T = 95 ° C) [14]

Quality characteristics	Corn meal	Extruded corn meal at 95 ° C
Water content (%)	14.5	8.50
Crude protein content (%)	11	11.0
Celullose content (%)	3.5	3.50
Starch content (%)	55	50.68
Ash content (%)	4.0	2.50
Fat content (%)	7.5	7.50
Phosphorous (%)	0.50	0.50
Calcium (%)	0.20	0.20
β-carotene content (mg/kg)	1.10	1.11
Test weight (g/l)	526.1	359.0

Extrusion process significantly reduces the moisture content in the moistened corn meal (from 14.5% to 8.5%), which makes extruded product suitable for long storage. This also leads to the reduction of test weight during the extrusion process (526.1 g/l : 359.0 g/l - table 7) caused by applying high pressure and temperature during the heat treatment. Reduction of test weight after extrusion process or other heat treatment was found by Bekrić [3] and Filipović et al. [16], and it is important because of storage and transport, and for feed production for animals with special needs (i.e. trout, pets, etc.).

Quality properties of basic chemical composition of extruded product in comparison to corn meal were not changed (tables 7). Starch content after extrusion decrease in comparison to the corn meal (table 7), which again indicate a partial degradation starch components, amylose and amylopectin, due to the relatively short time of exposure to elevated pressure and high temperature during the extrusion process. The parameters of particle size distribution indicate that the produced corn meal is made from extremely small particles (table 8), granulation of extruded corn meal is in the size range that is obtained by conventional milling of corn at feed plant at sieve Ø 3 mm.

Particle size distribution of the extruded corn meal (table 8) points the need for additional grinding extruded product, especially if it is used in the animal feeds mixture.

Table 8. Particle size distribution of enriched corn meal and extruded enriched corn meal [14]

Sieve opening (Ø, mm)	Sieve overtails (%)	
	Corn meal	Extruded corn meal
4.00	0.00	0.30
2.00	0.50	3.00
1.25	5.00	9.00
1.00	11.85	7.85
0.63	23.85	34.30
0.25	25.75	36.45
0.125	27.55	8.20
0.63	5.00	0.90
Bottom	0.50	0.00

The results presented in table 9, are confirming previous studies on the reduction of microbial contamination after appropriate heat treatments [23, 36]. It is evident that extrusion process reducing number of microorganisms in extruded enriched corn meal in comparison to untreated corn meal.

Table 9. Microbiological profile of corn meal and extruded corn meal [14]

Pokazatelj kvaliteta	Corn meal	Extruded corn meal
Total number of aerobic mezophile bacteria (per 1g)	4 500 000	140 000
Total number of molds (per 1g)	90 000	800
Sulphytoreducing *Clostridia*	500	400

CONCLUSIONS

Stable products were obtained by extrusion of whole-milled corn and light buckwheat flour mixture (ratio 9:1) at 115 ºC and 150 ºC. Application of higher extrusion temperature caused greater changes in physico-chemical properties of extrudates. Statistically significant changes in starch content, total and reducing sugar content, crude fat content and test weight were detected for extrudate at 150 °C in comparison with extrudate obtained at lower temperature (115 °C) and with nonterated mixture.
Corn extrusion at 90 and 95 ° C leads to physico-chemical changes in treated material, primarily to changes in the structure of proteins, which is demonstrated through significantly different levels of NSI, and accompanied by statistically significant differences of crude protein content. Dry extrusion of corn resulted in statistically significant changes of crude fat content in extruded product in comparison to untreated corn. The starch content of extruded corn was statistically significantly lower, with the consequent increase in the content of total sugar and reducing sugar.

Extruded enriched corn meal feed have higher nutritional value in comparison to the meal which is not extrude, also it is microbiological safe.

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