3-D plant protein extraction: designing sustainable processes

The importance of performing innovative work using new high-tech approaches is now undeniable. Traditional processing methods are often expensive, require the use of aggressive chemicals and complex technological equipment, also the great amount of wastes is referred to conventional technologies. Therefore, we’re all looking forward: creating new waste-free technologies, processing raw materials in the most complex and “green” way – for instance, using enzymes instead of chemicals. We are trying to create new technologies which will allow to set up huge-capacity as well as small-capacity enterprises, herewith obtaining products with special preferences and high-biological value.

Vegetable proteins are widely used in the food industry. The main advantages of the vegetable over animal protein are better productivity and lower cost of its production. Among the sources of vegetable protein one can mention such crops as soy, peas, beans, sunflower, lupine. Special attention is given to soybeans. Soybeans processing results in such products as soybean meal (“white flakes”) with a crude protein content of 50%, the high-protein products - concentrates and isolates, as well as the protein hydrolysates - a product of protein treatment with proteolytic enzymes. The traditional material for the production of high-protein products is a "white flakes" - a product obtained from soybeans with hexane extraction of soybean oil, and representing a flattened defatted soy flakes.

For protein concentrates isolates production on the basis of "white flakes" two approaches are conventionally used: extracting the protein into solution and its subsequent sedimentation and purification or extraction of solubles from white flakes under conditions where the protein is in insoluble state. The second approach referrers to concentrates manufacturing, and the most common methods are aqueous alcohol leaching or extraction at a pH corresponding to the isoelectric point of soy proteins.

Soy protein isolate manufacturing comprises such stages as protein extraction at alkali condition, meals insoluble residue removal, extract clarification and protein precipitation at the isoelectric pH, whey removal and protein precipitate washing, neutralizing and drying. As we can see, the process flowchart is rather long and complicated.

The preparation of high-protein products using traditional methods is associated with a number of difficulties of both economic and technological field. The group of technological difficulties includes significant effect of the particle size of the feedstock on the efficiency of the process, low extraction efficiency, the need for high solvents to feedstock ratio, which in turn leads to an increase in the cost of wastewater treatment and complexity of instrumental scheme as a whole. Due to the use of chemical agents and organic solvents in such processes, special security measures are required. And for economic reasons, these technologies can be applied only for large volumes.

To solve these problems, we have proposed a unique method of feedstock pretreatment, comprising pre-processing of low-fat or defatted raw material by means of baro-thermo-mechanical method to obtain a porous gel product for further processing in mild conditions which results in high-protein products.

The proposed technology has a number of advantages over traditional ones. Firstly, along with the traditional defatted white flakes low-fat raw material can be used. Low-fat material is obtained by expelling oil from soybeans without using any organic solvent, that is why the technology may be entirely "green". This in turn leads to a simplification of the equipment requirements and reduces the cost of security measures. In addition, this technology can be implemented in small enterprises. Second, the unique characteristics of the porous gel granules reduce water consumption during extraction as the structural modification of the feedstock provides high extraction efficiency. Reduced water to feedstock ratio allows using simple, low-cost and small size equipment, which in turns reduce the cost of drying and waste treatment. Third, when using porous gel granules, size of the feedstock particles does not affect the efficiency of the process and therefore it is possible to use cheap pressing equipment instead of centrifugation.

Talking about the "green" technology the most preferrable solvent is water at neutral pH. Native soy proteins under these conditions, as it is shown on a figure, possess 80% solubility. That is, in the processing of native soy material with water, the transition of soy protein into the liquid phase is not complete, and the residue is also not a high-protein product. For manufacturing product with a crude protein content of not less than 70%, we have to use alkali or acid - that means the usage of chemicals. At neutral pH value it is possible to obtain protein concentrate using ethyl alcohol but it is rather expensive in comparison with water and also flammable.

So, the extraction of native soy protein from white flakes using water at neutral pH is incomplete and requires additional chemical processing to get a high-protein products. The crude protein content within waste mass in these conditions does not exceed 60%. We offer to "flip" the process - to include maximum amount of protein containing in the raw material into a single three-dimensional network structure - porous gel granules and then extract the "polluting" impurities from the gel. As our technology suggests, the white flakes previously pre-treated in the baro-thermo-mechanical way are extracted with water at pH value 6.5-7.0. This method allows us to get two valuable products: soy protein concentrate with a crude protein content up to 80% and an extract of low molecular weight substances.

Our pre-processing suggests moistening the soybean meal and acting on it with high temperature, pressure and mechanical forces causing the structural deformation of raw material. Unlike traditional flour, shape, size and chemical composition of the porous gel granules can vary widely. It is the structure of the resulting product that allows us to speak about "3D-extraction" - we provide access to the elements of the products structure, regardless to its actual geometric size.
The resulting product has a porous network structure, the matrix of which are soy proteins. High permeability and porosity of the product is confirmed by excellent mass transfer properties which results in high extraction rate. The novelty of our approach is confirmed by several patents accepted either in Russia and other countries.

For your interest photographs of the starting white flakes, granules after thermo-baro-mechanical treatment and wet protein concentrate after washing are shown.

Thus, the main advantages of the proposed technology are usage either partially defatted product or traditionally defatted product and obtaining high-protein products without using any chemical agents. It should be mentioned that in the case of use partially defatted raw material we also obtain expelled soybean oil with high tocopherol content and improved properties.

Stages of proposed flowchart can be described as follows. Flaking beans are subjected to mechanical compression to obtain partially defatted soy flakes and soy expelled oil. Soy flakes are subjected to pre-processing to obtain porous gel granules which are further extracted with water to give soy protein concentrate and extract of low-molecular weight components. The extract is then evaporated under vacuum to a content of solids of 35-40% and used as such in the future.

As a result of laboratory and pilot experiments, we found out that the process is better to be carried out in the water ratio 1:5-1:6. Conventional processes are generally carried out at a ratio of 1:10, i.e. water savings in this case reaches two times, which leads to a substantial reduction of costs for the evaporation and drying processes. When we use porous gel granules as a raw material we obtain concentrate containing up to 80% of crude protein, and the loss of protein with the extract is 6-9%, i.e. more than 90% crude protein, contained in the feedstock, remains in the concentrate. Furthermore, due to the high porosity of the granules the extraction process takes 20-30 minutes compared with the hour or more for conventional white flakes. Given the fact that the extraction is carried out from the granular raw material there is no need to use centrifuges to separate the extracted product - they could be replaced by cheaper press or filtering equipment.

Full scheme of proposed extraction process involves a two-stage countercurrent extraction at very low water to feedstock ratio – only five or six parts of water. After separation, evaporation and drying the resulting products of our technology are soy protein concentrate with a content of crude protein about 75% (up to 80%), and low-molecular weight substances concentrate. The crude protein content therein is 10-15%, with 70% of solids accounted for soy oligosaccharides and 1% for soy isoflavnes.

The slide 17 presents resulting yields of our products based on raw soybeans. As can be seen from the table from one ton of beans one can receive about half a ton of soy protein concentrate with a crude protein content of 75%.

The proposed technology has a great economic input. The additional value of protein concentrate producing with the usage of our technology is 3.5-4 times greater in compare with traditional processing and using full-fat soybeans. Among the reasons of the increasing additional value one can mention reduced cost of required equipment, lower required space and lower buildings height. Due to the absence of hazardous chemicals the cost of special protective facilities is lower, too. The virtual absence of the lower limit of productivity, which makes the small scale production unprofitable, is also a great advantage.

During simple water extraction low molecular weight oligosaccharides, isoflavones, a small amount of albumins are extracted from the porous gel granules. However, the carbohydrates in the granules represent not only oligosaccharides but also polysaccharide fractions. Special enzymes can cleave polysaccharides into soluble components and remove them with the extracted solution, wherein the residue of high-concentrated protein remains.

Our studies using a multienzyme composition having desired activity have shown that via such kind of porous gel granules treatment it is possible to obtain granules of soy protein isolate (crude protein content of 90%) just in one step of enzymatic hydrolysis. We should pay attention to the fact that the efficiency of the process involved is very high at low water to feedstock ratio (1:6), while conventional technologies usually use ratio 1:10 for a better approach of the enzyme molecule to the substrate molecule.

At present, the protein hydrolysis is becoming increasingly popular. To obtain hydrolysates, protein-containing raw material is treated with proteolytic enzymes that split protein molecules into peptides and amino acids. Based on this, one of the ways of the proposed technology development can be a protein concentrate hydrolysis to produce the hydrolyzed protein. After the hydrolysis process is finished, the separation of the slurry results in two fractions: the liquid hydrolysate, representing the mixture of low-molecular weight proteins, peptides and amino acids, and the soy paste, where the dietary fiber and not-hydrolyzed protein are concentrated.

Because of the preservation of porous structure during extraction process wet protein concentrate is porous too. This fact allows us to carry out the protein hydrolysis process using low water to feedstock ratio, ordinary 1:6, which is considerably lower compared with the existing technical solutions. High porosity also leads to higher yield of hydrolyzed part and lower yield of insoluble residue and to remarkable reduction of time required for the protein solubilization.

According to our calculations, from one ton of porous gel granules one can receive more than 400 kg of hydrolyzed protein with a protein content of at least 75%. Insoluble residue contains more than 12% of crude fiber, which is also a valuable raw material for the food industry.

Amino acid analysis of the products obtained have showed that new products contain all of essential amino acids although they are slightly deficient in sulfur-containing amino acids. This may be explained by the composition of soy protein as it is.

Among the ways of development of proposed technology several directions can be mentioned. The first one is searching for cheaper and more available sources of vegetal protein and carbohydrates, for example, they may be peas, wheat, lupine. Using different sources of protein will make it possible to create new high-concentrated products with improved properties and more balanced amino acid composition. In addition to the production of protein products from vegetal material one should not forget about the possibility of obtaining products of a different nature - for example, cellulose or starch.

I'd like to draw your attention to the fact that we have already tested our approach using pea flour as starting material. We have extracted native pea flour and pre-treated pea flour as described above. The results differ dramatically. In the case of native flour the product were protein-carbohydrates extract needed to be treated with chemicals to produce high-protein product and the residue containing 33% crude protein. Using porous gel granules the loss of protein with the extract don't exceed 15% and the main product is pea protein concentrate with crude protein content about 72%. Thus, our approach can be used for different types of plant material.

In conclusion, briefly list the main applications of the products produced by our technology. Among them, the production of additives for meat products and meat analogs, proteins products for animal feeding. Protein hydrolysis is the way of receiving flavorings for meat and snack foods and soluble protein for high-protein beverages. It should be noticed that limited proteolysis allows obtaining products with different functional properties, which are widely used in foods manufacturing.

We hope this presentation was interesting and informative for you. Please contact using these contacts if you have any suggestions or partnership ideas. And now we will be glad to answer your questions.