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RECENT ADVANCES IN SOYBEAN MILK PROCESSING TECHNOLOGY

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The "beany" flavour of soymilk has probably been the principal obstacle to its widespread acceptance. A new technique makes it possible to manufacture soymilk that no longer has this objectionable feature. Therefore, soymilk should be reexamined in order to determine its potential for supplying a low-cost protein beverage with adequate organoleptic properties as a means of increasing the protein intake of protein-deficient diets.

The soybean is an excellent source of protein. Its protein content is high, the protein quality is good, and the soybean is cheap. In the Philippines the soybean provides the cheapest source of protein available among the usual foods (7). Table 1 shows that the soybean provides almost twice as much protein per peso as its nearest competitor, the mungbean, and nineteen times more protein per peso than pork.

In view of their high protein content and low cost it would seem that soybeans would be featured prominently in the diet of protein-deficient countries. Such is not the case; the direct human consumption of soybeans is generally very low. The reason for this is easy to determine. Soybeans are not very appetizing to eat and their acceptability is low for most palates. There has therefore been a search for processing techniques that will make the soybean more acceptable in flavour and texture.

One of the easiest products to make from soybeans is a water extract, which is usually called "soymilk" because of its milky appearance. Soymilk is made by immersing soybeans in water for several hours until they are saturated, then grinding the beans finely with water. Almost any kind of wet-grinding machine will do. The slurry of beans and

TABLE 1. COMPARISON OF SOYBEAN WITH OTHER PROTEIN SOURCES IN THE PHILIPPINES

	Grammes protein per kilo (as purchased)	Grammes protein per peso* (as purchased)
Soybean	391	559
Mungbean	244	287
Maize	87	263
Peanut (shelled)	256	213
Dried shrimp	524	210
Rice	74	123
Skim milk powder	360	115
Bread	101	101
Pork	102	29
Sweet potato	5	21

*Based on prices at Bayambang, Philippines, Jan.-June 1965.

TABLE 2. VOLATILES FOUND IN COLD-GRIND SOYBEANS

Pentane	2-Nonenal
Pentanal	Decane
1-Penten-3-ol	Heptadecane
Hexanal	Vinyl ethyl ketone
Hexanol	Vinyl amyl ketone
2-Hexenal	Propylfuran
2,4-Hexadienal	Pentylfuran
Hexanoic acid	Benzaldehyde
Heptanal	n-Propylbenzene
2-Heptanone	n-Butylbenzene
Heptanoic acid	Benzathiazole
Octanal	Diphenyl ether
Octanol	gamma-Nonalactone
3-Octanol	2-trans-4-cis-Heptadienal
3-Octanone	2-trans-4-trans-Heptadienal
2-Octanone	2-trans-4-cis-Decadienal
2-Octenal	2-trans-4-trans-Decadienal
1-Octen-3-ol	2-trans-4-cis-Nonadienal
2-Octen-1-ol	2-trans-4-trans-Nonadienal
1,7-Octadiene	5-Hydroxymethylfurfural
Nonanal	

water is strained or filtered in order to remove insoluble residue. The milky-looking water extract contains about 65 percent of the total solids, more than 80 percent of the protein, and most of the oil of the bean. About 1 percent of the protein and 2 percent of the total solids is lost in the soak water and the insoluble residue contains all the fibre, about 33 percent of the total solids and about 17 percent of the protein (4, 3).

The Chinese discovered the process of making soymilk about two thousand years ago. It appears that it should be a major contributor in solving the protein malnutrition of tropical countries. The problem is that soymilk has a strong disagreeable flavour. The flavour has been described as "beany", "bitter", "painty", and "throat-catching"; no matter what you call it, most people find it objectionable.

About ten years ago the Food Technology Group at Cornell University became interested in the soybean as a rich source of low-cost protein. They quickly came to the conclusion that soymilk provided a good vehicle to bring a nutritious, low-cost protein food to people in the developing countries but that the unpleasant flavour of soymilk was the principal obstacle to its widespread acceptance. A lengthy study of the chemistry, biochemistry and nutritional value of the soybean was initiated. At the present time, this work is being supported by a research grant from the U.S. Agency for International Development. Particular emphasis has been placed on determining the origin of the bad flavour of soymilk.

It was found that the enzyme lipoxidase, which is naturally present in the soybean, was the cause of the trouble. As soon as the soybean is ground with water the lipoxidase acts on the unsaturated fatty acid chains, producing a large number of smaller molecular weight compounds (6). By means of modern sophisticated chemical techniques such as gas-liquid chromatography, mass spectrometry, nuclear magnetic resonance, and infrared and ultraviolet spectrometry, eighty volatile compounds were isolated from soymilk and forty-one of them were identified. They are listed in Table 2.

The majority of these compounds are aldehydes, ketones or alcohols. At least thirty-one of these volatile compounds have some flavour impact and, with few exceptions, the flavour of the compound is unpleasant. One compound in particular, ethyl vinyl ketone, has a typical beany note (5). The addition of five ppm of ethyl vinyl ketone to a bland-flavoured milk imparts a distinct beany flavour.

A mechanism of formation of ethyl vinyl ketone from the linolenic acid portion of the fat component of soymilk has been postulated (5). The ethyl vinyl ketone is formed in six steps through free-radical and peroxide intermediates and is catalyzed by the lipoxidase.

The problem was how to inactivate the lipoxidase before it caused flavour damage. Heating the milk immediately after grinding did not work because the lipoxidase acted so rapidly that the beany flavour was evident no matter how quickly the milk was heated. Heating the beans before grinding inactivated the lipoxidase and solved the flavour problem, but it also rendered the protein insoluble, thus giving a suspension of cells and almost no true milk. After many trials the answer to the problem was found, and it proved to be a very simple solution. Instead of grinding the beans with water at ambient temperature, the beans were ground with boiling water. This simple modification of a centuries-old technique inactivates the lipoxidase before it produces the unpleasant flavour, and at the same time brings the protein into solution before it is rendered insoluble by the heat.

This so-called "boiling-water" grind produces a soymilk that is bland and pleasant tasting. The objectionable beany flavour is entirely absent if the temperature is maintained above 80°C (180°F) during the entire grinding process. A pleasant odor and taste that resembles cooked cereals is present. Only one volatile compound is present in detectable concentration in the milk. This is 1-octen-3-ol, which is formed in the intact beans during the initial soaking period (1). The flavour of 1-octen-3-ol is mildly pleasant; in fact it is one of the constituents of mushroom flavour.

The boiling-water-grind technique has not

been patented and is available free and without license to any interested party.

The flavour difference between the regular soymilk and the boiling-water-grind soymilk can be easily demonstrated in any laboratory or kitchen that possesses a Waring blender by using the following technique. Soak about one-half cup dry soybeans in water at ambient temperature for several hours. Drain off the water and divide the beans into two equal portions. Place one portion of beans in the blender, add 2 cups water at ambient temperature and blend for 2-3 minutes. Pour into a basin and sniff; the typical beany odour will be strongly evident. Now preheat the blender bowl by filling it with boiling water and blending for 2-3 minutes. Discard this water. (Caution: if the blender bowl is made of glass, bring it to 100°C in several steps in order to avoid cracking by thermal shock). Place the second portion of beans in the blender, add 2 cups of boiling water and blend for 2-3 minutes. Pour into a basin and sniff; the beany odour will not be present. Instead there will be a faint pleasant odour that resembles cooked cereal. The difference in odour and taste of the two soymilks is dramatic.

Research is now under way with the Food Technology Group of the University of the Philippines, College of Agriculture, at Los Baños to adapt the boiling-water-grind technique to Philippine conditions and to make a soymilk that is highly acceptable to the Philippine palate. This research effort is working in two directions.

The first consists of developing a commercial process for a sterilized soymilk in seven-ounce bottles that will appeal to the Philippine palate. This phase is almost complete. The bottled product will keep a good flavour for 4 to 6 months in regular storage in a tropical climate without refrigeration. We hope to interest a commercial processor in marketing this product in the same manner as carbonated beverages. We believe that it can be marketed at the same price as carbonated beverages. Each bottle will supply at least six grammes of high-quality protein. Extensive taste studies with hundreds of children and adults in the Philippines have shown that a bottled sterilized soymilk with 7 percent added sugar and 20 ppm to 40 ppm of a commercial essence of vanilla gives an acceptability ranging from 83 to 96 percent, depending upon the temperature of serving and the time of day. This consistently high level of acceptability is very encouraging. We are prepared to demonstrate the complete process to any interested party at the food technology pilot plant in Los Baños, Philippines.

The second attempt is to develop a boiling-water-grind technique suitable for the village level. The goal is to develop a process that will produce five gallons of good-quality milk per hour, using manual power only and with the capital cost for equipment not to exceed fifty dollars (U.S. $50.00). The objective here is to produce a milk locally each day and sell it in bulk, without sterilization and without refrigeration. This product should have a shelf-life of about 8 hours before spoilage. In rough cost calculations we estimate that by such a process one would be able to sell milk at slightly less than two cents (U.S.) per serving and make a net profit that is higher than the minimum Philippine daily wage on a sales volume of 10 gallons per day. At present there is no suitable process that meets these goals but research is directed towards this end.

Table 3 shows the procedure for making a sterilized soymilk in bottles and a bulk milk to be dispensed from a container. It is very important that the temperature be maintained at or above 80°C (180°F) throughout the grinding process. If the temperature falls below this level there will be some lipoxidase activity. The beany flavour is so pungent that even a small amount of beany-flavoured milk is sufficient to taint a whole batch. In order to maintain a minimum temperature of 80°C it is necessary to preheat the grinding machine, to ensure that the water is boiling (at 100°C, not 95°), and that the correct ratio of beans to boiling water is always maintained.

This procedure will give a milk with approximately the same protein content as cow's milk and a fat content about one-third that of cow's milk. The exact final composition will depend upon the fat and protein content of the soybeans that are used, and on certain processing variables. The calcium content is much lower than that of cow's milk, but it

TABLE 3. BOILING-WATER PROCESS FOR SOYMILK

1. Soak whole beans in water at ambient temperature 5 - 10 hours. Discard soak water.
2. Preheat grinder with boiling water.
3. Grind cold beans with fresh boiling water.
   9 parts by weight water plus 2 parts by weight soaked beans
   minimum slurry temperature 80°C at all times.
4. Filter. (Filter cake is used for animal feed or human food).

Bottled Soymilk	Fresh Soymilk
5. Formulate (sugar, fat, minor nutrients).	Hold at boiling point for 30 to 60 minutes to destroy antitrypsin.
6. Fill into 7-oz bottles and seal.	Formulate (sugar, flavouring).
7. Sterilize 12 min at 121°C (250°F).	Refrigerate.
Shelf life: 6 months.	Shelf life: 1 - 5 days with refrigeration; 8 hours without refrigeration.

TABLE 4. ESTIMATED INGREDIENT COST OF SOYMILK

	U.S.$
Soybeans, 1.0 kg at 20 cents/kg	0.200
Sugar, 0.65 kg at 22 cents/kg	0.143
Flavouring, 0.3 ml at $6.00/kg	0.002
Total ingredient cost	$ 0.345

Yield of soymilk: 50 x 200 ml servings per kg beans

Ingredient cost per serving: $\frac{0.345}{50} = 0.69$ cents

Feed value of filter cake has not been taken into account.

can be increased to any desired level by fortification with calcium salts. The fat content can be raised by adding a bland oil and homogenizing. The protein effeciency ratio of this soymilk is in the range of 2.2 to 2.4 adjusted to a casein standard with a PER of 2.5 (2).

Table 4 gives a rough cost estimate for the ingredients of a seven-fluid-once serving of soymilk. Other cost factors such as labor, fuel, overhead and selling expenses would have to be added. The important thing is that for less than one cent ingredient cost, a substantial contribution can be made to the daily protein intake by means of a highly-acceptable, refreshing beverage.

Table 5 shows the percent of daily protein intake supplied to various age groups by one seven-fluid-ounce serving of soymilk. Two standards of reference are listed; one is the FAO-WHO recommended daily protein intake and the other is the WHO-Interim Standard for the Western Pacific, which is about 20 percent lower than the FAO-WHO world standard (8). Using either scale it can be seen that one serving of soymilk can supply a significant proportion of the daily protein requirement to every age group. In the age group most susceptible to protein-calorie malnutrition, the preschool child, a single serving of soymilk can supply as much as 50 percent of the recommended daily protein intake.

The milk that is made by the boiling-water-grind method is bland in flavour and acceptable to most people. It can be formulated in many different ways in order to comply with regional taste preferences, traditions, or with special nutritional needs. The soymilk can be flavoured with chocolate, coconut, raspberry, caramel, and most other flavours. It can be fortified with extra fat or with minerals and vitamins. The sugar content can be changed to suit the taste of any group. The correct combination of sugar, fat and synthetic butter flavour gives a product that approaches cow's milk in flavour. It can be used successfully to tone the high-fat milk of water buffalo in order to reduce the fat content to that of cow's milk without reducing the protein content. It lends itself to adaptation to almost any situation.

A substantial amount of formulation research is now needed. This should follow two distinct lines: a) to develop new flavour formulations that will have a particular taste appeal to each national group, and b) to determine what fortification with vitamins and minerals would be desirable in order to remedy deficiencies of minor nutrients in each national group.

A bottled sterilized soymilk has been marketed successfully by commercial enterprises in Hong Kong, Malaysia and Singapore for many years. These milks have a noticeable beany flavour, although the beany flavour has usually been attenuated by means of some form of steam distillation which strips out a high proportion of the volatile flavour compounds. Although these bottled soymilks have been a success where there is a Chinese population, attempts to market soybean milk in other areas have generally failed. It seems that the Chinese do not object to the beany flavour of soymilk while most non-Chinese find the beany flavour highly objectionable. Since it is now possible to produce soymilk that is free from the beany flavour it would be appropriate to reexamine the potential of soymilk for supplying a highly-acceptable, low-cost protein beverage to those countries where protein malnutrition is prevalent.

Summary

A study of the flavour chemistry of soymilk has identified the volatile organic compounds that impart the characteristic "beany flavour" to soymilk. These compounds are not present in the intact bean but they appear as soon as the beans are comminuted. They are formed by the action of the enzyme lipoxidase on the unsaturated fatty acid chains of the oil fraction of the soybean.

Inactivation of the enzyme can prevent the formation of these volatile off-flavour compounds. If the beans are cooked before grinding the lipoxidase is inactivated and the product has a bland flavour free from beany notes. However, the cooking renders the protein insoluble and the resulting product is a suspension of cells rather than a true colloidal protein-fat emulsion. If uncooked beans are ground in water, followed by heating of the bean-water slurry, the beany flavour is pre-

TABLE 5. PROTEIN SUPPLIED BY SOYMILK*

Type of Person	WHO-Western Pacific Interim Standard for Daily Protein Intake		FAO-WHO Recommended Daily Protein Intake	
	standard grammes	% of standard supplied by 7 fl oz soymilk	standard grammes	% of standard supplied by 7 fl oz soymilk
Toddler (1 to 3 years)	11.7	51	14.3	42
Preschool (4 to 6 years)	14.6	41	17.5	34
Schoolage (7 to 9 years)	18.4	33	24.9	24
Schoolage (10 to 12 years)	22.4	27	31.0	19
Schoolage (13 to 15 years)	32.8	18	41.1	15
Adult male	39	15	46	13
Adult female	35	17	39	15
Lactating female	38.5	16	54	11

*Figures based on a minimum of 6 grammes protein in 200 ml soymilk.

sent. The flavour compounds are formed so rapidly that the product has a beany flavour no matter how quickly it is heated to the lipoxidase inactivation temperature after grinding.

A new technique has been developed in which the beans are ground in a preheated grinding machine with the correct amount of boiling water. With this procedure, the enzyme is inactivated before it can form the off-flavour compounds and the protein is brought into solution before the heat makes it insoluble. It is important that the temperature of the bean-water slurry be maintained at or above 80°C at all times during the grinding operation. The result is a milk that is completely free from the notorious beany flavour of soymilk. It is a true colloidal solution-emulsion that is stable and will not precipitate or settle on prolonged standing.

The research groups working at Cornell and in the Philippines are prepared to supply reprints, answer questions; and give pilot plant demonstrations to any interested parties. In the United States, contact Dr. W.B. Robinson, New York State Agricultural Experiment Station, Cornell University, Geneva, N.Y. 14456, U.S.A. In the Philippines contact Dr. M.C. Bourne, UPCO, College, Laguna, Philippines.

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