Advances in soybean processing and utilisation

Dr Bob Hosken

University of Newcastle

Introduction

The cultivation and utilisation of soybeans originated in China more than 3000 years ago, and subsequently spread throughout the Orient. Soybeans are a good source of nutrients, as they contain around 40% of high quality protein, 20% oil, as well as a number of minerals, vitamins and phytochemicals. Today soymilk, tofu, yuba, and the fermented products natto, miso, tempeh and soy sauce continue to be important foods in Asian countries, however acceptance of the traditional Asian style soyfoods has been slow in western countries because of the beany flavour caused by lipoxygenases.

Lui (1999) and Lui (2000) has reviewed soybean cultivation, processing and utilisation. It appears that soybeans had reached the United States (USA) by the mid-eighteenth century, however they were only grown in small amounts. In the late 1920s, William J. Morse spent 2 years in China gathering more than 10,000 soybean varieties, and this work enabled more widespread cultivation of soybeans in the USA. Today, global production of soybeans is around 140 million metric tons, with around 50% grown in the USA, Other leading producers include Brazil, Argentina, China, and India. While a large proportion of soybeans grown in China, South Korea and Japan are used domestically for foods, most of the soybeans grown in the United States, Brazil and Argentina are traded on global commodity markets, with large sales to the European Union, China, Japan and Mexico.

In western countries, soymilk is the most popular soyfood. In 1910, a patent for soymilk production was issued to Li Yu-ying, a Chinese living in France. Dr John Harvey Kellogg, an ardent vegetarian, and well known as the Director of the Batlle Creek Sanitarium and inventor of flaked breakfast cereals, developed a soymilk in 1920. One of his students, Dr. Harry W. Miller (also known as the 'China Doctor' 1874-1977) took the Sanitarium concept and knowledge of soymilk with him to China, where in 1936 he began to reintroduce Asian people to a more palatable soymilk. Henry Ford was also an early soyfood advocate, and between 1934 and 1943, he entertained reporters at luncheons in which every course contained soybeans, from tomato juice with soybean sauce to soybean cookies and soybean candy for dessert. By 1935, his cars contained many components made from soybeans

The western market for soyfoods is growing

In Asia, modern soymilk plants were established during the 1950s by Mr K. S. Lo of Vitasoy in Hong Kong and Yeo Hiao Seng in Singapore. The main factor that has limited the use of soyfoods in western countries was the unacceptable taste of soybean products, which is strongly linked to the action of the lipoxygenase enzyme on the soybean oil. When soybeans are hydrated and milled, the lipoxygenase breaks down the oil into a number of chemicals including hexanal, and these chemicals result in "off-flavours which are described as "beany", "painty", "rancid" or "bitter". During the late 1960s workers at Cornell University and the University of Illinois showed that heat could be used to reduce the action of lipoxygenase, so limiting the development of "off-flavours" produced in soy slurries. This knowledge, coupled with the development of UHT processing and aseptic packaging technology provided the platform for the expansion of the global soymilk market.

Soyfood marketing research information is provided by a number or organisations including the United Soybean Board (USB), Soyfoods Association of North America (SANA), and Peter Golbitz of Soytech, and some information is available at their web sites. Recent sales figures show that soyfood sales are one of the fastest growing sectors in the food industry, with growth of more than 15% per annum. The USA sales and growth of western-style soyfood categories are presented in Table 1

Table 1

Sales of soy foods by category in USA 2001

Category	$ Sales (millions)	Growth rate (%)
Soymilk	600	10-100% depending on form
Meat analogues	450	14
Tofu	250	3
Breakfast cereals	160	
Soy yoghurt	24	66
Frozen dessert	58	40
Soy cheese	58	12

Adapted from: *Soyfoods: The U.S. Market 2002*, speech presented by Peter Golbitz, Soyatech, at the 10th USB/SANA Soy Symposium, Chicago, IL, September 20, 2002.

Australia produces around 50,000 ton of soybeans per years, which only meets around 50% of demand, so the balance of our soy-based feed and food needs must be imported. Over the last decade there has been a marked increase in the consumption of soyfoods in Australia, especially soymilk (Ginn et al 1998). Soymilk consumption in Australia is a little over 2L/capita/year. There are 3 kinds of soy beverage on the Australian market, first the Asian style soybean drink made from water, soybean extract and sugar; second are the natural or wholebean soy beverages; and the third group are the formulated soy beverages, typically made from soy protein isolate, vegetable oils with added minerals and vitamins. Flavour can also be added. The beverages are marketed as either pasteurised fresh chilled products, typically in gable containers, or as shelf stable UHT/ aseptically packaged products.

Given the limited production of soybeans in Australia, and the growth of the culinary market for soybeans, it is appropriate that farmers focus on producing value-added culinary soybeans for use in domestic and export markets. Australian soymilk producers include Sanitarium Health Food Company, Vitasoy and So Natural Foods.

Many western consumers see soyfoods as being relatively expensive, and not having great sensory properties, however these factors are outweighed by the perceived health benefits. The perceived health benefits arising from consumption of soyfoods have included: good nutritional profile, a reduction in heart disease through reduced blood cholesterol, a reduced risk of cancer, control of menopausal symptons, weight control and longevity (Messina, 1999). The health benefits are related to the protein, fibre and isoflavone content of soybeans (Messina, 1999). Sales of soyfoods was greatly stimulated when in 1999, the USA Food and Drug Administration approved a rule that allowed health claims to be included on labels of soyfoods, based on evidence that the consumption of 25g of soy protein per day can help in cholesterol reduction (Liu 2000).

On the other hand, not everyone likes soyfoods. After expert sensory panel analysis of 7 brands of soymilk at the research agency of Arthur D. Little, the panel concluded that "Soy foods today simply do not meet consumer flavor expectations. The average consumer is not willing to trade taste for health benefits, no matter how great."

The rapid growth of the soyfoods market is providing new opportunities for food companies, and this is reflected in the mission statement of White Wave™ (USA), which is "to fully integrate soyfoods into mainstream American diets" (www.whitewave.com). Their pleasant tasting Silk® soymilk has rapidly gained sales dominance in the North American soymilk market. They are not alone in their vision, for example Dupont and General Mills have established a joint venture to market their strikingly presented 8th Continent soymilk, while Sanitarium, an Australian Company have purchased Soyworld as a vehicle for manufacturing and marketing their "So Good" range of soy products in North America. Many of the well-known global food companies including Heinz, Kelloggs and Kraft have also taken steps to ensure a share of the expanding soyfoods market.

The soyfood industry

Farmers, grain merchants and related organisations are required to get soybeans to the farm gate, from whence they can be processed into value added animal feeds or soyfoods for human consumption. People in the soyfood production chain include:

- Farmers, grain merchants and related support organisations who get soybeans to the farm gate.
- Soybean processors who convert soybeans into value added ingredients including flour, oil, protein isolates, lecithin and animal foods. Processors include Cargills, Du Pont Protein Technology, Archer Daniel Midland.
- Soy food manufacturers who process soy ingredients into soy products eg Sanitarium manufactures soymilk and meat analogues, Vitasoy,
- Process and packaging engineers eg Tetra Pak, APV
- Flavour companies who provide soy flavour masking agents and flavours eg Wild, Firmenich
- Support organizations including government and industry regulators and researchers. This includes ANZFA, CSIRO, Food Australia, University researchers and marketing agencies.

Designing new soyfood products

Value adding to soybeans, and the growth of the soyfoods market, is dependent applying a wide range of knowledge and skill to designing and producing new soyfood products which better meet the needs of consumers. The steps involved in developing a new soyfood product are outlined below, and successful implementation of the process, can be measured in sales and profits, depends on effective and efficient management of each step of the process.

The steps involved in designing a new soyfood product are:

- Identify consumer needs and wants through marketing research.
- Design product concepts and develop prototype foods through interaction of consumers, marketers and technologists.
- Develop sensory and objective measures of quality through scientific and marketing research.
- Select soybeans and optimise trial process specifications using scientific research and engineering design (Kwok and Niranjan, 1995, Murphy, et al 1997).
- Evaluate prototypes using market testing, so as to scale up production.
- Economical use of by-products requires innovative thinking.
- Design and engineer product form and packaging.
- Packaging and labeling requires an understanding of consumer behavour and legislation.
- The investment of profits in growing the market requires management vision.

Soyfoods are made mainly from soybeans or soy ingredients, and this is the unique attribute that defining this group of foods. In addition, various soyfoods have other specialised attributes that are designed to position them uniquely in the market place. For example, in western society soymilk is designed and packaged as an alternative to bovine milk, while meat analoques are designed as an alternative to meat. Some of the general attributes the need to be considered when designing new soyfoods are listed below.

Marketing attributes of soyfoods

- The design and appearance of the packaging need to appeal to consumers and their needs.
- The nutritional profile and health benefits must be better than competing foods.
- The colour, smell, taste, and texture product must meet consumer expectations.
- The product needs to be competitively priced in terms of purchase, use and disuse
- Provides benefits and psychosocial pleasures to consumers that lead to repurchase.
- Profitable for manufacturers and retailers

Other Ingredients added to soyfoods

Soyfoods are by definition made primarily from soybeans or soy ingredients, however the addition of other ingredients may be necessary to achieve the specified attributes. For example, in designing a soymilk, some of the ingredients that might be considered are listed below.

- Soybeans, soy extracts, defattted soy flour or grits, or soy protein isolates.
- Sweeteners may be various sugars or sugar alternatives.
- Salts for taste.
- Nutritional additives such as minerals and vitamins.
- Functional additives such as antioxidants, thickeners and colours.
- Flavour masking agents and flavours such as vanilla and wildberry.
- Preservatives and packaging related factors that contribute to shelf life

Soymilk processing technology

Soymilk is essentially a water extract of soybeans, and the basic steps of preparation are: selection of soybeans, adding water, wet grinding and separation of soymilk from fibre (okra), cooking to inactivate lipoxyygenase and trypsin inhibitors, formulation and fortification, and packaging of the soymilk. Soyfood processing has been reviewed in detail by Erickson (1995) and Lui (1999).

There are many variations on the basic soymilk processing steps, and the general aim of these processes are to produce a soymilk that has good sensory attributes, and that is convenient and safe to consume, produces little waste (okra) and is profitable to manufacture.

Some of the processing issues faced by soymilk manufacturers include:

1. Selection of beans: A good soymilk is white, has good mouthfeel and no beany flavour. To achieve this outcome, the preferred soybeans are large with a colourless hilum, and preferably low in lipoxygenase activity. Many consumers prefer soybeans that have been organically grown, and also avoid soybeans that have been genetically modified, creating strong demand for certified organic and GMO free soybeans. Sometimes the soybeans are firstly dehulled, while other manufacturers begin with dry milled full fat or defatted soy flour. An alternative approach is to use soyprotein isolate, which is prepared by adjusting the pH of a soybean extract to 4.6, at which the protein precipitates. The isolated soy protein can be

collected, purified and dried. The dried soy protein isolate can be suspended in water to make soymilk.

2. Water. The quality of the water used to make soymilk, impacts on the flavour. Sometimes bicarbonate is added to improve the solubility and extractability of the soy protein.

3. Grinding and extraction of soymilk. The wet grinding of soybeans breaks the soybeans into cell fragments, from which the protein is extracted. The soymilk is separated from the fibre (okra) by filtration or centrifugation.

4. Cooking is achieved by use of hot water, wet steam or steaming under pressure. The aim of cooking is to denature the proteins responsible for lipoxygenase activity and to reduce the activity of the trypsin inhibitors by around 90% (Kwok and Niranjan, 1995). The reduction of lipoxygenase activity results in less beany flavour, while the reduction of trypsin inhibitor improves protein digestibility.

5. Formulation and fortification. Sugars, salts, minerals, vitamins, flavours and thickeners are often added to soymilk to improve the nutritional and sensory attributes. Asian-style soymilks are often sweet and slightly beany, whereas most western style soymilks are formulated to be comparable to bovine milk. When soy protein isolate is used as starting material, some oil is added to form an emulsion.

6. Soymilk processing technology. Soymilk is homogenised and thermally treated to destroy microorganisms, ensure safety and extend the shelf life. The thermal treatments can take many forms including canning, pasteurisation or ultra-high temperate (UHT) treatment.

7. Packaging and labeling. In Asian countries, fresh soymilk is often sold in plastic bags with a straw, other manufacturers sterilise soymilk in cans, while UHT processing coupled with aseptic packaging into Tetra Pak or combiblock® aseptic containers is very popular.

Quality measures of soyfoods

The quality of soy products can be measured using both sensory and instrumental techniques (Murphy et al, 1997). Sensory measures are useful for identifying the product attributes that consumers like, while instrumental measures provide more objective measures. Soy based breakfasts and snacks are expected to have a crisp texture and grain taste, soy based meat analogues are expected to have a chewy texture and savoury taste, while soymilk is expected to be similar in texture and taste to bovine milk. Sensory testing can be applied to all soyfoods, however some of the instrumental measures can be very specialised. For example the mechanical properties of chewy snack foods and meat analogues is measured using a texture analyser, while for soymilks, a rotational viscometer is used. Some of the quality measures that are important for developing product specifications and for statistical process control are described below.

- Sensory techniques usually involve the use of a trained panel to measure the colour texture and flavour of the soyfood product. Panelists may describe the off-flavours of soymilk as: ‘beany’, ‘green’, ‘bitter’, ‘grassy’, ‘painty’ and ‘astringent’. They may describe poor texture as: ‘gritty’, ‘floury’, ‘chalky’.
- Nutritional profile requires measurement of protein, fat, minerals, vitamins phytochemicals and antinutrients (trypsin inhibitor). This information is needed for nutrition labeling.
- Colour can be measured using a Chroma meter, with measurement based on the CIE system, which measures L*, a* and b*. A high L value might indicate overcooking.
- Viscosity of soymilk is similar to milk, and is measured with a rotational viscometer. A texture analyser is used to measure mechanical properties of soy crisps or meat analoques.

- Particle size. Soymilk contains colloidal fat and protein and in some cases cellular particles. The size and distribution of these particles, which affects mouthfeel, can be measured with a particle size analyser.
- Particle stability: creaming and sedimentation of soymilk is undesirable, and potential particle instability in soymilk can be identified using turbidity measurements, based on changes over time of the back-scattering of light.
- Volatiles or aroma chemicals effect taste, and are identified and measured using gas chromatography (GC). According to Boatright (2002), the chemicals found in soymilk having the strongest odours were hexanal, acetaldehyde, methanethiol, dimethyl trisulphide (DMTS) and 2-pentyl furan. These chemicals cause off-flavours (beany and sulphurous0 in soymilk, that can be minimised by use of reducing agents.
- Microbiological safety. It is essential that soyproducts be safe to consume, so microbial testing must be carried out in relation to storage conditions and the expected shelf life.

Recent advances in soyfood processing

Soybeans contain around 40% protein, and it is this protein that provide the greatest commercial potential, so it is not surprising that recent advanced in soy food processing have focussed on elimination of soy off-flavours, and on developing techniques for obtaining proteins with more defined functionality. Some of this research is published in research journals, sometimes it is patented, however much of the applied research with commercial application is kept secret.

Recent research has identified the three soybean lipoxygenase isozymes (Lui, 1999), the activity of which contributes to hexanal formation and soy flavour. The chemicals that contribute to soy odours have been identified by Lei and Boatright (2001) and Ang and Boatwright (2003). King et al (2001) reported on the sensory evaluation of several soyfoods, in which the three lipoxygenase isozymes had been genetically removed. They found that removal of the lipoxygenase enzymes, did reduce the hexanal level, however improvement in the sensory properties was disappointingly minimal. On the other hand, more traditional approaches where soy flour was extracted with ethanol, was more effective in reducing the off-flavours.

When protein extracts of soybeans are placed in an ultracentrifuge, the proteins can be separated into fractions, and these fractions are described by their rate of sedimentation, which is measured in Svedberg (S) units. During the 1970s, techniques were developed for separating and purifying the soy protein fractions, the main fractions being 2S (contaiining trypsin inhibitor), 7S (containing β-conglycinin and lipoxygeanse) and 11S (containing glycinin) (Lui 1999). The major soybean globulins, β-conglycinin and glycinin have different nutritional quality and functional properties. Recent advances in the ability to better purify and crystallise these proteins, has allowed X-ray crystallographic studies to better reveal their detailed structure, so providing more detailed insights into how processing impacts on the structure and properties of soy proteins. Several novel techniques are now being applied to purifying soy proteins, these include the use of physical separation techniques to remove fat, electrodialysis, supercritical carbon dioxide extraction, ultrafiltration and membrane separation for the extraction, precipitation and isolation of the soy proteins. Bazinet et al (2000) has been using bipolar membrae electroacidifcation (BMEA) to separate fraction enriched with 11S and 7S proteins. Glycinin and conglycinin have different gelling, emulsification and foam properties. It is expected that over the next decade, more highly specified soy protein ingredients will provide the basis for innovative new food products and growth of the soyfood market.

Soyfood manufacturers invest in their future through quality improvement, promotion of their products and brands and by developing innovative new products. Investment is usually protected by trademarks, patents, and commercial confidence and secrecy agreements.

The patents listed in table 2, illustrate the kinds of advances that have been made in soyfood processing in recent years.

Table 2: Recent soyfood patents

Date and Patent	Authors	Patent Outline
16-04-1996 US 5508172	Lin Santa, HC; Singer, David A.; Wong, T. M. Ralston Purina, USA	Soy fibre with improved sensory properties. Treat soy fibre (okara) with enzymes to improve mouthfeel
19-08-1997 US5658714	Schimpf, K.J. Westfall, P.H Nardelli, C.A.	Isolation of proteins by ultrafiltration so as to separates proteins from phytic acid and other small molecules
16-10-1997 WO 97/37547	Crank, D. L. and Kerr, P. S,. E.J. du Pont de Nemours and Co.	Isoflavone enriched soy protein product and its manufacture
30-12-1997 US5702752	Gugger, E. T. Dueppen, D.G. Decatur	Production of isoflavone enriched fractions from soy protein extracts
10-3-1998 US 5725899	Cole, M.S. and Young, L. S.	Soy protein, vegetable oil and lecithin were blended, homogenised and spray dried to give a dry bland tasting material that could be reconstituted to give a milk-like beverage. The dried material could also be used to form films and has application in baked goods and yogurts etc
31-10-2000 US 6140469	Shen J.L Guevara, F and Spadafora, F.E. Protein Technology International	Production of a high isoflavone soy protein isolate. Used various extraction procedures to give a high recovery of isolfavones in either curd or whey. Isoflavone extracted with acid aqueous methanol solution.
1--2-2001 WO0106866	Boatwright, W.	Soy products with improved odor and flavor. Identifies volatile components of soy and used reducing agents to limit their development.
12-4-2001 WO 01/24644 A1	Gandhi, N.R. Jeneil Biotech	Soymilk composition and preparation of soy milk. Soybeans are microwave heat treated, finely ground to soy flour , enzyme treated, blended with a mineral mix and spray dried
1-8-2001 EP1120047 Japan	Akazawa, Toru	Soybeans are heated and enzymes used to separate heated soy cells, that can be used as a bland ingredient in food applications
17-10-2001 EP 1 145 648 A1	Silver, R.S. Kraft Foods	Soy milk is treated with enzyme and bacteria to give an economical product containing less stachyose and raffinose per meal, so less flatulence.
5-6-2002 EP1210879	Katcher, J Ahmad, A. Hassanein, A Kraft Foods	Method of deflavoring soy derived materials. Uses ultrafiltration at pH 9-12 to remove low molecular weight substances.

In summary, the driving forces that are expected to lead to greater soyfood ulitisation in Australia over the next decade include:

- The increased focus on breeding soybeans more suited to food applications.
- Both soy protein and isoflavones appear to have health benefits, and as these benefits become more established, they are expected to drive increased consumption of soy foods.
- Expected improvements in the taste of soy foods will drive greater consumer demand.
- New soyfood ingredients with more defined functional properties will stimulate wider use of soy ingredients in existing products and in the development of innovative new food products.
- The limited production of soybeans in Australia, coupled with the relatively small population are factors that limit the growth of soyfood sales, however these problems can be more than offset by effectively and efficiently targeting the global food market.

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