SDSU Extension

iGrow Soybean

BEST MANAGEMENT PRACTICES

Chapter 45:
Food Product Innovations Using Soy Ingredients

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Consumers demand a whole host of qualities in their foods that includes convenience, low cost, nutrition, health, wholesomeness, and above all, taste. The challenge for product innovation involves the introduction of new ingredients that improve food functionality and nutrition while retaining the familiarity of conventional foods. Soybean produces many different products, some of which are shown in Figure 45.1. The purpose of this chapter is to present key aspects of soy utilization in foods, provide some practical considerations relating to taste and consumer acceptance, and discuss SDSU's investment in overcoming these limitations.

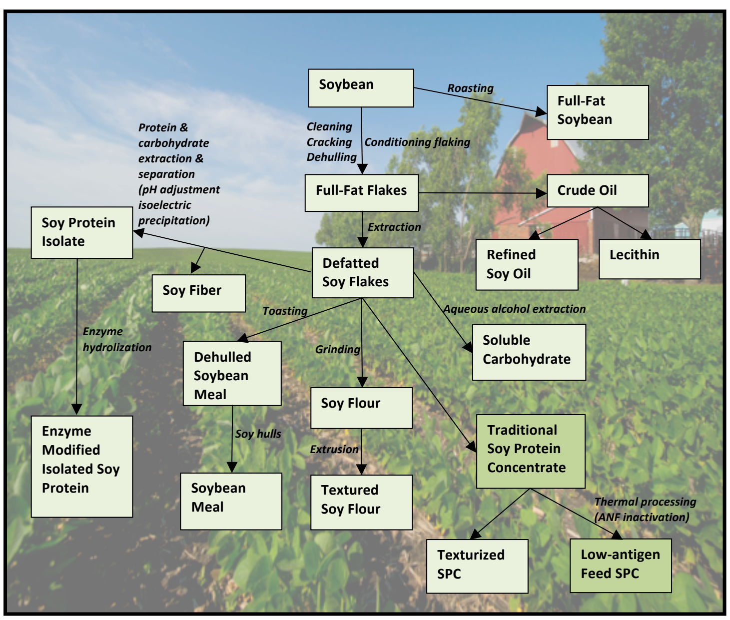

Figure 45.1. Processing flow diagram showing production of various soy products. (Source: SDSU)

Human food opportunities

The increasing awareness of ethnic cuisines and the growing sophistication of U.S. taste buds, provide opportunities for soybean products (Fig. 45.1) to lead food innovation while simultaneously improving human nutrition. Opportunities exist because soybean can be a vital source of vegetable oil and proteins in the human diet. In terms of nutritional composition, soybeans are made up of 38% protein, 18% oil, 35% carbohydrates, and 5% minerals (Kim et al., 2003). The carbohydrates consist of saccharides, namely, sucrose (2.5-8.2%), raffinose (0.1-1.0%) and stachyose (1.4-4.1%). In addition, they contain many essential amino acids (Table 45.1).

Table 45.1. Amino acids composition of soy/corn blends with increasing proportions of soy protein concentrates (SPC). (Source: Kalpesh Parmar Thesis, 2012)

Amino Acid	Raw soybean %	Soybean concentrate %	Distillers dried grains (DDG) %	Food grade DDG %	Blend-1 (30 SPC + 70 DDG) %	Blend-2 (50% SPC + 70 DDG) %	Blend-3 (70 SPC + 30 DDG) %
Crude Protein	47.8	68.9	34.8	35.1	41.7	45.8	45
Alanine - Total	2	2.99	2.46	2.4	2.42	2.32	2.34
Ammonia - Total	1.1	1.84	0.77	0.73	0.81	0.78	0.92
Arginine - Total	3.54	5.28	1.8	1.88	2.59	2.85	3.71
Aspartic Acid - Total	4.9	7.47	1.96	1.84	3.25	3.67	4.25
Cystine - Total	1.18	1.67	1.14	1.24	1.5	1.64	1.46
Glutamic Acid - Total	8.06	12.1	5.6	5.31	7.02	7.24	8.23
Glycine - Total	1.9	2.95	1.38	1.45	1.75	1.8	2.14
Histidine - Total	1.18	1.75	0.99	1.07	1.17	1.1	1.36
Isoleucine - Total	1.86	3.07	1.18	1.19	1.62	1.44	2.2
Leucine - Total	3.53	5.32	4.28	4.46	4.56	4.05	4.37
Lysine - Total	2.76	4.3	0.97	0.92	1.65	1.8	2.36
Methionine - Total	0.67	1.41	0.93	1.01	0.92	0.81	0.82
Phenylalanine - Total	2.26	3.41	1.9	2.1	2.31	2.14	2.66
Proline - Total	2.32	3.5	2.94	2.97	2.92	2.76	2.85
Serine - Total	2.62	3.68	1.98	2.14	2.44	2.59	2.78
Threonine - Total	1.94	2.8	1.5	1.57	1.76	1.84	2.15
Valine - Total	1.89	3.14	1.54	1.57	1.91	1.63	2.37

South Dakota State University has been conducting research designed to increase the amount of soybean used in human food. A Test Kitchen (Fig. 45.8) was developed in the Health and Nutritional Sciences Department in 1990 at the behest of the South Dakota Soybean Research and Promotion Council (SDSRPC). The Test-Kitchen employs undergraduate nutrition and dietetics students for the development soy-based food products. It is a training ground for future nutrition practitioners who learn about culinary and scientific aspects of soy substitutions for the purpose of fat reduction and flavor enhancement in conventional baked foods. The outcomes from the Test Kitchen are featured in a gourmet soy cookbook, *Favorites from the Heartland*, published by the SDSRPC.

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New food product development is both a scientific and a creative exercise. Food innovations materialize in subtle ways as stealth ingredients that do not reveal their presence in food formulations, are used to improve functionality. Soybeans are critical in food experimentation because soybean protein has unique chemical and physical properties that make it particularly suited for improving food texture, appearance, nutrition, and processing ability.

However, soy ingredients present unique opportunities in new food formulations. A bland flavor allows for incorporation into a wide range of products. While use of the unprocessed bean presents several problems for American taste buds, refined ingredients such as protein concentrates and protein isolates hold prospects for use in conventional foods.

Unprocessed soybean has inherent flavor problems owing to chemical changes in the fat content and the occurrence of non-digestible oligosaccharides. Widespread acceptability has been slowed by abdominal discomfort caused by consumption of oligosaccharides. In addition, low protein digestibility is seen in humans as evidenced by a low Biological Value of 74 for protein isolates compared to 83 for egg white (Hoffman et al., 2005). It is difficult to avoid the occurrence of the green-beany flavor of soybean in untoasted full-fat or defatted soybean flour. A beany flavor is an undesirable trait that limits its use.

Soybean also contains the oligosaccharides stachyose and raffinose. These sugars are indigestible and can cause flatulence and abdominal discomfort in humans and animals. These undigested oligosaccharides are broken down in the gut by microbes producing gases such as carbon dioxide, hydrogen, nitrogen, methane, etc. Different processing techniques are used to minimize these problems. Generally, heat treatment is used for inactivation of lipoxygenase enzymes and trypsin inhibitors. Aqueous alcohol washing is used to remove oligosaccharides.

Soy proteins are composed of four major groups, 2S, 7S, 11S, and 15S globulins. The 7S and 11S globulins, known as glycinin and β-conglycinin, are the two major storage proteins and make up approximately two-thirds of the total proteins. These proteins have properties that impact solubility, foaming, emulsification, oil absorption capacity, and hydration. Emulsification and foaming properties are closely associated with solubility. Water absorption, water holding, water hydration, and water-binding capacity are terms used interchangeably. Hydration properties are important in baked goods, cheeses, and meat products. Emulsifying properties of soy proteins are particularly suited for use in coffee whiteners, comminuted meats and, mayonnaise. Foaming capacity is important in cakes, whipped toppings, and frozen desserts.

Soy protein concentrate

Soy protein concentrates (SPC) were developed as flavor improvers and for increasing the protein content of foods. Soy protein concentrate has a protein content of at least 65% (H.Wang et al., 2004). SPC preparation involves retaining the soybean globulin proteins while selectively removing the soluble sugar carbohydrates. This increases the protein content in the final product. Preparation of soybean protein isolates (SPI) involves the extraction of the protein followed by precipitation and centrifugation. These products provide high quality protein and are comparable to animal protein, but consisting of no cholesterol and little or no fats. The FDA has allowed a claim that "A daily diet of 25 g of soybean protein which is low in cholesterol and unsaturated fat can reduce total LDL cholesterol moderately" (FDA, 1999).

Producing protein concentrates

Soybean concentrates can be produced using a number of different approaches. These approaches include:

- Aqueous alcohol and heat treatment/water extraction processes.
- Aqueous acid leaching.

The extraction technique influences its properties. Soybean protein concentrate is produced by the aqueous alcohol and heat treatment/water extraction processes. In contrast, the products made by aqueous acid leaching have high solubility if neutralized prior to drying. These concentrates may vary in particle size, water and fat absorption properties, and flavor. They all have improved flavor characteristics and they also provide functional characteristics such as fat-micelle stabilization, water and fat absorption, viscosity control, and texture control in forming fat emulsions in food systems. Many of these characteristics are interrelated in a stable food system. Both pH and temperature affect the emulsifying properties of soybean concentrate, which absorbs a significant amount of water.

Processing conditions can vary the amount of water that can be absorbed. In fact, these conditions can be varied to influence how tightly the water is bound by the protein in the finished food product. Processing techniques such the acid leaching, steam injection, and jet cooking can result in a product with higher dispersibility. These concentrate are more desirable for functional properties in emulsion-type applications. Soy protein concentrate, regardless of the production process used, has certain oil and water-holding characteristics as well.

Effects of soy, corn, and wheat protein concentrates on food texture properties

Table 45.1 shows the nutritional advantages of combining protein sources from soy and corn processing in yielding nutritionally advanced high protein fractions or blends. Increased soy protein concentrate inclusions in soy/corn distillers dried grains (DDG) blends improved the amino acids composition of the resulting blends (30:70, 50:50, and 70:30). The use of such protein blends in various applications is currently under investigation. Improved protein content, amino acid profiles and dietary fiber content in soy/corn DDG have obvious positive implications for the food ingredient market. Incorporation of such blends in wheat flour substitution can also improve dough functionality and introduce food functional properties not traditionally seen in the conventional flour blends.

Tables 45.2 and 45.3 provide data on changes that occur in food systems owing to the addition of high-protein ingredients such as soy protein concentrates or corn protein concentrates in wheat-based formulations. The farinograph output (Fig. 45.2) in general shows increased dough extensibility largely due to gluten dilution and increased water requirements for dough formation.

Protein and fiber constituents in food adjuncts change the water-holding abilities of dough owing to the competition for water in the food system. Such trade-offs are manifested as reduced dough volume, decreased dough stability, changes in machinability and also reduced eating quality. There is a need to balance the formulation to retain the desirable traits of taste and texture. Advanced instruments such as the Farinograph®, Mixolab®, and Texture Analyzer® remove the guesswork in estimation of optimal water content, mixing requirements while providing explanations for starch-protein interactions and other changes in the functional nature of the food constituents.

Advanced instrumentation for product development

The Farinograph® is a dough-recording mixer (Fig. 45.2). The output of a Farinograph test is a mixing curve. Different types of information can be obtained from the mixing curve. The flour water absorption is the amount of water needed to produce a dough of "perfect" consistency. It is an important parameter in the baking industry. This test also determines the:

- Dough mixing time (or dough development time) which corresponds to the amount of time required to obtain a dough with the proper consistency.
- Dough mixing stability, how long the dough can be mixed before it starts breaking down. Dough mixing tolerance index (MTI). Dough eventually sustains break down when mixed; the MTI is a measure of the dough resistance to over-mixing.

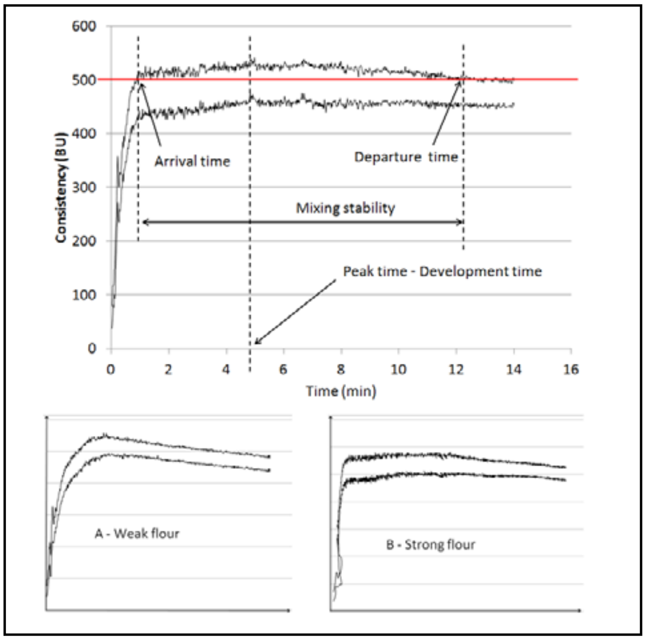


Figure 45.2. Typical Farinograph output (Farinogram).
MTI = Mixing Tolerance Index difference between peak consistency and dough consistency five minutes after peak time (BU).
A = Farinogram of a weak flour.
B = Farinogram of a strong flour.

High water absorption, high mixing stability, and low MTIs are indicators of good dough quality. Dough extensibility tests are another popular quality test (Fig. 45.3). In this test, a dough piece is stretched upwards or downwards in one direction. This test is used to measure dough strength, the amount of force required to break to dough, and the dough extensibility (a measure of how much the dough can be stretched before it starts to break).

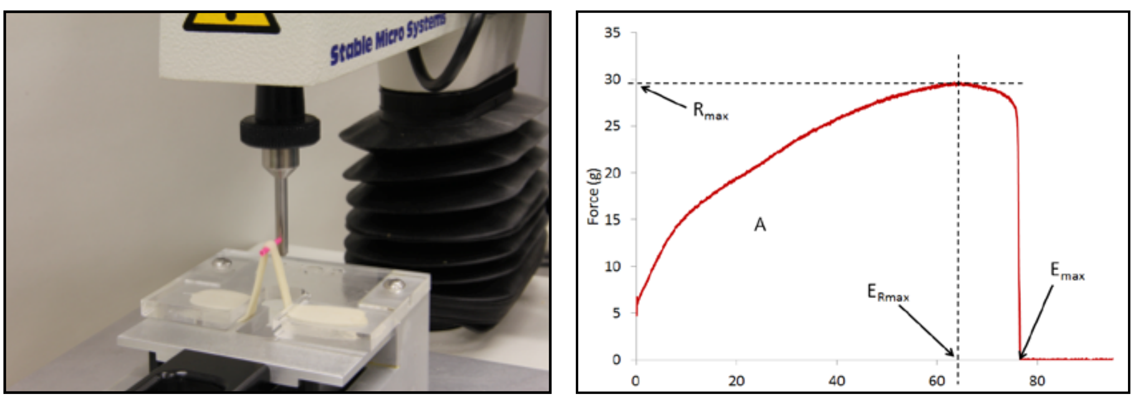


Figure 45.3. Kieffer rig dough extensibility attachment and a typical extensibility curve.
R_{max} = Dough strength (grams), amount of force required to break the dough.
$E_{max=}$ = Dough maximum extensibility (millimeters), distance travelled by the hook when the dough breaks.
E_{Rmax} = Dough extensibility at maximum resistance (mm), distance travelled by the hook when the dough starts to break.
A = Area under the curve, measure of the energy "stored" by the dough during the test.

The substitution of flour by 5% SPC increased the blend protein content by approximately 2.5% while the addition of 5% food grade DDG increased the protein content by 1%. The addition of the SPC-DDG blends also significantly increased the blend's protein content. Both the SPC and the DDG had similar effects on the water absorption of the blend. The water absorption increased by 3% when 5% of SPC or DDG were added to the flour; 8% and 4.5% when 10% of SPC and DDG were added respectively; and 19% when the flour was substituted with 15 % SPC or DDG (Tables 45.1 and 45.2).

Table 45.2. Effects of soy protein concentrate or distiller grains proteins on wheat dough properties when tested independent of each other. (Modified from Parmar, 2012)

Sample	Protein (%)	Water Absorption (%)	Dough Development Time (min)	Dough Stability (min)	MTI (BU)	Dough Strength (g)	Dough Extensibility (mm)
Control (wheat)	17.6^{I}	62.7^{G}	8.8^{CD}	14.4^{E}	19.7^{AB}	30.5^{B}	102.4^{A}
Wheat + SPC-5%	20.1^{F}	65.5^{EF}	9.2^{CD}	19.8^{CD}	8.5^{BC}	29.2^{BC}	58.4^{D}
Wheat + SPC-10%	22.4^{D}	70.4^{C}	10.1^{CD}	27.2^{A}	4.0^{C}	20.9^{D}	70.1^{C}
Wheat + SPC-15%	24.8^{B}	82.1^{A}	10.9^{C}	12.3^{E}	18.5^{AB}	32.7^{A}	47.3^{E}
Wheat + DDG-5%	18.1^{H}	65.3^{F}	9.9^{CD}	12.6^{E}	26.5^{A}	12.3^{G}	54.8^{D}
Wheat + DDG-10%	19.1^{G}	67.2^{D}	6.3^{D}	11.0^{E}	24.5^{A}	11.7^{G}	41.8^{F}
Wheat + DDG-15%	20.2^{EF}	81.9^{A}	17.7^{B}	15.3^{DE}	17.0^{AB}	28^{C}	37.3^{F}

Table 45.3. Effects of soy-DDG combinations on wheat dough properties. (Modified from Parmar, 2012)

Sample	Protein Content (%)	Water Absorption (14% mb)	Dough Development Time (min)	Dough Stability (min)	MTI (BU)	Dough Strength (g)	Dough Extensibility (mm)
Control (Wheat)	17.6^{h}	62.7^{c}	8.8^{bc}	14.4^{e}	19.7^{cd}	30.5^{de}	102.4^{a}
Blend-1-5%	19.5^{f}	64.8^{c}	10.4^{bc}	24.5^{cd}	16.0^{de}	30.9^{cd}	61.9^{d}
Blend-1-10%	21.4^{d}	71.6^{ab}	10.8^{bc}	24.5^{cd}	16.0^{de}	30.9^{cd}	61.9^{d}
Blend-1-15%	23.4^{a}	73.7^{a}	13.3^{a}	55.4^{a}	23.0^{bc}	32.89^{bcd}	48.4^{e}
Blend-2-5%	18.4^{g}	64.9^{c}	7.6^{d}	17.2^{e}	15.3^{def}	27.9^{e}	78.1^{b}
Blend-2-10%	20.8^{e}	69.0^{b}	11.3^{ab}	22.1^{d}	18.0^{d}	33.0^{bcd}	52.1^{e}
Blend-2-15%	22.5^{b}	71.1^{ab}	12.2^{ab}	30.4^{b}	12.3^{ef}	34.0^{ab}	47.0^{ef}
Blend-3-5%	17.3^{i}	64.9^{c}	7.0^{d}	15.8^{e}	15.0^{def}	30.2^{de}	76.2^{b}
Blend-3-10%	19.5^{f}	68.6^{b}	11.6^{ab}	26.9^{c}	11.0^{f}	33.8^{abc}	53.6^{e}
Blend-3-15%	21.8^{c}	73.2^{a}	12.8^{a}	21.8^{d}	26.3^{ab}	36.6^{a}	40.7^{f}
Wheat flour	17.6^{h}	62.7^{c}	8.8^{bc}	14.4^{e}	19.7^{cd}	30.5^{de}	102.4^{a}
Commercial Pizza flour	13.5^{j}	58.9^{d}	2.3^{e}	6.9^{f}	31.0^{a}	21.2^{e}	68.6^{cd}

The water absorption increased as the substitution level with the SPC-DDG blends increased. This is due to the added protein and fiber; these constituents have a high water-holding capacity, therefore more water is required to hydrate the blend. The substitution affected the dough characteristics; adding 15% of Blend 1 (25% SPC – 75% DDG) resulted in a significant increase in the dough development time. Blend 2 (50% SPC – 50% DDG) and Blend 3 (70% SPC – 30% DGG) had similar effects on the dough development; substituting at the 5% level resulted in an increase in the dough development time. The flour blends with a level of substitution of 10% and 15% had longer development times in comparison to the 5% blends; however, there was no significant difference between the 10% and 15% blend.

The effects of SPC and DDG fortification on the dough development time were assessed separately. The addition of up to 15% SPC did not significantly affect the dough development time. However, the addition of 15% DDG significantly increased the dough development time. Dough formation in flour dough occurs when the flour proteins (glutenins and gliadins) are hydrated and form a cohesive mass, which is a protein composite commonly referred to as gluten (Fig. 45.4).

The SPC-DDG blend consists of constituents with a high water holding capacity. When part of the flour is substituted with the SPC-DDG blend, the constituents from the SPC-DDG blend compete with the flour proteins for water which in turn results in a delay to reach the target consistency. Therefore, flours fortified with the SPC-DDG blend will have longer development times.

The mixing stability was also affected by the addition of the SPC-DDG blend, the substitution of flour by the different SPC-DDG blends resulted in an increase in dough stability. Adding 5% or 10% of SPC to flour increased the dough mixing stability, but the substitution at the 15% level significantly decreased the mixing stability. On the other hand, the addition of DDG did not significantly affect the mixing stability.

When the SPC-DDG blends were used in flour, the mixing tolerance index increased with increasing substitution. Substitution with SPC at the 15% level decreased the dough mixing tolerance while the addition of DDG did not impact MTI. The addition of the SPC-DDG blends up to the 15% level did not impact dough strength, however increasing the level of substitution reduced extensibility. Adding the SPC-DDG blend altered the dough stretchability and color (Fig. 45.5).

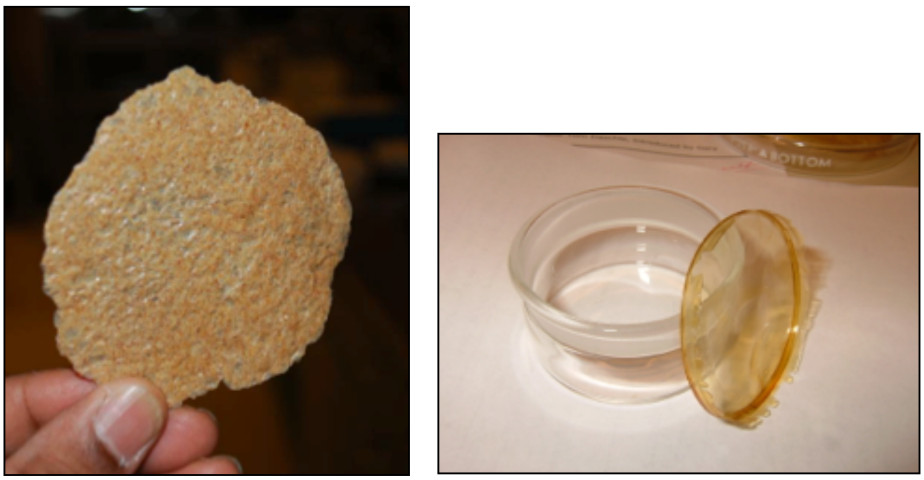


Figure 45.4. Wheat protein (gluten) and corn protein (Zein) showing potential foam and film production food applications, respectively. (Photos courtesy of Dr. Padu Krishnan, SDSU)

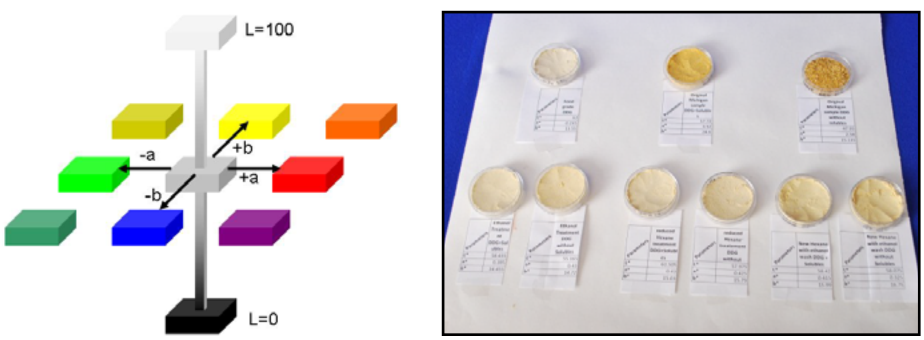


Figure 45.5. L, a, b color space and color changes in DDG during processing. Higher brightness values L and lower redness (a) are achieved with processed DDG using solvent extraction. (Graphics and photo, P. Krishnan, SDSU)

SDSU investments in food quality and crop quality efforts

The Food Science program in the Health and Nutritional Sciences Department, South Dakota State University, has devoted over 2000 ft2 of space for research and innovation in the area of food and nutrition. Analytical instrumentation acquired with the support of the South Dakota Soybean Research and Promotion Council (SDSRPC) include a combustion protein analyzer, a liquid chromatography mass spectrometer, gas chromatography mass spectrometer, solvent extractor, and a host of food preparation equipment (Fig. 45.6). A texture analyzer was acquired with federal, state, and SDSRPC support. A Vita Cow® (aka Soy Cow) was also acquired for the processing of soymilk and related soy products. A test kitchen equipped with stainless steel counters, food grade equipment, and a sensory evaluation facility allows for the product development and evaluation efforts (Fig. 45.7).

The development of a Crop Quality Laboratory (CQL) in the Seed Technology Laboratory adds additional research space (1300 ft^2) for grains and oilseeds. Images of the new laboratories are provided in Figure 45.8. The CQL features wheat, flour and dough quality measurement equipment for routine evaluation of South Dakota crops. In addition, capabilities exist for experimental baking and tortilla and noodle processing.

Basic and applied research in the area of cereal grains and oilseeds is supported through a variety of commodity, industry, and federal agencies. Fundamental properties of locally grown varieties of wheat, oat, and soybeans are studied for the nutritional, health, and food functional traits. The economic value of cash crops is enhanced by their end-use properties. High value and economical sources of protein from corn and soybeans are useful in feeding livestock and in aquaculture, while wheat proteins are used directly in the food industry. The latter are then transformed into high quality and cost effective protein in human nutrition through the food we eat.

More recently, a 2012 award of a $500,000 grant from the South Dakota Board of Regents Productivity Improvement Program has made possible the acquisition of a pilot scale extruder. This versatile cooker-extruder will be centrally located in SDSU and used in research and development efforts in the area of food, aquaculture, and biomaterials. A well-equipped, state-of-the-art food laboratory can be used to develop new products that can be locally manufactured.

Research into foods for healthy living include new oat varieties with enhanced soluble fiber and anti-oxidative properties, new blends of soy and corn proteins in bread formulations, high temperature processing of flat breads, high fiber pizza crusts and Asian noodles, high-selenium gluten, and anti-tumor canola meal constituents. The program engages the national food industry for support in several proprietary research projects. Basic research into dough rheology and breeding techniques also employ food science research knowledge. These areas provide excellent training grounds for master of science and Ph.D. students interested in science careers in academia and the food industry.

Figure 45.6. Equipment contained within the food laboratory (and pilot facility). The equipment shown is a texture analyzer used to measure extensibility and force needed to shear food products, a protein analyzer, a gas chromatograph mass spectrometer, and a side view of a pilot-scale food extruder. (Photos, P. Krishnan, SDSU)

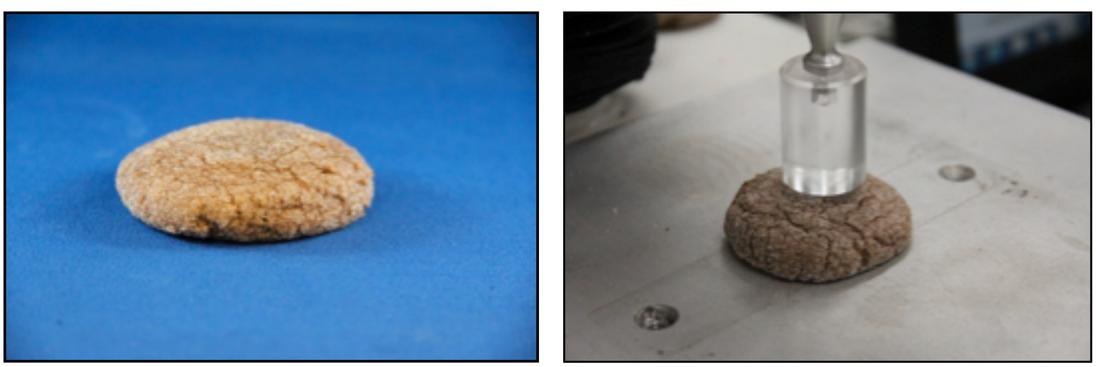
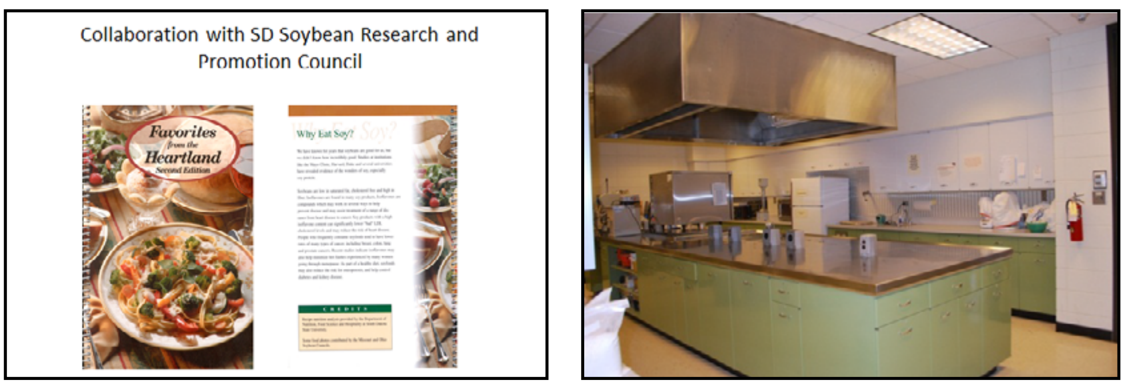


Figure 45.7. Tofu fudge cookie developed by the SDSU Test Kitchen (left) and texture analysis of tofu cookie (right). (Photos, P. Krishnan, SDSU)

Crop Quality Lab and Baking Room

Sensory Analysis Booth



Soyfoods Cookbook and Test Kitchen

Soymilk Production Unit “soy cow” and Faye Tyler Wade Lab

Figure 45.8. Facilities available for food product development activities. (Photos, P. Krishnan, SDSU)

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Acknowledgements

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