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Authors' address: National Food Research Institute, Tsukuba, Ibaraki 305-8642, Japan, e-mail: kenohtsu@nfri.affrc.go.jp.

High-pressure food processing of rice and starch foods

Rikimaru Hayashi

The use of pressure (P) in addition to temperature (T) (Hayashi 1987, Hayashi et al 1987) has been accepted in the field of food science and technology over the past 15 years, and research and development are now under way in the food industry, universities, and government institutes (Hayashi 2002). Several commercial products are now on the market that are prepared using high-pressure techniques.

This paper describes the principle of high-pressure treatment and the effects of high pressure on foods, with emphasis on the high-pressure effects on starches. Finally, recent successes of the Echigo Seika Company in the application of high-pressure techniques to rice and rice products are discussed.

Principle and method

High pressure means high hydrostatic pressure generated by the compression of water. A pressure of 100 MPa or higher (usually lower than 1,000 MPa) is used under temperatures below 100 °C. A unit of pressure is expressed in kg cm^{-2}, bar, or pounds in^{-2}, but now the international Pascal unit is commonly used. Therefore, 1,000 bar or 1,000 kg cm^{-2} almost equals 100 MPa.

Food, which is contained in a plastic bag and sealed by carefully removing air, is placed in a pressure vessel filled with water and high pressure is then generated in the vessel by a pressure pump.

Pressurization of food

An egg is not crushed by compression at 600 MPa, but the egg white and yolk are coagulated. The color of egg yolk of a pressurized egg is naturally yellow, whereas a boiled egg changes to a faded yellow. The color difference is attributed to changes associated with pressurization: pressure affects only noncovalent bonding and coagulates proteins without splitting covalent bonds, thus keeping the color and smell intact.

High pressure induces protein denaturation in the same way as high temperature.

Meat protein is also denatured by pressure treatment at 400 MPa, preserving the properties of raw meats. An example of prawns or shrimp is interesting: although a boiled prawn turns red and the meat coagulates, the appearance of a pressurized prawn is the same as that of raw shrimp, but the meat coagulates after pressurization at 400 MPa for 10 min.

High pressure also has an effect on starches: a thick suspension of rice starch forms a ball by standing against its own weight after pressurization at 700 MPa, indicating that starches are gelatinized by the pressure treatment.

Versatile utility of high pressure

A high-pressure treatment generally coagulates protein, thereby inactivating the enzymes, gelatinizing the starches, and killing microorganisms. Thus, the use of high pressure promises to be a versatile process in food science and technology. Pressure produces a new texture in meats and starch-based foods, while keeping the original nutrients, flavor, and color.

High-pressure effects on pure starches

High-pressure-induced gelatinization of starch

Effect of pressure on amylase digestibility of starches. The starches of potato, maize, and wheat are gelatinized by pressure treatment at warm conditions of 45–50 °C. The pressurization produces unique properties that are different from those of heat-gelatinization: heat-treatment destroys starch granules, resulting in a transparent solution, but a pressure-treatment swells the granules while maintaining the granular structure. Nevertheless, amylolytic enzymes such as α-, β-, and glc-amylases digest the pressurized starches well, being similar to the phenomenon in which the pressure-treatment of proteins increases protease digestibility (Hayashi and Hayashida 1989).

The pressure-induced gelatinization of starches exhibits a sigmoid curve, suggesting that a two-state transition is involved, as in heat-induced gelatinization (see below).

Effect of pressurization time on amylase digestibility of starches. To attain full amylase digestibility of starches, pressurization under warm conditions for 2 to 6 h is necessary.

Interestingly, pressurization of starches for a longer time makes amylase digestion difficult: the amylase digestibility of starches decreased by 20–50% after pressurization for 17 h compared with the maximum digestibility obtained after pressurization for 2 to 6 h.

These observations suggest that pressure induces gelatinization of starches, similar to heating, but prolonged pressurization produces a new stable structure of starches, which is not susceptible to attack by amylase (Ezaki and Hayashi 1992).

Birefringence of starches after pressurization. The birefringence of starches is lost as increasing pressure is applied.

Wheat starch is sensitive to pressure and birefringence is lost at 200 MPa.

In the pressurization of starches, the number of granules exhibiting complete birefringence decreases without increasing the incomplete birefringent granules. This loss of birefringence shows that the crystalline structure is destroyed by high pressure as well as by high temperature and that the high-pressure-induced gelatinization of starches follows a two-state transition without an intermediate state of destruction.

Physical properties of pressurized starches

When a 50% water suspension of starches is pressurized at 100 to 500 MPa and at 45 °C for 1 h and air-dried, followed by analyses of their physical properties, the results are as follows.

According to X-ray crystal analysis, the crystalline structure of potato, waxy maize, and maize starches decreases with an increase in pressure, although the crystalline structure of potato starch does not change up to 500 MPa. The decrease in the high-pressure-induced crystalline structure is parallel with the increase in amylase susceptibility.

Amylograms show that the transition temperature of pressurized starches is elevated, thus decreasing the viscosity.

Interestingly, differential-scanning calorimetry (DSC) of pressurized starches shows that the peak temperature of the DSC patterns increases while the peak area decreases, indicating that some pressure-induced structural state of the pressurized starches is perturbed by low energy at higher temperatures.

Summary of pressure-induced changes in starches

The structure of pressurized starches changes accompanying the increase in amylase digestibility, a loss of birefringence, and a loss of crystallinity. These unique structural properties, which are somewhat different from those of heat-gelatinized starches, should be analyzed in detail for effective applications of high pressure to starch and related foods.

Rice-based foods produced by high-pressure processing

Dr. Akira Yamazaki, of Echigo Seika Company Ltd., studied the properties of pressurized rice in detail to introduce the use of high pressure to the food industry (Kinefuchi et al 1999, Sasagawa and Yamazaki 2002). He equipped several large high-pressure machines in his own factory and succeeded in sending rice and rice products to the market by introducing the high-pressure technique to the manufacturing process of rice products, cooked rice (*gohan*), rice crackers (*osembei*), and rice cakes (*omochi*).

High-pressure effects on rice grains

Traditionally cooked-rice grains change their shape and develop some cracks, but rice grains after high-pressure pretreatment followed by heat-cooking swell, and their original shape is maintained without cracks.

High-pressure cooked rice for microwave ovens

Bread is purchased in the store and toasted just before eating. This is a typical life style, especially on a busy morning. However, 45 min are required to cook rice. Cooked rice tastes best and has its best texture just after steaming. Warming of cold cooked rice makes the taste worse. In general, heating a starch-based food twice leads to an unpalatable food. In history, instant-rice is a dream of Japanese consumers.

Dr. Yamazaki succeeded in producing oven-cooked rice with a good taste and texture for consumers, although the production scale is only enough to fulfill the requirement of a small city. He also succeeded in producing instant rice containing miscellaneous cereals. These instant cooked-rice cereals exhibited good taste and good texture by a 3-min heating in a microwave oven.

When high-pressure pretreated and successively heat-cooked rice is compared with traditionally cooked rice, its properties are as follows: first, it is more gelatinized; second, it is more slowly retrograded; and third, it is gelatinized to a greater extent by heating just before serving. Japanese consumers who are particularly sensitive to rice accept these properties.

High-pressure rice cakes

During New-Year days, the Japanese public is freed from the kitchen and enjoys the New-Year cerebrations, eating rice cakes (*omochi*) every day, which are a preserved food. The company introduced the high-pressure technique for producing the traditional rice cake and a special kind of *omochi*, which contains herbs with a natural color, smell, and taste, and this is now available on the market.

Merits of high-pressure food processing

High-pressure processing is useful not only for producing high-quality food, but also for improving the manufacturing process. The production time for rice crackers is shortened by introducing a high-pressure technique into the traditional processing system and the total energy cost is decreased by 10% and the labor force by 56%.

Conclusions

The use of high pressure for food processing and cooking, in addition to heating and cooling, is now in our hands. Two factors, T and P, are useful for the manufacturing of good foods, including starch-based foods. Although T and P are used independently, their combined use is also important for the optimal use of high pressure. For example, heat-tolerant bacterial spores are inactivated by pressurization under elevated temperature.

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Author's address: Food Science and Technology, College of Bioresource Science, Nihon University, Kamenoi 1866, Fujisawa, Kanagawa 252-8502, Japan, e-mail: hayashi2@brs.nihon-u.ac.jp.

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On the evening of 23 October 2004, a huge earthquake struck Niigata Prefecture, especially Ojiya City. This city, the location of Echigo Seika Company Ltd., was the seismic center. I express my sincere sympathy to the people there, and, as it is now a very busy season for the coming New Year, I regret the damage to the rice-processing systems of the company, including the high-pressure machines, resulting from this earthquake.

Developing novel processes for incorporating the unique nutritional and functional properties of rice into value-added products

Elaine T. Champagne, Harmeet S. Guraya, Frederick F. Shih, and Ranjit S. Kadan

An expanding global rice market and diet diversification have presented the rice industry in the United States and other developed countries challenges and opportunities to develop new markets for rice. Global trade has expanded with advances in technologies leading to record yields of high-quality rice. Countries that at one time were importers or had only a small share of the export market are now major exporters. The United States, once the lead exporter of high-quality rice, has been hit hard by this shrinking export market. Outside of the U.S., countries such as Brazil, China, Japan, Taiwan, and India have been faced with declining per-capita consumption because of diet diversification. Value-added rice products that capture the unique nutritional and functional attributes of rice offer a means to keep rice as a mainstay of the diet and to expand domestic markets. This paper will highlight new product introductions in the U.S. and technologies recently developed at the USDA-ARS Southern Regional Research Center for value-added rice products.

New product introductions

Domestic usage of rice in the United States has tripled in the last ten years in response to consumer demand for more healthful foods, more convenient products, and a growing interest in ethnic foods. The market has been flooded with new product introductions. Foods that use rice now include baby food, bakery goods, breakfast cereals, candy, desserts, beverages and dairy items, side dishes, package mixes, entrees (frozen, shelf-stable, chilled), meats and meat substitutes, sauces and spreads, snacks, soups, and pet foods.

Rice usage in entrees has increased 10-fold in the last 20 years. Interest in ethnic foods has boosted this growth. Frozen ethnic entrees represented a $2.2 billion industry in 2000 (Brandt 2001). A popular new addition is bowl meals—a frozen entree in a microwaveable bowl usually containing individually quick-frozen rice, meat or poultry, and vegetables. They have contributed largely to the growth of the entree market.

Package rice mixes to serve as side dishes combine rice with seasonings, dehydrated vegetables, and other ingredients. The use of rice in packaged mixes doubled during the 1990s (USA Rice Federation 2000). Mixes for Louisiana Cajun and Creole foods, such as jambalaya, gumbo, and etouffee, and difficult-to-make dishes, such as risotto, are popular. Rice for mixes is either regular or parboiled, with a low moisture content around 6.5%. For a product in which distinct grains are important, such as a pilaf, or when a sauce will add moisture, parboiled rice often performs better than regular rice.

Snack bars using rice include granola, breakfast, and energy bars. Energy bars, introduced in the 1990s, account for 80 to 100 new product launches a year and represented about $500–700 million in sales in 2000 (Kreuzer 2001, Mintel In-