Texture-modified foods for the elderly and people with dysphagia: insights from Japan on the current status of regulations and opportunities of the high pressure technology

Anastasiia Maksimenko¹,³, Anna Lyude² and Tadayuki Nishiumi¹

¹ Graduate School of Science and Technology, Niigata University, 8050 Ikarashi 2 no-cho, Nishi-ku, Niigata-shi, Niigata, 950-2181, Japan
² Institute of Science and Technology, Niigata University, 8050 Ikarashi 2 no-cho, Nishi-ku, Niigata-shi, Niigata, 950-2181, Japan
³ E-mail: anastasiia.a.mak@gmail.com

Abstract. The group of people aged 60 and over is expanding worldwide. Whereas the group aged over 80 years is growing fastest among all population segments. There is an increasing necessity to provide the elderly with balanced and functional nutrition aimed to maintain healthy aging and prevent diseases and, at the same time to cope with the special needs of people with masticatory and swallowing dysfunctions. This study outlines the current situation with elderly-oriented foods in Russia and the rapidly aging Japan. The study demonstrates that in Japan, there is a regulation system and commercial products tailored for older people, particularly those with dysphagia and/or need for special nutrition. However, providing appetizing and healthful products with a modified texture for the safe and nutritious diet of seniors remains an unresolved issue for the food industry in both countries. The study presents basic physiological disorders associated with food intake and specific aging-related nutritional needs to be considered when developing food for the elderly. Qualification of texture-modified products is given. A review of the recent research indicates that high pressure technology has feasible potential in developing healthy foods, including processed meat and fish products with reduced content of food additives, foods for the aging population, and people with dysphagia.

1. Introduction
Both the proportion and the number of senior persons aged 60 and over shows the fastest growth rate among all population segments in virtually all countries. By 2025, the number of older persons worldwide is expected to reach more than 1.2 billion [1]. In Japan, the population has decreased for the ninth year in a row. In contrast, the ratio of older people aged 65 years old and over to the total population has consistently continued to rise since 4.9% in 1950, surpassing 28.4% (with 12.9 % of the total labor force) in 2019. By the estimate of the National Institute of Population and Social Security (Japan), this percentage is expected to be 35.3% in 2040. By age groups, in 2019, the population aged 70 and over was 27.15 million or 21.5% of the total population (an increase of 980,000 compared to the previous year's estimate). The population aged 75 or over was 18.48 million, and 14.7% (up 530,000). The population aged 80 and over was 11.25 million, 8.9% of the total population (up 210,000) [2]. In recent decades, the Russian Federation also has seen a noticeable increase in the number and proportion of the
elderly population over 60 years old. In 2019 their share in the total population exceeded 22% and amounted to about 40 million people [3].

The phenomenon of aging has a significant impact on various aspects of society. A serious problem is an increasing necessity in medical and nursing care services. National Center for Geriatrics and Gerontology (Japan) states that more than 70% of home-care patients aged 65 or older fall into different levels of the "undernutrition risk" group. Problems "with chewing most or some foods" are experienced by 30% and 38% of home-care patients aged over 65, respectively (only 26.1% can chew all food freely). Swallowing impairments are reported in 50% of home-care seniors of this age group. Eating and swallowing disorders are reported at the high ratio of the elderly population being treated at nursing homes and healthcare facilities [4]. Data to fully grasp the spread of mastication and swallowing disorders in the Russian population distributed by age groups is limited. However, in general, dysphagia occurs in older people independent in everyday life in 27.2% cases, in elderly patients in intensive care units - in 47.4%, and people in need of constant nursing care - in 51% of cases. Dysphagia occurs at any age, but over the years, the number of cases observed increases [5].

Diseases of the elderly are costly to individuals, families, and the health care system, therefore identifying and implementing effective measures to increase longevity and preserve health have high social, economic, and political significance. A balanced healthy diet and physical activity are the main factors of healthy aging. In this regard, on the one hand, the importance of functional foods for the elderly that contains ingredients boosting resistance of the human body to diseases, allowing it to maintain an active lifestyle for a long time, is increasing. On the other hand, the importance of food oriented for groups of people with physiological problems is expanding.

Due to the favorable demographic trends in the Russian Federation and the increase in the average life expectancy of the population, the increase of persons with masticatory and swallowing disorders or specialized nursing and nutritional needs should be anticipated. Thus, the creation of more diverse and purpose-oriented nutritious products for elder people considering the peculiarities of their physiology should become the priority area for the Russian food industry.

In order to get insights from the experience of the most rapidly aging country Japan, the first objective of this review is to outline the situation regarding foods for the elderly, in particular, those aimed at people with eating constraints or having specific nutritional needs. Moreover, this paper aims at scrutinizing the existing scientific and technological basis available for tailor-making foods for the groups mentioned above, with the precise attention to the texture modification technology. Relevant literature review, together with governmental regulations, government programs related to the food and health sector, statistical government reports, together with the official international statistics, constituted a base for the study.

2. The current situation in the Russian Federation and Japan

In the Russian Federation, functional foods for the elderly are designed for the age groups of 60 to 74 years and of 75 to 89 years old. Functional food products are products intended for systematic use as part of a daily diet by a healthy population of all age groups in order to reduce the risk of various diseases, preserve and improve health [6]. Functional foods for the elderly are an independent scientific discipline that considers the nutritional characteristics of elderly and weakened people, the quantity and quality of food for the prevention of age-dependent diseases, and premature aging. The basic principles of functional food science are an energetically balanced diet, compliance of the chemical composition of food with age-related characteristics of the body, therapeutic and preventive orientation, the balance of all essential components, rational diet (4-5 times a day). It also implies using easily digestible foods, alkaline diet, normalization of intestinal microflora of aging body, food enrichment with nutrients that have wellness properties, inclusion in the diet products that moderately stimulate the secretory and motor function of the digestive organs [6, 7].

However, creating an optimal-balanced diet for the elderly with the content of natural food components is quite a difficult challenge. In the Russian Federation, it is approached through
modification of natural components of food, correction of the composition of products by fortification them with macro-, micro-nutrients, biologically active components [8].

Currently, a relatively wide variety of healthy foods for the elderly have been developed - bakery, confectionery, meat, fish, fat- and oil-products, and non-alcoholic beverages. The Russian market has a wide range of health orientated bakery products ("8 cereals", "Healing", iodized bread, vitaminized bread), cereals products with various additives, and phytocomponents. Meat products with the addition of caraway seeds, milk thistle oil, lactulose, and combined meat products with plant-based components (wheat protein, pea protein, soybeans, legumes, whey protein). All these ingredients contribute to the enrichment of the products by polyunsaturated fatty acids, dietary fiber, vitamins (C, B group, E, carotene); include antioxidants, oligosaccharides, and minerals, and improve digestion [8]. However, the share of functional foods for the elderly is 3-5% of the total number of food products in the Russian market [9].

Japan has comprehensively implemented the "National Health Promotion Movement in the twenty first century (Health Japan 21 (the second term))". The National Movement goal is to extend healthy life expectancy and reduce health discrepancy, targeting 53 specific areas. Within the program, by cooperating of Ministry of Health, Labor and Welfare, Consumer Affairs Agency and Ministry of Agriculture, Forestry and Fisheries, a substantial system of specialized foods to promote health was established. The system of Foods with Function Claims (FFC), including Food for Specified Health Use (FOSHU) and Foods for Special Dietary Uses (FOSDU) regulates and evaluates the market of all functional products. Over the years, the Japanese government and relevant ministries has stimulated collaboration of authorities from academia, healthcare practitioners and food industry and reformed its policies to respond to the need of the aging population. From 2006, the Ministry of Agriculture, Forestry and Fisheries has invited the participation of medical/nursing care workers, food manufacturers, and distributors for the discussion. As a result, from February 2013, a new regulation policy for nursing care foods called "Smile Care Food" was established (figure 1). Elderly and nursing care-oriented foods were divided into three categories and labeled with colors and marks to indicate the purpose. Yellow and red labels should comply with the Japanese Agricultural Standards (JAS) for Dysphagia-friendly Food.

![Figure 1. "Smile Care Food" system in Japan. Adapted from MAFF, 2020 [4].](image-url)

Blue label: food for people having no dysfunctions in eating; it aims at supplementing nutrition to maintain health. Blue label food should comply with the standard: contain not less than 100kcal (per 100g or 100ml) and not less than 8.1g (per 100g) or 4.1g (per 100ml or 100kcal) of protein. As of June 2019, there are 149 items from 35 companies that have been licensed. Yellow label: food for people with problems with mastication [4]. By the tenderness degree, the food is divided for: soft food easy to bite, crush or mash (with moderately chewy texture); food that can be crushed by the tongue; a group
that can be smashed by tongue and palate; and food that can be swallowed without chewing. Two products from one company are licensed. Red label: food for people with swallowing dysfunctions. Food that can be swallowed after some mastication; it includes mixes of solid and gel foods, e.g., porridge; food like pudding and mouse that can be swallowed after some crushing in the mouth. Homogeneous jellies that do not need to be chewed and can be swallowed at once. Nowadays, 13 items from one company are licensed [4].

Ever-increasing demand has not been satisfied by adequate supply. However, spurred by the new regulatory system, the sales of nutritional supplement foods (blue label) doubled in 2020, and foods for patients with dysphagia tripled compared with 2010. By 2025 market for products for swallowing (red label) and masticatory (yellow label) problems alone is expected to reach 27.1 billion Japanese yen or 252 million US dollars [4]. A list of commercial products for the blue label includes multiple thermal high pressurized fish preserves with traditional Japanese flavors of miso paste and soy sauce, allowing to digest calcium from fish bones fully. Simultaneously, there are multiple processed fish products with bones completely deleted. Stewed meat and vegetable dishes, preserves made of various legumes including soybean, seaweed varieties are widely presented [4].

3. Special foods for the elderly: texture-modified foods
The main aspects that need to be considered when developing healthy nutrition for older people have been described in detail by Aguilera et al. [10]. As shown in figure 2, the nutritional needs of older people can be described as those related to safe eating and sensory enjoyment experience and needs related to physiological changes (changes in body composition and special nutritional needs) caused by aging.

![Figure 2. Need for texture-modified and special foods for the elderly](image_url)

**Figure 2.** Main aspects to be considered in the design of healthy foods for the elderly. Adapted from Aguilera et al., 2016 [10].

The disease of the precise interest to the current paper is dysphagia i.e. the difficulty associated with swallowing safely the mouth contents through the right throat pipe [10]. Difficulties with swallowing increase dramatically during aging, and may cause malnutrition and morbidity due to aspiration pneumonia. According to the World Gastroenterology Organisation, dysphagia is a common problem. Every 17th person will have some form of dysphagia during his/her lifetime. The disease affects 40-70% of stroke patients, up to 80% of neurodegenerative disease patients, up to 13% of adults aged 65 years and over, more than a half of elderly patients receiving treatment in healthcare facilities, and 60-75% of patients at the radiotherapy treatment of head and neck cancer [11].

Thus, foods for individuals suffering from dysphagia are recommended to be defragmenter into small and tender particles (e.g., < 1.5 mm). To be smoothly swallowed, the bolus should be moist, cohesive, and slippery. The physiological dysfunctions and specific nutritional needs developed during aging require a supply with soft, easily and safely swallowed, nutritious and tasty special foods. These particular conditions should be targeted if creating dysphagia-friendly commercial products [10].

Food with a soft texture and/or reduced particle size or thickened liquids (drinks) aimed at the elderly market segment dietary dysfunctions make up a group of texture-modified (TM) food. It is necessary to
refrain from producing adhesive and sticky textures, and fibrous, problematic to break down structures for elderly-oriented foods. TM food consists of food that is softened by processing, minced, made into puree or liquid. TM foods also include liquids that have been thickened to various extents. Dysphagia-friendly TM foods can be classified in several categories such as the relatively universal standardization by the Japanese Society of Dysphagia Rehabilitation (used for creating "Smile Care Food" system); or the International Dysphagia Diet Standardization Initiative (IDDSI), while other categories can be generated by the exact healthcare facilities [10, 12]. Figure 3 (the classification by IDDSI) presents a grouping of TM foods different in viscosity and/or texture. They vary from thin liquids to common soft foods and those that have been soften by chemical or physical means. Due to the international requirements to classify age-appropriate everyday foods of soft, tender textures, the IDDSI Framework, created in 2015, was updated in July 2019 by the adding of the "Easy to Chew" level, which became a sub-level of level 7 "Regular". The IDDSI framework consists of eight levels (from 0 to 7), where levels 0-4 are drinks, while levels 3-7 are foods [12].

Essential criteria of texture required in TM foods are hardness (hard to soft), adhesiveness (i.e., the tendency of particles to adhere at their surfaces), and cohesiveness (ability to form a swallow-safe bolus in the mouth) [10].

The development of TM foods for specific purposes can be divided into three categories. The first category aims at easy chewing mainly and includes traditional processes that cause softening of such typical meals as fruits, vegetables, and meat. The second group of purposes mostly deals with the rheology of liquids for secure swallowing or as carriers and aims to produce biopolymer particles and micro-gels. Developing novel emerging structures represents the third group of technologies. Some technologies for TM foods retain the overall appearance and flavor of whole pieces while softening their structure (i.e., they breakdown easily in the mouth). As the appearance and taste of processed foods remain familiar, this method is much appreciated. The effect of texture softening can be attained by several well-established techniques including high pressure treatment. Appropriate control of process variables can preserve the color and flavor of food, and at the same time can adjust its soft texture to varying degrees [10].

4. Application of high pressure for texture-modified and functionally improved healthy products

High pressure processing is a technology by which a product is treated at or above 100 MPa by means of a compression fluid. High pressure was first applied in the food industry in Japan in the late 1980s. This technology has been known for its ability of microbial inactivation at low temperatures. In addition, it can be used to create novel products avoiding thermal degradation and to obtain equivalent products with minimal effects on taste, color, and nutritional value [13]. High pressure processing can be applied
under three different forms: a static process in a vessel known as high hydrostatic pressure, a dynamic process in which a fluid is forced through a nozzle jet under high pressure known as high pressure homogenization, and hydrodynamic pressure processing or shockwaves which instantaneously develop pressure waves up to 1 GPa [14]. Today, more than 160 industrial vessels are in use throughout the world [15]. Almost half of the equipment (44%), is intended for processing products based on fruits and vegetables. The avocado industry was one of the main engines of this innovative technology, such as non-thermal pasteurization and increased shelf-life [16].

The meat sector has also adopted high pressure technology. Currently, the use of high pressure processing in the meat industry represents around 25-30% of the total equipment installed [17]. Over the past decade, high pressure has been actively utilized for food preservation by inactivating pathogenic microorganisms in meat products. However, the technology is no longer considered only as a simple substitute for conventional pasteurization. It is an alternative to heat treatment, which can be used as a method of ensuring microbial safety and changing the texture of the product while maintaining nutritional value. High pressure can affect myofibrillar protein conformations and lead to protein denaturation, solubilization, aggregation and/or gelation; high pressure modifies protein by the rupture of non-covalent interactions (electrostatic and hydrophobic) in tertiary and secondary structures within protein molecules and the subsequent re-formation of intra/inter-molecular bonds; thereby modifying the textural properties, enhancing water binding and the stability of meat gels, maintaining nutritional value [14]. Various applicability of high pressure technology can be summarised as shown in figure 4 [18].

**Figure 4.** Possibilities of high pressure technology for the food industry. Adapted from Nishiumi et al., 2020 [18].

The scientists make further efforts in the direction of the expansion of processed meat products with novel textures to satisfy the nutritional needs of the elderly and specific populations with chewing and swallowing dysfunctions. Various pressurized muscle products for this specific diet have been successfully developed (figure 5). In particular, Tokifuji et al. [19] and Yoshioka et al. [20] produced new products for individuals on a dysphagia diet using ground pork and fish meat with high pressurization at 400 MPa for 20 min. Obtained muscle gels conformed to the criteria of Japanese Dysphagia Diet regulations.
Applications of high pressure technology

| Applications | High pressure conditions | Achievements | Proposed mechanism |
|--------------|--------------------------|--------------|--------------------|
| Development of texture-modified meat products. Minced pork meat gel as a dysphagia diet. Tokifuji et al. (2013) | Ground pork formulated with 1:0.5 or 1:1 (w/w) water, 1.5% salt and 0.05% rosemary followed by high pressure at 400 MPa/20°C/20 min. | Pressurized pork gels with 1:1 (w/w) water were smoother, more elastic, easy-to-swallow, and left little residue in the oropharynx. It could be used as a dysphagia diet. | Under high pressure, the network of myosin filaments gave superior textural and organoleptic properties. |
| Development of texture-modified meat products. Minced fish meat gel as a dysphagia diet. Yoshioka et al. (2016) | Ground fish formulated with 1:0.5 (w/w), 1:1 (w/w) or 1:1.5 (w/w) water and 1.5% salt followed by high pressure at 400 MPa/20°C/20 min. | Fish gels under pressure with water 1:1 or 1:1.5 were rated as moderately elastic, juicier and smoother, useful for the dysphagia diet and for the elderly. | The high pressure-induced fish gel was formed by irregular lateral associations of myosin filaments at a low salt concentration. |
| Development of low salt, and/or low phosphate meat products. Minced beef meat gel. Maksimenko et al. (2019) | Ground beef formulated with 0-2% salt and/or 0-0.5% phosphate followed by high pressure at 0.1-200 MPa/20°C/10 min. | High pressure at 150 MPa can be adapted to reduce salt and phosphate contents in low fat beef gels with acceptable organoleptic and functional properties. | High pressure in combination with low salt content modified protein structure and improved the cohesive and elastic properties of meat gels. |

Figure 5. Application of high pressure technology for the development of texture-modified and sodium-reduced healthy muscle products.

Traditionally, salt (sodium chloride), phosphate (sodium phosphate), and fat are the main components required for the manufacturing of comminuted meat products. They play an important role in affecting such functional characteristics as cooking losses, water holding capacity, and textural properties, as well as sensorial properties of tastes and flavors. However, high sodium intake, 20% of which is attributed to the consumption of processed meat, is associated with high blood pressure and cardiovascular diseases. High phosphate intake has a potential risk, particularly concerning bone metabolism, cardiovascular, and renal functions. High dietary fat induces the risk of obesity and other chronic disorders. Thus, especially when developing healthy meat products for the elderly, low levels of the abovementioned components, together with maintained palatability characteristics, become crucial [14].

In recent studies, high pressure technology has proved to be a useful method to enhance the functional properties of myofibrillar proteins for successful assisting in salt, phosphate, and/or fat reduction in meat products [21-25]. In particular, Maksimenko et al. [23] concluded that the use of high pressure pretreatment at 150-200 MPa in combination with low sodium chloride concentration could reduce the sodium level to 1% whilst retaining the organoleptic and textural characteristics. They suggested that the improvement in texture properties and the preservation of the water-holding capacity in the low sodium chloride and/or sodium phosphate beef samples caused a modification of protein structure - the loss of M-protein and aggregation of α-actinin under high pressure treatment.

As stated by Chen et al., 2017 [14], transformations in structure and functionality of myofibrillar proteins in meat under high pressure treatment are dependent upon the protein systems and such high pressure conditions as time, grade, temperature, and processing flow. An appropriate choice of high pressure parameters can change the quality of meat, the functional characteristics of muscle proteins, and partially compensate for the lower content of food additives, thereby boosting the value of meat products. Due to these mechanisms, high pressure technology allows the creation of innovative products with increased functionality, products with a modified structure for certain population groups, including the elderly and people with specific health needs, products with reduced content of food additives, and clean-label products.
5. Conclusion
Providing a fast-growing population of the elderly with tasty and nutritious foods has been a crucial concern for many countries around the world. Japan, as the most rapidly aging society, has promoted extensive cooperation of the relevant authorities from academia, healthcare practitioners, and the food industry and established significant experience in tackling this issue. “Smile Care Food” - a unique system of regulation, evaluation, and labeling of the elderly and special needs-oriented foods, settled a base for vast market expansion and the creation of multiple commercial products for different healthcare purposes.

The food industry worldwide implements various approaches for developing soft, easily digestible, and tasty foods for the safe and nutritious diet of older people. However, their amount and usability are still behind the ever-increasing demand. The present work has paid attention to one of the promising directions-creation of texture-modified products tailored for people with physiological difficulties, including masticatory and swallowing ones.

High pressure technology as innovatory food preservation and modification technique alternative to thermal treatment, nowadays faces the extensive spread of research and industrial trials on its potential to develop products with reduced food additives and allergenicity, products with improved texture and digestibility. This technology opens opportunities for developing novel products for the elderly and people suffering from dysphagia.

In the Russian Federation, advancements in the area of functional products for the elderly mainly focus on modifying the composition of the product by enriching them with vitamins, micro-macro-elements, and adding the dietary fiber; commercial supply is limited. Given the increase in the aging population, the present paper suggests that researchers and practitioners in the Russian Federation consider and further scrutinize texture-modifying technologies as a tool for the nutrition of older adults having physiological difficulties.

References
[1] World Health Organization. Nutrition for older persons. Ageing and nutrition: a growing global challenge (https://www.who.int/nutrition/topics/ageing/en/)
[2] National Institute of Population and Social Security Research (http://www.ipss.go.jp/)
[3] Population Pyramids of the World (https://www.populationpyramid.net/sources)
[4] Ministry of Agriculture, Forestry and Fisheries, MAFF 2020 Efforts Relating to "Smile Care Food" Retrieved from https://www.maff.go.jp/j/shokusan/seizo/kaigo.html
[5] Amosova N N, Balashova I N, Belkin A A, Zakharov V O, Zueva L N et al. Bulletin of Rehabilitation Medicine 4 99–112
[6] Dzakhmisheva I SH 2013 Merchandizing and examination of the combined goods and functional food (Manual) ed I Sh Dzakhmisheva, Z A Dzakhmisheva, R M Alagirova (Nalchik: Print Center)
[7] Kochetkova A A 2009 Food Industry 3 4–5
[8] Dzakhmisheva Z A and Dzakhmisheva I S 2014 Fundamental Research 9 2048–51
[9] Pushmina I N 2012 Siberian Bulletin Spec. Education 8 27–31
[10] Aguilera J M and Park D J 2016 Trends Food Sci. Technol. 57 156–64
[11] World Gastroenterology Organisation 2014 Retrieved from https://www.worldgastroenterology.org/
[12] International Dysphagia Diet Standardization Initiative 2019 Retrieved from https://iddsi.org/
[13] Simonin H, Duranton F and De Lamballerie M 2012 Compr. Rev. Food Sci. Food Saf. 11 285–306
[14] Chen X, Tume R K, Xiong Y, Xu X, Zhou G, Chen C and Nishiumi T 2017 Crit. Rev. Food Sci. Nutrit. 58 2981–3
[15] Guillou S Lerasle M Simonin H and Federight M 2017 High-pressure processing of meat and meat products Emerging technologies in meat processing: Production, Processing and Technology ed Enda J Cummins and James G Lyng (John Wiley and Sons) chapter 3 pp 37–
[16] Balda F P, Aparicio B V and Samson T C 2012 *J. Food Sci. Engineering* **2** 543–49
[17] Bolumar T, Middendorf D, Toepfl S and Heinz V 2016 Structural changes in foods caused by high-pressure processing *High pressure processing of food* (New York: Springer) pp 509–40
[18] Nishiumi T Maksimenko A, Kikuchi R and Tsutsuura S 2020 *Hydraulics & Pneumatics* **59** 25–30
[19] Tokifuji A, Matsushima Y, Hachisuka K and Yoshioka K 2013 *Meat Sci.* **93** 843–48
[20] Yoshioka K, Yamamoto A, Matsushima Y, Hachisuka K and Ikeuchi Y 2016 *Food Nutr. Sci.* **7** 732–42
[21] Sikes A, Tobin A B and Tume R 2009 *Innov. Food Sci. Emer. Technol.* **10** 405–12
[22] Iwasaki T, Noshiroya K, Saitoh N, Okano K and Yamamoto K 2006 *Food Chem.* **95** 474–83
[23] Maksimenko A, Kikuchi R, Tsutsuura S and Nishiumi T 2019 *High Pressure Res* **39** 385–97
[24] O'Flynn C C, Cruz-Romero M C, Troy D J, Mullen A M and Kerry J P 2014 *Meat Sci.* **96** 1266–74
[25] O'Flynn C C, Cruz-Romero M C, Troy D J, Mullen A M and Kerry J P 2014 *Meat Sci.* **96** 633–9