



Food for the elderly based on sensory perception: A review

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ABSTRACT

Background: The impairments of physiological functions caused by aging are common problems in the elderly, especially the impairments of sensory perception. Besides, close relationship between food sensory perception and nutritional status also suggests the importance of dietary management for the elderly population. The foods taking sensory perception into account are urgently needed by the elderly.

Scope and approach: This review analyzed sensory perception changes and their effects on food behaviors and nutritional status. Besides, sensory properties essential for aged-foods and acquisition methods, as well as current status of such foods were summarized.

Key findings and conclusions: Soft, smooth and moist foods were more suitable for the elderly with chewing and swallowing dysfunction, which can be prepared by gelation, enzyme treatment, blade tenderization and other non-thermal technologies. Flavor enhancement/enrichment, irritant addition and packet sauces were recommended to compensate the impairment of chemical sensory. Molds, piping bag and 3D printing were suggested for refining appearance of pureed foods, and improving appetite of the elderly.

1. Introduction

Currently, many countries are experiencing a shift in the population age distribution from the younger to older age, and population ageing becomes a global phenomenon. According to the World Health Organization (WHO), elderly people are typically defined as those aged 60 or 65 or over. In the latest report *World Population Ageing 2019*, the number of people aged 65 years or over has reached 703 million in 2019 and would be 1.5 billion in 2050 (World Health Organization, 2022). Therefore, it is necessary to take action to promote the healthy aging (Zhang and Zhao, 2021; World Health Organization, 2022).

Nutrition is an important and modifiable factor to promote health and well-being. However, inadequate food intake due to poor oral health, sensory impairment, digestive tract disorders, loss of mobility, and socio-cultural changes, may result in malnutrition (Grassi et al., 2011; Chwang, 2012; Doets and Kremer, 2016; Methacanon et al., 2021). In general, the impaired oral cavity is associated with teeth loss, hyposalivation, as well as chewing and swallowing dysfunction, affecting food perception and swallowing safety (Schwartz et al., 2018). In addition, it was reported that age-related oral cavity and chemical sensory (olfactory and gustatory) impairments led to reduced sensitivity to flavor changes and appetite, and further affected their food intake

(Doets and Kremer, 2016). Therefore, understanding the age-related changes in sensory perception is crucial for aged food design.

Many researches about aged food mainly focus on the personalizing nutrition in the elderly (Chwang, 2012; Baugreet et al., 2017; Arikawa et al., 2020; Rusu et al., 2020), the flavors strategies to increase food intake (Henry et al., 2003; Laureati et al., 2008), food texture properties and texture-modified technologies (Chen and Lolivret, 2011; Eom et al., 2015, 2018; Aguilera and Park, 2016; Cichero, 2016; Chun et al., 2020). However, there is limited comprehensive summary about the sensory properties and acquisition methods of aged food to promote healthy aging. This review aimed to summarize the aged-related changes in sensory perception and discuss their effects on food consuming behavior and nutritional conditions of elderly. Besides, sensory properties essential for aged-foods and acquisition methods, as well as current status of such foods were summarized. Furthermore, perspectives and suggestions for further studies were presented.

2. Bibliometric analysis

We identified all relevant papers by searching Web of Science (WOS) Core Collection. An advanced search was performed on the literature, and the search terms were as follows: (1) TS = ((food OR diet OR meals

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OR eats) AND (the elderly OR older adults OR older people OR senior citizen)); (2) search was set from January 1, 1981 to April 16, 2022, considering the first related paper was published in 1981; (3) document types included article, review, meeting paper, published online and book chapters. (4) categories were set to “Food Science Technology” and language was set to all. Reference lists of retrieved articles were scrutinized to identify additional relevant studies. Consequently, a total of 784 papers were obtained by using COOC6.725 and VOSviewer software.

The research themes of aged food were divided into two categories, i. e. food nutrition and health of the elderly, and sensory perception and food behavior of the elderly (Fig. 1a). As shown in Fig. 1b, more studies mainly focused on the chemosensory changed, food intake/preference and nutrition of elderly before 2016. Since then, numerous studies have turned to the texture properties of aged food, texture assessment and modified technologies, as more attention on oral health including chewing and swallowing dysfunction. Specifically, these literatures came from more than 60 countries, with the United States, Japan, China, Italy, Spain, Netherlands and France being the top countries (Fig. 1c), in addition to top 10 institutions (Fig. 1d). These countries all entered the aging society earlier, and France was the first country in the world to enter an aging society. As shown in Fig. 1e, University of Leeds, Zhejiang Gongshang University, University Bourgogen Franche Comte, Korea Food Research Institute, and INRA mainly focused on studies of food texture, chewing and dysphagia in the elderly. University of Guelph, University of Copenhagen, Wageningen University, University of Helsinki, INRA, and University Bourgogen Franche Comte concentrated on food liking and sensory perception in the elderly. In addition, University of Copenhagen, Instituto de Salud Carlos III and Harokopio University mainly focused on nutrition of the elderly.

3. Sensory perception changes in the elderly

Individual capability in sensory perception of food is directly or indirectly associated with physiological functions, including oral manipulation (chewing and swallowing), chemical sensory (gustation and olfaction) (Fig. 2). Many other factors, including increasing risk of chronic disease, cultural environment, religion beliefs, custom and education, economic condition, as well as external product information, also affected their food consumption (Sydner and Fjellström, 2005; Quevedo-Silva et al., 2018; Chalerm Sri et al., 2020). Since this review emphasized sensory perception related to food of the elderly, those

external factors were not described herein.

3.1. Gustation and olfaction

Chemical senses (gustation and olfaction) play a crucial role in food flavor perception. Gustation enables us to distinguish flavor compounds, such as sour, sweet, salty, bitter and umami (Schwartz et al., 2018). The taste substances from both the original food released after structure broken and new taste substances formed by saliva enzymatic hydrolysis can produce taste by dissolving in saliva and food water into taste bud cells (Liu et al., 2017). However, it was reported that age-related changes evoked a decline in gustatory function, including decreased number of taste buds, papillae or taste-bud density in the epithelium, and worse saliva quantity and quality, as well as decreased ability of chewing, which may limit the entry of taste stimuli into receptors (Shimizu, 1997; Kano et al., 2007; Doets and Kremer, 2016).

Olfaction enables us to perceive aromatic compounds in foods. Two major regions (olfactory epithelium and vomeronasal organ) in nasal cavities are related to odor perception. These tissues contain different types of chemoreceptors, such as odorant receptors, vomeronasal receptors and trace amine associated receptors, that can detect and transmit chemical messages (such as odorants, pheromones and volatile amines) to the olfactory bulb and accessory olfactory bulb of the brain (Connor et al., 2018). Unfortunately, age-related anatomical changes of elderly were reported to induce a decline in olfactory function, especially those who needed special nursing care. These changes included the nasal neuro-epithelium caused by cumulative damage, selective loss of odor by recipient cells, olfactory bulb volume, and the volume and gray matter of brain structure involved in olfactory processing, as well as the transport of neurologic signals caused by neurotransmitter deficiency (Ferdon and Murphy, 2003; Doets and Kremer, 2016).

3.2. Chewing and swallowing

In the mouth, the food is cut by the incisors or the canine teeth, chewed and sheared by the molar teeth, and then hydrated and diluted by the saliva to form a swallow bolus (Salles et al., 2011; Schwartz et al., 2018). However, aging is often accompanied by oral injuries, such as decreased occlusal force (Ohi et al., 2018), teeth loss (Nomura et al., 2020) and reduced salivary secretion (Prakash et al., 2013).

Swallowing is the second major process after the bolus is formed. The bolus is transported to the back of the mouth mainly through the

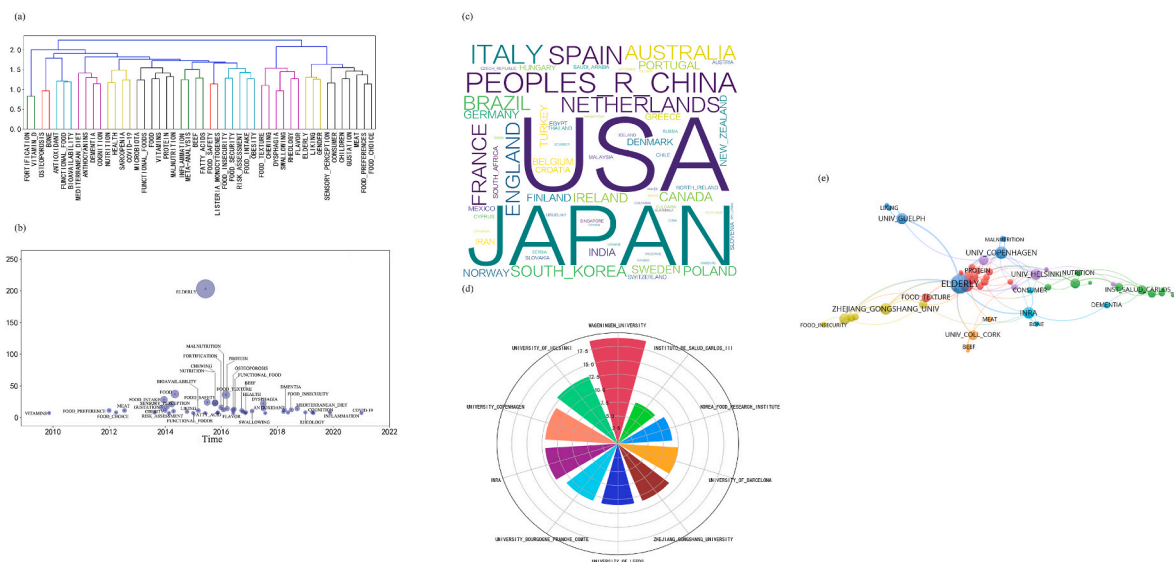


Fig. 1. Bibliometric analysis of aged-food based on sensory perception. a: Keyword clustering analysis using dissimilarity matrix; b: Distribution of topics over the time; c: Visual analysis of author’s countries; d: Visual analysis of top 10 author’s institutions; e: Visual analysis of main research directions of institutions.

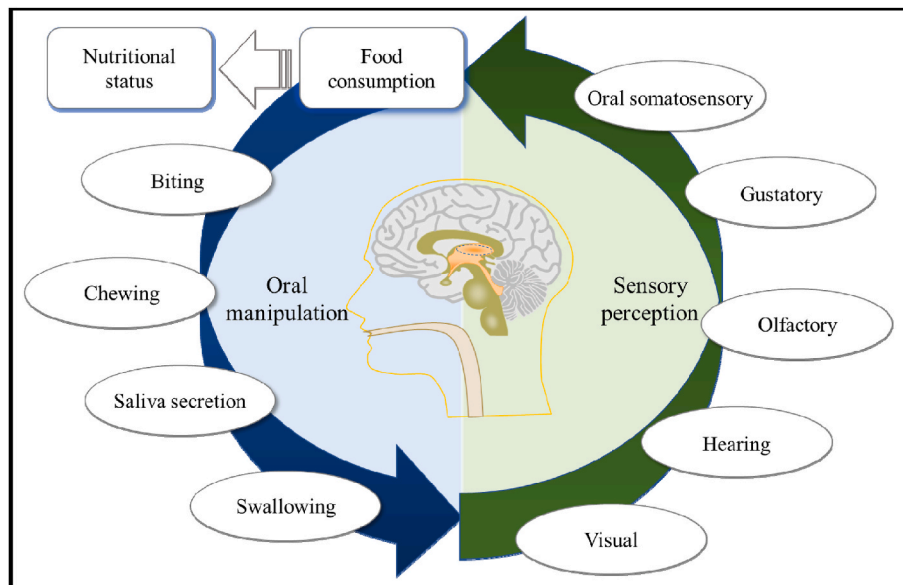


Fig. 2. The relationships among food sensory perception, food consumption, and nutritional status.

pressure formed by the tongue and the oral jaw. During this process, the soft palate blocks the nasal cavity to prevent food reflux, and the epiglottis blocks the larynx to prevent food residue from entering the trachea to cause aspiration pneumonia. The bolus is then transported to the distal esophagus through the pharynx (Chen and Zhihong, 2015; Methacanon et al., 2021). However, reductions in muscle mass and connective tissue elasticity may lead to increased possibility of food crumbs penetrating into the upper airway, resulting in cough or choking (Abu-Ghanem et al., 2020). Besides, the decrease of salivary secretion, chemical sensory impairment, properties of foods/bolus, and other age-related diseases, such as neurologic diseases, esophagus and metabolic deficits, were also proved to be factors worsening the clinically dysphagia (Sura et al., 2012).

3.3. Salivary secretion

Saliva produced by the parotid, submandibular, sublingual salivary and minor glands plays an important role in the oral feeding process (Motsuo, 2000). Firstly, it can regulate oral sensation, dissolve taste compounds and release flavor. Secondly, the enzymes in saliva contribute to the hydrolysis of carbohydrates. Thirdly, it can improve the flow-ability and stretch-ability of food to form safe and comfortable swallowing-bolus. Fourthly, saliva can dilute and clean substances in the oral cavity before swallowing (Chen and Lolivret, 2011; Cichero, 2016; Schwartz et al., 2018). To the elderly, many factors were reported to cause the decrease of saliva, such as tooth loss, drugs and diseases (Nederfors et al., 1997; Eliasson et al., 2006; Meurman et al., 2006; Furuta and Yamashita, 2013), as well as an age-related decrease in acinar cells of salivary parenchyma (Cassolato and Turnbull, 2003).

3.4. Sensory perception differences between elderly and others

Unlike the young populations, older people may experience more frequent health and nutrition problems, mainly due to the impact of impaired sensory perception. It was reported that elderly had an about 4 or 5 times higher threshold values compared with younger adults for basic taste, such as sweeteners, salt, acids and bitter compounds (Baugreet et al., 2017). Older adults had poorer gustation and olfaction abilities compared to the young people, which had a significant effect on food liking. For example, the elderly had a higher interest in taste and flavor fortified foods (Laureati et al., 2008). Besides, the elderly aged above 60 were found to pay more attention to the texture of food and

beverages than the young adults (Forde and Delahunty, 2004).

4. Sensory perception changed food consumption behaviors and nutritional status

The elderly with olfactory dysfunction were reported to need much more time to sniff and taste for completing sensory evaluation and they scored lower on the overall odor intensity of food compared with those with normal olfactory (Flaherty and Lim, 2017; Arikawa et al., 2020). The decreased chemosensory functions were related to the loss of appetite or the tendency to flavor-reinforced food, such as sugar or salt fortified foods (Laureati et al., 2008; Schwartz et al., 2018), as well as lower interest in salt-reduced meatballs (Kremer et al., 2014). However, it was also found that loss of chemical sensory did not necessarily lead to the preference for flavor enhanced foods (Baugreet et al., 2017). Similarly, their responsiveness to the odors varied greatly among the elderly (Flaherty and Lim, 2017; Arikawa et al., 2020).

Poor chewing ability was reported to affect flavor release and perception of food properties, such as tenderness, elasticity and firmness (Vandenberghe-Descamps et al., 2017). People with difficulty in chewing and swallowing food had a reduced appetite, and they were more concerned about food texture. For example, they avoided consuming fibrous, hard, stringy, chewy, dry, or crunchy textured food, since these foods may pose a risk of choking. In addition to the above texture properties, other texture characteristics may also cause a choking in the elderly (Table 1). The fear for dieting, choking and the inadaptability of texture-modified food led to single variety or reduced food intake in the elderly (Namasivayam-MacDonald et al., 2017). Single variety or reduced food intake influenced the process of absorption, transmit and metabolism, and further led to a decrease in body weight and loss of muscle mass, which in turn increased frailty and morbidity (Baugreet et al., 2017). Consequently, it is necessary to consider the expectations of the elderly in terms of food sensory characteristics to promote healthy aging.

5. Food properties essential for aged-food

5.1. Texture

Food texture properties, including hardness, cohesion, adhesion, etc., are crucial factors for safe swallowing. Geometric properties (i.e. food size and shape) are also associated with the risk of choking.

Table 1
Food characteristics associated with choking in adults.

Food characteristics	Food	Reference
Fibrous, hard, firm, stringy, chewy, sticky, dry, crumbly, crunchy, shaped (round or long)	Bread, sandwiches, and toast	Cichero (2015)
Hard or dry; Chewy or sticky	Nuts, apple, seeds Lollies, marshmallow, chewing gum, popcorn, biscuits	Cichero (2018)
Soft slippery dome-shaped, “one bite”	jellies	Walker et al. (2012)
Large piece; Semisolid, adherent, crunchy, and round or long shapes	Meat; Banana, scrambled eggs, apricot, pasta, peanut butter sandwich, bread, potato chips, grape	Wick et al. (2006)
Solids and two or more pieces semisolids	Sausages on a bun, sandwiches, meatballs, meat and vegetables/noodles Puree, ground meat, mashed fruits	Berzlanovich et al. (2005)
High cohesive and adhesive	<i>Mochi</i>	Sanpei et al. (2014)

Considering the hardness of foods increases the number of chews and oral processing duration, soft foods are more popular among the elderly with chewing and swallowing dysfunction. Food cohesiveness refers to the ability to hold food particles together to form a cluster. It was reported that foods with low cohesive force were easier to generate fragments during swallowing and may cause choking. Besides, foods with high cohesiveness were difficult to pass through the pharynx because of high resistance to stretching degeneration, and thus increasing a swallowing risk (Nishinari et al., 2019; Vieira et al., 2020). Food adhesiveness refers to the ability of adhering food particles to oral surfaces. It was reported that older adults had difficulty with pushing the sticky food, such as nut paste, into the back of the mouth smoothly due to the weakened tongue force, resulting in sticking food onto the hard palate or teeth. Once the sticky food has been softened by saliva, they would be uncontrollably released, and thus cause choking (Cichero, 2016). Therefore, smooth foods, instead of sticky foods, are more suitable for the elderly.

Swallowing-behaviors are also affected by food heterogeneity, i.e. irregularities in the matrix. The duration of food in the mouth increased with the heterogeneity increment under a similar maximum force at break (Laguna et al., 2016). The particles for safe-swallow were recommended with average size around 2–4 mm, while large food particles, e.g. bananas, were required to be soft enough before swallowed (Hadde and Chen, 2020). Recently, tribological properties were considered to be used to evaluate the degree of lubrication in dysphagia diet, but the key characteristics suitable for dysphagic individuals were still an unsettled question (Munialo et al., 2020; Vieira et al., 2020; Methacanon et al., 2021). In addition, no quantitative standards of the above physical parameters have been put forward to evaluate texture-modified food.

Texture-modified food refers to foods with soft textures or thickened liquids which are specially targeted at the old people with dysfunctions. Since thickened liquids are not typical food associated with chemical sensory, it will not be discussed in this review. Various technologies have been used to develop texture-modified food for people with dysphagia (Table 2). Among them, gelation and enzyme treatment were widely applied. Specifically, gelation of food refers to the mashed or pureed foods with certain viscosity and cohesion, which is modified by starch-based or hydrocolloid-based thickeners, such as modified starch, xanthan gum, pectin, carboxymethyl, or the mixtures. Starch-based thickeners were reported to be easily hydrolyzed by amylase in the saliva, which would produce residues and further increase the risk of inhalation cough during swallowing. For these reasons, non-starch

hydrocolloid gels have attracted extensive attention due to their better stability (Yang et al., 2021). It was reported that enzyme treatment not only softened plants or meat tissues, but also maintained their shape. Enzymes, such as bromelain and papain, can affect the integrity and fiber structure of meat by degrading the myofibrillar proteins and collagen, thereby reducing mastication efforts. Since the enzymes were difficult to be impregnated inside the foodstuffs deeply using only enzyme treatment, the freeze-thaw enzyme impregnation was proposed (Eom et al., 2015, 2018).

Blade tenderization is currently one of the most effective interventions to ensure tenderness, which means piercing the meat with sharp blade. Besides, it was reported that heating may lead to the hard texture of meat and meat products, since the constriction of collagen and coagulation of myofibrillar protein (Vandenbergh-Descamps et al., 2018). Other non-thermal technologies, such as high-pressure and high hydrodynamic pressure, were applied to modify the texture, sensory characteristics, and extend the shelf life of food materials. Compared to traditional thermal processing methods, these non-thermals had less effect on color, taste and nutritional characteristics. For example, high-pressure processing has been considered to improve the gelation behavior of protein by changing its conformational structure, depending on the applied pressure level. It was reported that the treatment under high pressure (≥ 300 MPa) caused some larger and less homogeneous myofibrillar protein gel cavities. In addition, the protein underwent significant denaturation and destabilization, resulting in lower hardness of meat, which can be used as an alternative method to produce meat-based dysphagia foods. High hydrodynamic pressure processing can tenderize vacuum-package meat by high-pressure shockwave to pass through water, but the brine was required for increasing the meat tenderness. Therefore, the disadvantage in this processing technology may be the possibility of causing high blood pressure or kidney disease due to high salt intake. In addition, pulsed electric field, ultrasound and gamma irradiation were also considered to be promising techniques for meat tenderization, but unfortunately, no related research has been conducted in terms of developing dysphagia food (Sungsinchai et al., 2019).

5.2. Taste and flavor

Strategies have been identified to solve chemosensory impairment in the elderly. One approach was adding natural raw material rich in umami taste or intense flavor, such as tomatoes, sharp-aged cheese, mushrooms, soy sauce and garlic onion. Besides, concentrated jam, seasoning oil/vinegar, or spices with strong flavor, such as basil, leek, garlic and rosemary of sage, also may promote the appetite of elderly (Baugreet et al., 2017). For instance, considering “burning” and “cool” sensation through trigeminal nerve did not change with aging, it was feasible to use spices to improve food perceptions (Pushpass et al., 2019). Intense natural oriental spices, such as shallot, ginger and garlic, increased the average food and energy intake of the elder hospitalized patients by 13–26% (Henry et al., 2003). It was reported that the meals with *Bisto* chicken or onion gravy increased the food preference and improved energy, protein, and fat intake of elder adults (Baugreet et al., 2017). Besides, increasing the intake of sweet and fatty foods balanced the taste loss of elderly, since aroma compounds were dissolved strongly in a fatty environment (Cichero, 2017). Other ways, such as microencapsulation of effervescent powders and tiny high-pressure bubbles of carbon dioxide, were also used to change the flavor of pureed food by promoting activation of the trigeminal pathways (Cichero, 2017).

The heterogeneity of gustation and olfaction impairment in the elderly made the strategy of flavor enhancement and enrichment unable to be applied. Packet sauces may be a good choice, since the elderly can choose their favorite ones and add them as they need (Ribes et al., 2021). For example, the elderly can be served with the options of mayonnaise, ketchup, mustard, or other kinds of sauces.

Table 2
Texture-modified food for the elderly.

Food	Material	Evaluation method	Processing Technology	Reference
Fresh vegetables	Fresh vegetables (Garden pea, carrot and bok choy) Hydrocolloids (xanthan gum, kappa carrageenan, locust bean gum)	Syneresis, rheological characterization, textural properties, scanning electron microscopy, IDDSI test	Gelation	Pant et al. (2021)
Cooked beef pastes	Beef blade roast, hydrocolloids, NaCl	Moisture content, fat content, rheological properties, texture profile analysis, IDDSI testing methods	Gelation	Dick et al. (2021)
Hot pepper paste stir-fried pork and seasoned spinach	Sugar, hot pepper paste, sesame oil, soy sauce, onion, sake and gelatin	Moisture content, texture characteristics, sensory evaluation	Gelation	Kim and Joo (2016)
Barbecue beef	Beef, onion, soy sauce, sugar, sake and gelatin	Moisture content, texture characteristics, sensory evaluation	Gelation	Kim and Joo (2014)
Pan-fried flat fish	Fish, onion, salt, olive oil and gelatin	Moisture content, texture characteristics, sensory evaluation	Gelation	Kim and Joo (2015a)
Stir-fried anchovy	Fish, soy sauce, oligosaccharide, olive oil and gelatin	Moisture content, texture characteristics, sensory evaluation	Gelation	Kim and Joo (2015b)
Dongchimi	Radish, garlic, pear, chili pepper, green onion, salt, gelatin, xanthan gum, carrageenan	pH, acidity, lactic acid bacteria, texture measurement, sensory and preference test	Gelation	Chun et al. (2020)
Nikogori	Head, bone, skin and tail mixed parts of yellowtail and bream, scales of bream, head of salmon, dark-color soy sauce and gelatin	Rheological properties, chemiluminescence procedure, calculation of IC50 value, sensory evaluation	Gelation	Nagatsuka et al. (2007)
Hot thickened soups	Food thickener, clear soups	Rheological measurement	Thickening	Kim et al. (2014)
Burgers	Beef, chicken, papain, microbial transglutaminase	pH value, objective color, water activity, texture profile analysis, shear force, compression test, electrophoretic profile, cooking loss, diameter reduction	Enzyme impregnation	Ribeiro et al. (2021)
Softened edible seaweed kombu	Kombu, protease, sodium phosphate buffer	Sensory evaluation, puncture test, probe tack test, analysis calcium content, light microscopy, scanning electron microscopy	Enzyme impregnation	Kato et al. (2016)
Papain-treated Minced fish	Papain and sea bream meat	Total free amino acid content, toughness, sensory evaluation, nucleic acid-related compounds, histological examination	Enzyme impregnation	Matsuguma et al. (2014)
Beef and chicken	Boneless beef, frozen boneless chicken breasts, Alcalase, Neutrase, Flavourzyme, Protamex, Collupulin, Alphasase NP and Bromelain	Mechanical properties	Enzyme impregnation	Eom et al. (2015)
Softened root vegetable foods	Balloon flower root, burdock root, carrot, lotus root, enzyme composition (Exo-1,4- α -D-glucosidase, Cellulase, Glucoamylase, α -Amylase, α -Amylase, xylanase, β -Glucanase, α -Amylase, Pectin lyase, polygalactoturonase, Endo-1-4- β -xylanase, Pullulanase, Heat-stable α -amylase, A multi-enzyme complex)	Mechanical properties, low-vacuum scanning electron microscopy	Freeze-thaw enzyme impregnation	Eom et al. (2018)
Thawed neritic squid	Neritic squid, papain, bromelain,	Chromaticity testing, pH, total volatile basic nitrogen, light microscopy of squid mantle muscle tissue, SDS-PAGE, texture analysis, sensory evaluation,	Hot-air drying, alkali soaking, vacuum orbital shaker, enzyme-injection, enzyme-soaking, ultrasonic cleaning-enzyme, ultrasonic cleaning-alkali soaking	Grygier et al. (2020)
Meat product meat	Meat, papain Chicken breast, roast beef and beefsteak	Texture, color, cooking loss Oral comfort assessment,	Sous-vide, papain Blade tenderization, marinade and low-temperature cooking	Botinestean et al. (2021) Vandenberghe-Descamps et al. (2018)
Beef semitendinosus	Meats	Meat color, fiber diameter, SEM observation, TAP investigation,	Sonication	Chang et al. (2012)
Minced fish meat gels	Fish, NaCl	Texture properties, protein composition, ultrastructural observation, sensory evaluation	High pressure	Yoshioka et al. (2016)
Tuna Fish	Butternut pumpkin, beetroot, canned tuna	–	Making purees, 3D printing	Kouzani et al. (2017)
High-protein yoghurt-type product	Multiple bioactives-loaded double emulsion, high-protein yoghurt, black pomace extract	Rheological properties, color, vitamins stability, bio-actives release, comfortability	–	Keršienė et al. (2020)
High-moisture content bread	Pregelatinized starch paste, wheat flour, superfine sugar, non-fat dry milk powder, unsalted butter, refined salt, and freeze-dried instant yeast	Sensory evaluation, texture properties, rheological, gelatinization,	–	Sugiura et al. (2017)
Riceberry rice pudding	Rice	IDDSI texture, <i>in vitro</i> digestion, clinical trials,	–	Suttireung et al. (2019)
Pureed cakes	Apple, orange, vanilla, carrot and chocolate	Texture evaluation, sensory quality evaluation	–	Houjaïj et al. (2009)

“–”, Not available in the literature.

5.3. Food appearance

The simplest processing treatment of texture-modified food is mashing, mincing or softening, but the lack of sensory or taste appeal of these foods may result in the rejection and reduction of intake. Most of the participants thought that the appearance of food was the most important sensory indicators for the pureed food (Rusu et al., 2020). To allow people with dysphagia to have partial normal daily routine, it is necessary to provide diet food with nutritional balance, visual appeal and taste. The food can be manufactured by conventional preparation methods, including smashing into purees, mixing with thicken agents, and then being given an attractive appearance (Fig. 3). These purees were shaped mainly by molds or piping bag, but special training was needed for a successful operation. Three-dimensional (3D) printing, firstly used in the food production in 2007, can provide standardized and automatic preparation of the visually appealing pureed food. 3D printing used in the food industry include extrusion or fused deposit modeling (FDM), inkjet printing, binder jetting, selective sintering and bio-printing, among which extrusion 3D printing is the most widely used. Extrusion 3D printing requires materials with high viscosity and self-supporting properties, which can be accomplished by adding the food viscoelasticity modifiers, such as xanthan gum, pectin, agar and kappa carrageenan, into purees (Pereira et al., 2021). It can be used to create complex geometrical structures, but the effect of post-processing on products cannot be ignored, such as deformation of the structures and changes of product characteristics. Some solutions have been figured out to reduce the structural deformations of the printed samples during the post-processing. For example, the addition of hydrocolloid retained the mechanical properties of samples during the baking process (Kim et al., 2018). The alternative post-processing methods, such as microwave vacuum drying and infrared heating, were used to retain and improve the printed characteristics of structure (Yang et al., 2019; Pereira et al., 2021). These studies have provided information for decreasing food structural changes during the post-processing. 3D printing has been employed in food design for people with swallowing disorders, such as cooked beef pastes, fresh vegetables, black fungus and pork (Kouzani et al., 2017; Dick et al., 2020, 2021; Liu et al., 2021; Xing et al., 2021).

6. Current aged food status based on sensory perception

6.1. Elderly food status

Special diets for aged people depend on whether they require texture modified food or not. The elderly consuming regular food may choose cooking by themselves or be provided by care institutions. However, the elderly living independently may prepare their own food or eat with their family members (Rusu et al., 2020). It was reported that many independent aging consumers were attracted by soft and functional food products, such as cholesterol-lowering dairy spreads, calcium-enriched liquid milks and protein shakes. In some countries, meals can be home-delivered by organizations. For example, Meals on Wheels

America operates through a network of more than 5000 community-based programs in virtually every community in America for serving food to seniors to help them live healthier (<https://www.mealsonwheelsamerica.org/>). However, for the older or people needing long-term care, only 50% of them were served by regular diet, 40% served by texture-modified meals and 10% served by special-type diets (Aguilera and Park, 2016).

Although texture-modified foods are a promising opportunity for food companies, such commercial products are not prevalent in the market (Aguilera and Park, 2016; Rusu et al., 2020). Japan was the fastest country to enter the ultra-aging society. It was reported that the total domestic market for nursing, elderly and therapeutic foods accounted for about ¥173.6 billion in the fiscal year of 2019 calculated by the manufacturer's shipment (Data from "Market of foods for long-term care, elderly and treatment 2020" reported by Yano Research Institute). Leading food companies in South Korea have established specialized food brands for the elderly and developed a variety of food, such as nursing food, soft food, etc. These foods were processed based on traditional foods, such as stewed fish, steamed ribs and roast meat, which can be easily chewed, swallowed and digested by the elderly or patients (Shin, 2021). Several America and Germany companies developed separate production lines of texture-modified food for people with chewing and swallowing dysfunction (<https://www.hormelhealthlabs.com/>; <https://smoothfood.de/>), such as Magic Cup® Frozen Desserts, Hormel Vital Cuisine® 500 Shakes, Thick & Easy® Shaped Pureed Frozen Foods, Thick & Easy® Texture Modified Bread & Dessert Mix and so on. They aimed to provide safe, attractive and tasty foods for the people with swallowing difficulties. However, there are still some problems of aging foods in many countries, such as confused classification, single variety and lack of technological content.

In order to guarantee the quality of these special foods, some countries have established several initiatives. For example, in Japan, several initiatives have been issued for guiding the aged-diet, such as Food for Special Dietary Uses of 2009, the Dysphagia Diet 2013, and the "Smile-Care" foods of 2015. "Smile-Care" foods can be divided into three main categories using blue, yellow and red labels, i.e. blue suitable for those need nutritional support to stay healthy but without chewing or swallowing problems, yellow for those with chewing disorder and red for those with swallowing disorder (https://www.maff.go.jp/j/shokusan/s_eizo/kaigo.html). Australia, Ireland, New Zealand, Sweden, UK, USA and Denmark have published descriptors of terminology and definitions for texture-modified foods and liquids (Cichero et al., 2013), but unstandardized terminology among countries may increase the risk associated with cough or choking in the population with dysphagia. International Dysphagia Diet Standardization Initiative (IDDSI), an independent and not-for-profit entity, ultimately established a food framework with eight successive levels for people with dysphagia, including texture-modified foods and thickened liquids (Fig. 4), and also provided details regarding the testing methods (<https://iddsi.org/Testing-Methods>). To deal with the dysphagia problems across the age spectrum, IDDSI suggested the use of regular food plus four to five levels food

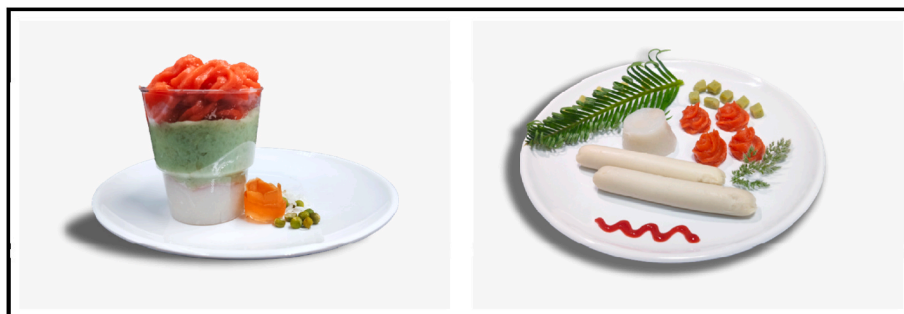


Fig. 3. Visually appealing diet for dysphagia.

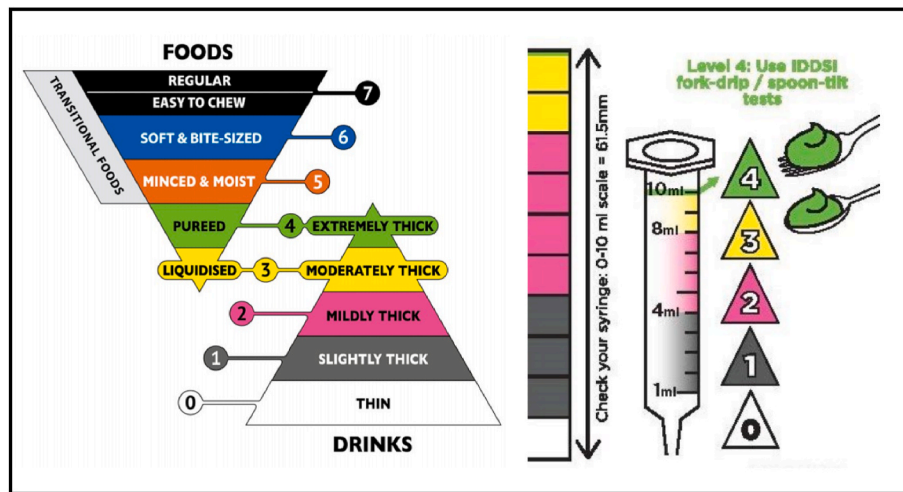


Fig. 4. IDDSI framework for people with dysphagia including texture-modified foods and thickened liquids (<https://iddsi.org/Framework>).

texture modification.

6.2. Elderly food design

More suitable and acceptable foods in terms of appearance, taste, flavor and texture are urgently needed for the elderly. Table 2 lists texture modified foods for the elderly with chewing and swallowing dysfunction. For the texture modification of meat or meat products, non-thermal technologies were used as an alternative to prevent the occurrence of hard meat texture and preserve nutritional characteristics of modified foods. Gelation, enzyme treatment, blade tenderization, or their combinations were also used in the texture modification of meat or meat products (Kim and Joo, 2016; Yoshioka et al., 2016; Sungsinchai et al., 2019; Dick et al., 2020). For the texture modification of rice, non-thermal processing technology has been considered as the most effective method, such as reducing the hardness, decreasing the gumminess and springiness (Sungsinchai et al., 2019). Furthermore, addition of fiber to the rice puddings changed the physical properties, and thus made it suitable for patients with dysphagia (Suttireung et al., 2019). For the texture modification of fruits and vegetables, non-thermal technologies, such as high-pressure processing and ultrasound, as well as gelation and enzyme treatment have been used (Kato et al., 2016; Liu et al., 2021; Pant et al., 2021). More measures and suggestions were listed in Table 3 for developing aged-foods, including sensory properties, food temperature, nutrition, digestibility, bio-accessibility, food type, packages and affordability.

7. Conclusions and future perspectives

At present, the population is aging worldwide. The impairments in chewing/swallowing and chemical sensory are common problems in the elderly, which affect their food consumption. It is urged to provide the elderly with soft, smooth and moisty foods for chewing and swallowing safely and efficiently by gelation, enzyme treatment, blade tenderization and other non-thermal technologies. To compensate for the loss of chemical sensory, flavor enhancement/enrichment and irritant addition were the most commonly adopted strategies. Besides, packet sauces were recommended considering the elderly were different in gustation and olfaction. Molds, piping bag and 3D printing were also suggested for improving the appearance of pureed foods.

There were still some challenges in developing aged-foods in terms of sensory features, including appearance, flavor, taste and texture, as well as other characteristics, such as nutrients, digestibility, convenience and pleasure. Firstly, measurements of texture parameters are required for quality control in the texture-modified food. Although IDDSI has

Table 3

Major factors and the requirement when developing food products for aged people (Eun Lee, 2016; Baugreet et al., 2017; Rusu et al., 2020).

Factors	Measures and suggestions
Texture	provide the elderly with soft, smooth and moist food for chewing and swallowing safely and efficiently by gelation, enzyme treatment, blade tenderization, and other non-thermal technologies
Flavor	flavor enhancement/enrichment and irritant addition strategies; sauce with independent package
Appearance	molds, piping bag, or 3D printing
Eating temperature	stored at temperature above 60 °C or below 5 °C
Nutrition	nutritional optimization (macro- and micronutrients fortification). If conditions permit, precise nutrition can be provided.
Digestibility	improve the digestibility and bio-accessibility of nutrients by change the processing and formulation of foods
Food type	made-on-site, refrigerated, frozen
Packaging	accessible packaging, such as easy-to-open, easy-peel; legibility of labels, such as font and picture size, clearer diagrams, readability for elderly; usability, that is, lighter pack for ease of handling and protect against press; improved opening mechanism, that is, resealable packages or with good grip.
Affordability	self-made, self-processing, centralized cooking, meals on wheels

developed feasible methods, including fork drip test, spoon tilt test and fork pressure test, for examining food size and texture, they are more applicable to frontline production, rather than quality control in laboratories. Secondly, for the elderly with different degrees of oral function impairments, texture parameters range should be clearly divided. Thirdly, *in vitro* dynamic systems to simulate human digestion, particularly elderly oral mastication and digestion, could become increasingly valuable for determining the impact of dysphagia diet made by different thickened or different texture-modified technologies on food digestion. Undoubtedly, the development of aged food is challenging since this requires for multi-disciplinary knowledge, including such as nutrition, food science technology, geriatrics, etc., and a series of standards to escort for aged-food.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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