Review

Texture-modified foods for the elderly: Status, technology and opportunities

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A B S T R A C T

Background: The group of elderly people (e.g., 65 + years old) exhibits the fastest growth rate among all populations segments. By 2050 worldwide there will be more than 400 million individuals aged over 80 years. Providing soft, palatable and healthy texture modified (TM) foods for seniors, particularly those with masticatory/swallowing dysfunctions and/or needing special nutrition, is a major challenge for the food industry.

Scope and approach: This review starts with the most frequent physiological dysfunctions related to the food intake and specific nutritional needs that develop in aging. Bases for formation of soft TM foods, particularly soft gels and microparticles from food biopolymers, are revised. Technological approaches to soften foods, produce small soft particles and microgels, and emerging structuring microtechnologies are presented.

Key findings and conclusions: Feeding the elderly with tasty and nutritious foods is a preoccupation in many countries of the world. TM foods are classified according to their textural and rheological properties from thin liquids to softened foods. Japan and South Korea appear to lead in commercial efforts. In the meantime, scientific knowledge is accumulating on the characteristics of raw materials to be used, mechanisms leading to structure formation and the control of desirable properties, particularly those related to texture. Several opportunities arise for the design of soft and tasty products and carriers to feed the elderly safely and nutritionally.

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1. Introduction

1.1. An ageing population

For first time in history, the fraction of older people is the fastest growing segment of the global population. By 2020 more than 700 million people will be over 65 years of age and by 2045 life expectancy at birth will have risen from the current 70 years–77 years. It is expected that around 2 billion people by 2050 will be aged 60 and over and in many countries (e.g., Japan, Germany and South Korea) ca. 15% of their population will be over 80 years of age (Table 1). These predictions mean that worldwide by 2050 there will be over 400 million individuals older than 80 years (United Nations, 2015). Due to the recent emergence of this phenomenon the requirements for food and nutrition by the elderly, particularly the very old and frail, are demanding urgent attention. This escalating market constitutes a unique opportunity for R&D departments in the food industry (IUFoST, 2014).

The objective of this review is to outline the situation regarding foods for the elderly, in particular, those aimed at people with constrained eating habits or having special nutritional needs. Additionally, the current scientific basis and technological knowledge available for tailor-making soft foods will be described as well as some applications of texture-modified foods for the elderly.

1.2. Main physiological changes affecting food consumption and nutritional needs during senescence

As depicted in Fig. 1, food requirements for elderly people may be divided into those related to the oral experience (e.g., safe eating and sensory enjoyment) and those associated to the physiologic changes of ageing (e.g., changes in body composition and special nutritional needs).
1.2.1. Masticatory and swallowing dysfunctions

Ageing individuals experience increasing difficulties in masticating and swallowing the oral contents due to anatomical and physiological alterations. Dysmasesis, or the difficulty in chewing caused by the loss of teeth (edentulism) is common among older adults, particularly those belonging to low-income groups and women. Around 20–25% of individuals older than 60 years of age in the U.S. and Canada suffer from edentulism (Emami, Freitas de Souza, Kabawat, & Feine, 2013). However, the loss of masticatory ability is only partly responsible for the type of diet and nutrient intake by these group (Tada & Miura, 2014). More relevant is dysphagia or the difficulty associated with swallowing safely the oral contents through the right pipe (Cichero et al., 2013). Dysphagia increases dramatically during senescence and can cause malnutrition and morbidity by aspiration pneumonia (Khan, Carmona, & Traube, 2014; Teramoto et al., 2008). Thus, it is recommended that foods for patients suffering from dysphagia break down into soft and small particles (e.g., <1.5 mm) and that the bolus is moist, cohesive and slippery, hence, easy to swallow (Cichero et al., 2013).

1.2.2. Gradual loss in chemosensory perception and appetite

A large number of elderly people suffer from a progressive loss of taste and smell as well as trigeminal stimuli, which has a detrimental effect on their dietary habits and the enjoyment of meals (Doetz & Kremer, 2016; Lee, Shin, Rhyu, Kim, & Ye, 2013). This is quite unfortunate since flavor is the most important determinant for food purchase in the elderly (Nordin, 2009). Although a deficit of taste rather than of olfaction is more common, in both cases the cause has been attributed to neuroanatomical changes in the respective receptor cells and in the orbitofrontal cortex involved in processing pleasant stimuli. This loss of chemosensory sensations often results in reduced appetite, poor meal appreciation, a decreased food intake (age-related anorexia), loss in body weight, nutritional deficiencies and even the increased risk to ingest spoiled food (Donini & Cannella, 2009; Hummel & Nordin, 2005). Consequently, foods for the elderly should be flavorsome and attractive to consume, and their loss of flavor sensitivity has to be compensated by the addition of extra tastants and odorants.

1.2.3. Loss of muscle and bone mass

Most humans start to lose weight around age 65 mainly due to a progressive decline in skeletal muscle mass which is known as sarcopenia (Buffa, Floris, Putzu, & Marini, 2011). Thus, older adults require a higher daily protein intake (e.g., around 1.0–1.3 g/kg body weight) than younger people mostly because they metabolize protein inefficiently (Bauer et al., 2013; Breen & Phillips, 2011; Morais, Chevalier, & Gougeon, 2006). Experiments with seniors have demonstrated that hydrolyzed protein supplements (e.g., casein and whey protein hydrolyzates) are better assimilated than their natural counterparts and lessen age-related losses of muscle mass (Pennings et al., 2012; 2011). Osteoporosis is a skeletal disorder prevalent during senescence and characterized by a loss of bone mass and bone strength leading to an increased risk of...

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**Table 1**

<table>
<thead>
<tr>
<th>Country</th>
<th>2015 60+</th>
<th>2015 80+</th>
<th>2050 60+</th>
<th>2050 80+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>20.4</td>
<td>3.9</td>
<td>28.3</td>
<td>8.3</td>
</tr>
<tr>
<td>Austria</td>
<td>24.2</td>
<td>5.1</td>
<td>37.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Canada</td>
<td>22.3</td>
<td>4.2</td>
<td>32.4</td>
<td>10.6</td>
</tr>
<tr>
<td>Chile</td>
<td>15.7</td>
<td>2.7</td>
<td>32.9</td>
<td>10.3</td>
</tr>
<tr>
<td>China</td>
<td>15.2</td>
<td>1.6</td>
<td>36.5</td>
<td>8.9</td>
</tr>
<tr>
<td>France</td>
<td>25.2</td>
<td>6.1</td>
<td>31.8</td>
<td>11.1</td>
</tr>
<tr>
<td>Germany</td>
<td>27.6</td>
<td>5.7</td>
<td>39.3</td>
<td>14.4</td>
</tr>
<tr>
<td>Japan</td>
<td>33.1</td>
<td>7.8</td>
<td>42.5</td>
<td>15.1</td>
</tr>
<tr>
<td>Mexico</td>
<td>9.6</td>
<td>1.5</td>
<td>24.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Netherland</td>
<td>24.5</td>
<td>4.4</td>
<td>33.2</td>
<td>11.8</td>
</tr>
<tr>
<td>South Korea</td>
<td>18.5</td>
<td>2.8</td>
<td>41.5</td>
<td>15.9</td>
</tr>
<tr>
<td>United States</td>
<td>20.7</td>
<td>3.8</td>
<td>37.9</td>
<td>8.3</td>
</tr>
<tr>
<td>World</td>
<td>12.3</td>
<td>1.7</td>
<td>21.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>


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**Fig. 1.** Main aspects to be considered in the design of healthy foods for the elderly.
fracture (Cederholm, 2009). Older women are more exposed to fractures because their bone loss accelerates after menopause, hence, they suffer around 80% of hip fractures (Liberman & Cheung, 2015). A poor diet (e.g., one with a low intake of protein, vitamin D and calcium) and a sedentary life are closely associated with sarcopenia and osteoporosis.

1.2.4. Other specific nutritional needs

Other nutritional needs develop with aging as some physiological functions start to deteriorate. As mentioned, older people are particularly exposed to nutritional deficiencies due to a reduced appetite and a decrease in food intake, so specific recommendations have been proposed for this age group (Lungdren, 2012; WHO, 2002). Energy requirements decrease with age and are different for males and females, e.g., estimated average calorie intake for adults aged 85 are 1580 and 1412 calories per day, respectively. As a consequence of masticatory and swallowing problems ageing people tend to eat foods that contain a lower content of dietary fiber precluding its modulatory effect on the bowel function and making constipation a common disorder (Chen & Huang, 2003; Donini, Savina, & Cannella, 2009). Thus, soft fiber-rich foods or fiber-added supplements have been recommended for elderly patients with constipation (Gallegos-Orozco, Foxx-Orenstein, Sterler, & Stoa, 2012). Total plasma and LDL cholesterol are known to increase with age and constitute risk factors associated with cardiovascular diseases (Liu & Li, 2015). Many old adults suffer from dementia and Alzheimer disease but there is not enough scientific evidence that ingestion of omega-3 fatty acids improve the cognitive function (Ubeda, Achón, & Varela-Moreiras, 2012). Similarly, it appears that there is no need of micronutrient supplements (i.e., vitamins and trace minerals) in healthy old people if they consume adequate amounts of a well-balanced diet, most of which already contain fortified foods (McCormick, 2012). Nevertheless, the issue of recommended daily nutrient allowances during later life is under constant revision (WHO, 2002).

In conclusion, physiological dysfunctions and specific nutritional needs developed during aging require a sourcing of special foods which have to be soft, easily and safely swallowed, nutritious and tasty (Fig. 1). These unique requirements should serve as targets for designed food products aiming at this market segment.

2. Special foods for the elderly: texture-modified foods

2.1. Classification of TM foods

As noted, physiological changes and special nutritional demands occurring during ageing have important implications in the amount and types of foods for older consumers. Texture-modified foods (TM foods) is a term that refers to foods with soft textures and/or reduced particle size as well as thickened liquids (drinks) aimed at the market segment of seniors with eating dysfunctions (Cichero, 2015). Food textures recommended for the elderly should be soft and moist; sticky and adhesive textures should be avoided as well as fibrous structures that are not easily disintegrated (Cichero, 2016). Foods with soft textures are preferred because they are disintegrated and mixed in the mouth by a tongue-palate compression avoiding teeth mastication (Ishihara et al., 2013). TM foods include foods which are softened by processing, minced, pureed or liquidized as well as liquids that have been thickened to various extents (IDDSI, 2016), as discussed later in section 4. For patients with dysphagia TM foods are classified into several categories such as the standardization by the Japanese Society of Dysphagia Rehabilitation, the International Dysphagia Diet Standardization Initiative (IDDSI) and the guide developed by Swedish researchers (Rothenberg & Wendin, 2015; Wendin et al., 2010), while other categories are usually generated by hospitals. Fig. 2 (based on the classification by IDDSI) presents a grouping of TM foods varying in viscosity and/or texture from thin liquids to soft conventional foods and those which have been softened by chemical or physical means. Main textural parameters determined in TM foods are hardness (hard to soft), adhesiveness (i.e., tendency of particles to adhere at their surfaces) and cohesiveness (ability to form a swallow-safe bolus in the mouth).

2.2. Current market situation and opportunities

Special diets for older age consumers depend on whether they can shop and prepare their meals, have to remain at home or must stay in a care institution or hospital. Those with independent mobility and minimal needs may prepare their own food or purchase pre-packed special whole meals at some retail stores. Interestingly, many autonomous aging consumers are attracted by soft and functional commercial food products based on their claimed health benefits such as cholesterol-lowering dairy spreads, calcium-enriched liquid milks, energy drinks, yogurts and protein shakes. In some countries meals are home-delivered by organizations such as the Meals on Wheels program (www.mealsonwheelsamerica.org). The situation changes if consumers are very old and remain in a long-term care facility or hospital; then, typically only 50% of meals are regular meals while 40% are texture-modified diets and the rest are special-type diets (IUFOST, 2014).

Although TM foods are an opportunity for food companies as a wealth of scientific and technological knowledge is available to tailor-make products with soft textures, products for this market segment have been slow to emerge (Costa & Jørgen, 2010; Scott-Thomas, 2012). This has not been the case in Japan where the variety and supply of foods targeted at elderly consumers (some 30 million by 2012) is expanding steadily. The market value of the “senior-friendly” food industry in 2010 (year of last data available) was around US$ 4 million and growing at 11% per year in South Korea (KHIDL, 2013). Guidelines for TM foods in Japan have been issued through several initiatives: Food for Special Dietary Uses (FOSDU of 2009), the Dysphagia Diet 2013, and recently, the “Smile-Care” foods (Higashiguchi, 2015). Several companies have a special product line for individuals with swallowing disorders consisting of purées and thickened beverages (www.hormelhealthlabs.com). Since 2006 there is a policy in South Korea regarding “senior-
friendly" foods in anticipation to a super-aged society (i.e., the 20% + people aged 65 and over) to be reached in 2026 (Kim, 2015). Other countries and regions of the world are implementing similar directives regarding special foods for medical, senior, health and wellness care.

3. Scientific bases for designing soft structures as TM foods

The emerging market for TM foods offers the opportunity for designing special soft structures which satisfy the requirements posed in Fig. 1, an approach currently underway in Japan and South Korea (Kim & Joo, 2015; Kim, Chun, Lee, & Park, 2015). Proteins, carbohydrates and lipids are the basic building-blocks for the design of most TM foods as presented in Fig. 3 (Aguilera, 2006). Fig. 3 shows the approximate dimensions of some important molecular components, structural elements and food matrices which already constitute some of these soft products (i.e., jellies, mousses, sauces, creams and thick beverages) or may be used in the design of novel particulate foods (Lesmes & McClements, 2009).

Globular proteins unfold and denature when heated, increasing the viscosity of liquids (e.g., in protein drinks). On further heating they may self-assemble into nano-sized aggregates and fibrils, eventually becoming the network chains of gels (Chen, Remondetto, & Subirade, 2006). Proteins are not only valued for these structural roles but also for some essential amino acids (e.g., leucine) whose high content in hydrolyzates appear to favor muscle protein synthesis during aging (Katsanos, Kobayashi, Sheffield-Moore, Aarsland, & Wolfe, 2006).

Polysaccharides are used to thicken aqueous food dispersions, stabilize emulsions and foams, and as gelling agents (Funami, Ishihara, Nakama, Kohyama, & Nishinari, 2012). An excellent review on the rheological properties of polysaccharide solutions and gels as related to taste and swallowing of TM foods is presented by Nishinari et al. (2016). Dextrins deliver viscous clear solutions and together with gums and starches are often used as thickening agents and encapsulating matrices for nutrients, antioxidants, colorants, enzymes and flavors (Ray, Raychaudhuri, & Chakraborty, 2016). Dietary fibre which may relieve constipation can be added directly to foods, as cellulose derivatives (e.g., microcrystalline cellulose) or resistant starch (Elleuch et al., 2011). Starch while widely utilized to thicken liquids have been under-exploited as texture-modifiers in gels and pastes used as TM foods (Chung, Degner, & McClements, 2013). Since starch granules imbibe large amounts of water during gelatinization they may be pre-loaded with water-soluble micronutrients and bioactives during this process (Zhang, Cai, Shan, Zhang, & Dong, 2014). Moreover, starch may be partly gelatinized so they elicit different glycemic responses (Parada & Aguilera, 2011).

Monoglycerides and phospholipids may be used as emulsifiers in interfaces due to their amphiphilic nature or self-associated into a multitude of nanosized structures (e.g., micelles and vesicles) as delivery vehicles for nutrients and bioactives. Triacylglycerol molecules (triglycerides) crystallize from the molten state and cluster together into aggregates, eventually developing a fat network that occludes portions of liquid fat resulting in a plastic matrix (Marangoni & Wesdorp, 2012). Food nano- and microemulsions may be used to encapsulate and deliver hydrophobic components such as flavors, vitamins, and nutraceuticals, a subject recently reviewed by McClements (2015). Oleogels, formed by a liquid lipid phase trapped within a stable gel network, are finding applications in drug delivery, as carriers of unsaturated fats and to enhance the texture of foods (Marangoni, 2012).

4. Technological alternatives for the design of TM foods

Technological alternatives to engineer soft TM foods for special purposes can be divided into three groups; i) conventional processes that cause softening of traditional meals (e.g., meats, fruits and vegetables), largely for easy chewing and oral manipulation; ii) techniques to produce biopolymer particles and microgels, mostly used to modify the rheology of liquids for a safe swallowing or as carriers; iii) new emerging structuring technologies.

Table 2 presents technologies for TM foods which retain the overall appearance and flavor of whole pieces while softening their

![Fig. 3. Some molecules and structural elements relevant in the design of soft texture-modified foods for the elderly (approximate scales).](image-url)
structure (i.e., they breakdown easily in the mouth). This approach is highly appealing and sought after since processed foods look and taste familiar. The texture-s部分ing effect may be achieved by several known technologies, among them: freeze-thawing (with or without enzyme infusion), enzyme impregnation, high-pressure processing, use of pulsed electric fields and sonication. Proper control of process variables allow preserving the color and flavor of food products while tuning their soft texture to different extents. Most applications of these technologies in TM foods are actively pursued in Japan and in South Korea (Kim et al., 2015).

There are several technologies leading to small particles which may find applications in TM foods (Table 3). Aggregation and microparticulation of proteins have been known to the food industry for a long time and products used as fat replacers and thickening agents for drinks and semi-solid foods (Singer & Dunn, 1990). Technologies are mainly based on the ability of globular proteins in solution to undergo denaturation and aggregation yielding different morphologies (e.g., spherical particles, flexible strands and fibrils) with main dimensions varying from around 10 nm to a few microns (Nicolai & Durand, 2013).

Another group of technologies is aimed at forming soft particles and fibers from biopolymer solutions. Microgels are soft, stable and small particles (e.g., sizes from < 1 μm to 100 μm) whose structure can be tuned within a wide range of sizes, shapes and textural properties (Nicolai, 2016). Formation of microgels is usually performed by direct gelling into a particle or fiber shape sometimes under shear, or by size reduction of a bulk gel using mechanical means. In contrast to a bulk gel with a predominant viscoelastic behavior, a suspension of microgels is usually free-flowing (Dickinson, 2015). The formation, structure and properties of gel microparticles has been reviewed by Stokes (2012) and some fabrication technologies are described in Table 3.

Besides their role as texture modifiers microgels have also been suggested as delivery vehicles for nonpolar compounds such as

### Table 2

Conventional technologies used to soften traditional foods and meals.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Foods</th>
<th>Principle/claims</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enzymatic treatments</td>
<td>Beef, chicken (eventually other foods)</td>
<td>Impregnation of foods with enzymes which breakdown cell wall components and/or structural tissues leading to bland textures</td>
<td>Eom, Lee, Chun, Kim, and Park (2015); Betoret, Betoret, Rocculi, and Dalla Rosa (2015)</td>
</tr>
<tr>
<td>Freeze-thawing infusion</td>
<td>Bamboo shoots, roots, fish, mushrooms, etc.</td>
<td>Impregnation of substances (e.g., enzymes) into foods combined with slow freezing and vacuum. Softens the food while keeping flavors.</td>
<td>Nakatsu et al. (2014, 2012); Shibata et al. (2010); Sakamoto, Shibata, Ishihara, and Nakatsu (2008)</td>
</tr>
<tr>
<td>High-pressure processing</td>
<td>Several foods (meat, fruits, salads, ready-meals, etc.)</td>
<td>High pressures soften cellular foods but retain flavors and nutrients, and may improve bioavailability of bioactive compounds</td>
<td>Barba, Terfe, Buckow, Knorr, and Orlien (2015); Zuckerman, Bower, Eastridge, and Solomon (2013); Pandirangi and Balasubramaniam (2005)</td>
</tr>
<tr>
<td>Pulsed electric fields</td>
<td>Several cellular foods</td>
<td>Tissue softening in fruits and vegetables is induced by cell membrane electroporation</td>
<td>Puértolas, Luengo, Alvarez, and Raso (2012); Toepfl, Heinz, and Knorr (2006)</td>
</tr>
<tr>
<td>Sonication</td>
<td>Meats (possibly other foods)</td>
<td>Loosening of collagen fiber arrangement and decrease in textural properties of meat caused by cavitation and shear</td>
<td>Chang, Xu, Zhou, Li, and Huang (2012); McClements (1995)</td>
</tr>
</tbody>
</table>

### Table 3

Some technologies proposed to make protein aggregates and microgel particles.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Materials</th>
<th>Principle/claims</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating/aggregation</td>
<td>Globular protein solutions</td>
<td>Heat induced aggregation (T &gt; 60 °C) form spherical particles (50 nm to few microns) or fibrils (ca. 10 nm diam.)</td>
<td>Abbasi, Emam-Djomeh, Mousavi, and Davoodi (2014); Nicolai and Durand (2013); Zhang, Arrighi, Campbell, Longchamp, and Euston (2016)</td>
</tr>
<tr>
<td>Microparticulation</td>
<td>Globular protein or mixed biopolymer solutions</td>
<td>Solutions are heated, often under shear. Spherical particles form with sizes down to 100 nm</td>
<td>Singer and Dunn (1990); Westerik, Scholten, and Corredig (2015)</td>
</tr>
<tr>
<td>Coacervation</td>
<td>Biopolymer mixed solutions (e.g., protein-polysaccharide)</td>
<td>Composite particles in the nanosize range (e.g., 155–320 nm) with various surface and core properties have been produced from coacervates</td>
<td>Joyce and McClements (2014); Saglam, Venema, van der Linden, and de Vries (2014)</td>
</tr>
<tr>
<td>Homogenization of bulk gels</td>
<td>Protein and/or polysaccharide gels (or mixtures)</td>
<td>Grinding of bulk gels with mechanical devices (e.g., Ultra-Turrax). Gel particles (&quot;broken gel&quot;) may range from 20 to 200 μm</td>
<td>Leon, Medina, Park, and Aguilera (2016); Shimojo, Pires, de la Torre, and Santana (2013); Jimenez-Colmenero et al. (2012); Capela, Hay, and Shuh (2007); Egan et al. (2013; 2014); Wichchukit, Oztop, McCarthy, and McCarthy (2013); Burey et al. (2008)</td>
</tr>
<tr>
<td>Droplet gelation</td>
<td>Usually alginate but also whey protein solutions</td>
<td>Solutions are usually delivered as droplets into a Ca++ coagulating bath (sizes from 100 μm up to a few mm)</td>
<td>Ray et al. (2016); Zhang et al. (2015); Shewan and Stokes (2013)</td>
</tr>
<tr>
<td>Encapsulation</td>
<td>Polysaccharides (starch, dextrans) lipids and proteins</td>
<td>Hydrogel or dry microcapsules used to protect sensitive and volatile food components</td>
<td></td>
</tr>
<tr>
<td>Shearing</td>
<td>Whey protein isolate, hydrocolloids</td>
<td>Shearing is applied during thermal gelation leading to &quot;fluid&quot; gels</td>
<td>Moakes, Sullo, and Norton (2014); Gabriele, Spyropoulos, and Norton (2009)</td>
</tr>
<tr>
<td>Emulsification- gelation</td>
<td>Protein-based O/W emulsions</td>
<td>Lipid droplets trapped inside a protein gel matrix in the form of microspheres. Impingement of a spray produced by a high-pressure nozzle with a fog of a coagulating phase</td>
<td>Zhang et al. (2015); Dickinson (2012)</td>
</tr>
<tr>
<td>Pressure-spraying</td>
<td>Usually alginate and WPI solutions</td>
<td></td>
<td>Ching, Bansal, and Bhandari (2015); Sohail, Bhandari, Turner, &amp; Coombes, 2012</td>
</tr>
</tbody>
</table>
antimicrobials, antioxidants, vitamins and flavors which can be dispersed in the aqueous phase inside tiny micelles or into more functional liposomes (20 nm – few hundred μm) (Zhang, Zhang, Tong, Decker, & McClements, 2015). Hydrocolloid gel particles of micron sizes and high water contents (e.g., >95%) are particularly attractive due to their soft texture and flowability, and are finding uses as structuring agents, to strengthen dispersed phases and as thickeners in soups and sauces. These hydrocolloid microparticles are usually formed by gelation of preformed droplets or gelling under shear (Burey, Bhandari, Howes, & Gidley, 2008).

Table 4 lists some emerging microtechnologies which may lead to innovative applications in the design and fabrication of TM foods. Microfluidic devices process small amounts of fluids in channels with cross sections of a few hundred microns. Systems have been develop to generate emulsions and foams with a monodispersed discontinuous phase and gel microspheres of uniform sizes and various shapes (Skurtys & Aguilera, 2008). 3D printing refers to rapid prototyping techniques based on digitally-controlled depositing of materials and stacking layer-by-layer. Complex food structures based on liquid deposition or powder binding may be obtained from “printable” mixtures of carbohydrates, proteins and lipids. Electrospinning uses a high voltage electric field to produce electrically charged jets of a biopolymer solution which become nanofibers upon evaporation of the solvent. Electrospun protein fibers (e.g., <1 μm in diameter) are finding applications in the encapsulation of probiotics and bioactives, as dietary supplements and to impart texture and mouthfeel to foods. Another electrohydrodynamic fabrication method is electrospraying whereby almost spherical droplets are formed from a jet flowing out from a nozzle and subjected to an external electrical field which upon solvent evaporation yields nano- or microparticles.

5. Soft gel microparticles as texture modifiers and effective carriers

As previously mentioned, thickeners play an important role in TM foods by slowing down the flow of liquids during swallowing and avoiding their aspiration through the airway (Cichero et al., 2013). Starches and gums are presently the preferred commercial options, thus, there is a challenge for increasing the availability of thickeners to be used in TM foods and widening their properties (Zargaraan, Rastmanesh, Fadavi, Zayeri, & Mohammadifar, 2013).

Due to their small and tuneable size, soft texture and freeflowing state, gel microparticles are excellent alternatives to tailor

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Emerging microtechnologies that may be used in the manufacture of texture-modified foods.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Principle</td>
</tr>
<tr>
<td>Microfluidics</td>
<td>Small monodisperse droplets (ca. 100 μm) of biopolymer solutions or oil become trapped as hydrogels or emulsion gels.</td>
</tr>
<tr>
<td>3D printing</td>
<td>Rapid prototyping technique based on digitally-controlled depositing of materials layer-by-layer.</td>
</tr>
<tr>
<td>Electrospinning</td>
<td>Technique which allows the production of very thin fibers by placing a high voltage over a polymer solution being spun.</td>
</tr>
<tr>
<td>Electrospraying</td>
<td>Solution is sprayed into an electric field which breaks up the jet into fine droplets leading to nano- and micro-capsules</td>
</tr>
</tbody>
</table>

Fig. 4. Microgels are soft structures which may be used in texture-modified foods and incorporated in a variety of products.
the rheological properties of foods (Stokes, Boehma, & Baierc, 2015). They may be mixed into thin liquids or added to purees to modify their flow behavior and texture perception. If loaded with flavors and provided with a weak and fragile texture they will elicit stronger aroma intensities during breakdown in the mouth (Kalviainen, Roininen, & Tuorila, 2007). The most innovative use of soft gel particles came with the artificial caviars introduced by molecular cuisine. Small spheres with a tough outer layer and a soft center where produced by dipping droplets of flavored and colored alginate solutions into a calcium bath (Barham et al., 2010). Today, “artificial caviars” are a standard components in dishes, drinks, desserts, etc., served in modernist restaurants (Vega & Castells, 2012). In fact, the use of small “gelatinous” beads and other light creations of molecular cooking (i.e., foams or “airs”) have been proposed as an inspiration to create attractive TM foods for the elderly (Kim & Joo, 2015).

The abundant literature on gel microparticles emerging in recent years basically endorses their use as encapsulating agents and delivery systems rather than their application in modifying texture or fulfilling major nutritional roles (Joye & McClements, 2014; Oh, Lee, & Park, 2009). For example, texture control of matrices can be achieved by the addition of protein microparticles (Punwanti, Peters, & Van der Goot, 2012) and elderly people are willing to try protein-enriched foods should the texture increase their protein intake (van der Zanden, van Kleef, & de Wijk, 2015). Alternatively, softness and calorie density may be tuned by adding a dispersed gas phase in the form of bubbles (Zuniga & Aguilera, 2008) with the added beneficial effect that the perceived intensity of tastants in the gel phase is increased (Goh, Leroux, Groeneschild, & Busch, 2010). Moreover, gelled microparticles may be loaded with insoluble fiber to increase faecal bulk and prevent constipation while partly masking the rough texture and insipid flavor of fiber (Debusca, Tahergorabi, Beamer, Partington, & Jaczynski, 2014; Elleuch et al., 2011). Last but not least, several food products are emulsion gels where lipids droplets are encased inside a soft biopolymer matrix (e.g., yogurt, frankfurters, sauces, etc.). Emulsion gelled microparticles are small biphasic structures where the presence of a lipid phase presents many opportunities (Dickinson, 2012), Egan, Jacquier, Rosenberg, and Rosenberg (2013) have proposed the addition of WPI-based gelled microparticles loaded with lipids to soups and food bars and other food systems. These microparticles may be used also as delivery systems for lipophilic bioactive ingredients (carotenoids, ω-3 fatty acids, phytosterols, etc.) and fat-soluble tastants and aromas (Lesmes & McClements, 2009). In the interface with pharma, WPI microgels were shown to lower the plasma insulin peak and delay the postprandial amino acid profile when compared to the protein powder (Pouteau et al., 2012). Fig. 4 summarizes some of the formats that soft gel microparticles may attain when used in TM foods and some of the possible applications.

6. Conclusions and future trends

As a consequence of the continuous worldwide increase in life expectancy a huge market of 400 million elderly over 80 years of age is expected by 2050. Older individuals needing special foods due to physiological dysfunctions (e.g., dysphagia, constipation, etc.) and/or specific nutritional requirements (e.g., protein, calcium, essential fatty acids, etc.) will benefit from texture-modified foods which are soft, palatable and nutritious. In the meantime, scientific knowledge is accumulating on the characteristics of raw materials to be used, mechanisms leading to structure formation and the control of desirable properties, particularly those related to texture. Several opportunities arise for designed soft and tasty products and carriers to feed the elderly safely and nutritionally.

Conflicts of interest

The authors declare that they have no conflict of interest.

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