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Changes in orosensory perception related to aging and strategies for counteracting its influence on food preferences among older adults

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ABSTRACT

Background: The aging of the world population is accelerating. To meet the food and nutritional needs of the expanding aging population, it is necessary for both food researchers and food industry to obtain a good understanding of how aging affects orosensory perceptions. There is a need for potential strategies to counteract these adverse effects on food preferences in order to maintain food appetite in old age.
Scope and approach: This review paper has two main objectives: 1) to review evidence and causes of orosensory changes with aging and to indicate influences of age-related orosensory changes on elderly's food preferences; 2) to summarize the effects of compensatory strategies (e.g., flavor and texture modifications) for counteracting age-related orosensory changes and suggest potential compensatory strategies for further investigations, which have great potential to contribute to the food appreciation among specific elderly segments with greater orosensory impairment and higher needs for sensory modified foods.
Key findings and conclusions: Research indicates that the interindividual variability in orosensation impairment among the elderly population is not only increased with age, but also related to events (e.g. increased dependence) that are associated with aging. Generally, flavor and texture modifications are the most important strategies in compensation of losses in masticatory and chemosensory ability thus enhancing the appreciation of foods and stimulating food intake, especially among the less dependent elderly with poorer health. In future studies, food researchers and food industry should consider targeting these specific subgroups of elderly while exploring a well-balanced multisensory compensatory framework for specific food systems.

1. Introduction

The population of industrialized countries is currently aging and will continue to do so in the decades to come (Koehler & Leonhaeuser, 2008). The percent of senior citizens aged above 65 is increasing significantly in European countries (WHO, 2015), and it is predicted that the future population aged 80 and above will be even larger as more individuals are expected to live to higher ages (Koehler & Leonhaeuser, 2008). These demographic changes presents challenges to social and public policies (Koehler & Leonhaeuser, 2008; Walker & Maltby, 2012), as public expenditures for health care, food supply systems, and welfare services for older adults will rapidly increase (Giacalone et al., 2016).

Malnourishment of the elderly is one of the significant problems in this segment of the population (WHO, 2015). Changes in orosensory function can lead to poor appetite, which can contribute to the nutritional deficiency in older adults (Brownie, 2006). Increasing the elderly's food appetite, which may increase their food intake generally, is a key factor to achieve the prevention of malnourishment among the older adults (Brownie, 2006; Mathey, Siebelink, De Graaf, & Van Staveren, 2001). Levering food appeal is an important direction for people working within food innovations and food catering for the elderly. Thus, it is critical for product developers and food providers, especially those who are interested in promoting healthy aging through food consumption,

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to have sufficient knowledge on how aging affects orosensory perception and food preferences. Such knowledge would support further development of compensatory strategies for elderly with orosensory impairment (Mathey et al., 2001; Popper & Kroll, 2003).

Situated within this context, this paper has two main objectives: 1) to review evidence and causes of orosensory changes with aging and to indicate influences of age-related orosensory changes on elderly's food preferences; 2) to summarize the effects of commonly-used compensatory strategies (e.g., flavor and texture modifications) for counteracting age-related orosensory changes, suggest potential compensatory strategies deserve further investigations, which can contribute to the food appreciation among specific elderly segments with greater orosensory impairment and higher needs for sensory modified foods.

This review focuses on the chemical senses, which include gustation, olfaction and also oral somatosensory perception, as these are considered as most important in the food experience. Changes in vision and audition, albeit also relevant, will therefore not be discussed in depth in this review.

Recently, orosensory perception and food liking of older adults or practical sensory methods using the elderly are of great interest in related research areas, which can be seen from two recent review articles of high-quality about related topics (Doets & Kremer, 2016; Methven, Jiménez-Pranteda, & Lawlor, 2016).

Different from the scope of the above reviews, this article is more focusing on giving a concise overview of potential compensatory strategies which may counteract age-related orosensory changes and contribute to the food appreciation among specific elderly segments, which will be helpful for food product developers and providers.

2. Influences of aging on orosensory perception

Generally speaking, the aging process of the human being is associated to a decline in orosensory functions, which can be a consequence of e.g. senescence of the sensory receptors systems and reductions of their neural systemic efficiency (Imoscopi, Inelmen, Sergi, Miotto, & Manzato, 2012; Kremer, Mojet, & Kroeze, 2005; Tepper & Genillard-Stoerr, 1991). The orosensitivity usually decrease gradually with aging and some of the older people with orosensory loss are not aware of the occurrence (Nordin, Monsch, & Murphy, 1995). The independent influence of aging on orosensory perception has been widely demonstrated in the food science literature, yet reported effects are highly variable in their magnitudes among individuals and across different stimuli in various food or drink media (Kremer et al., 2005; Mattes, 2002; Murphy, 1993). The following sections will review existing evidence and major causes of perceptual changes across the orosensory senses – taste, smell, trigeminality and oral touch – emphasizing also that different senses are affected differently by the aging processes. Some examples are shown in Table 1. Possible explanations for inconsistent research results will be explored as well.

2.1. Taste

The sense of taste comprises five "basic" taste qualities: *saltiness* produced by sodium ions, mainly from table salt; *sweetness* evoked by sugars and artificial sweeteners, such as sucrose and aspartame; *sourness* produced by hydrogen ions of various organic acids; *bitterness* from quinine, caffeine and many other substances; *umami* taste typically produced by monosodium glutamate and other substances such as disodium inosinate and disodium guanylate (Toko, 2000; Yamaguchi & Ninomiya, 1998). *Astringency* is also an important sensation which can activate the taste sense and the trigeminal system as well (Schöbel et al., 2014) and the rough puckering sensation may be impaired with the decline in salivary function.

Changes in the gustatory sense are classified in three different categories (*dysgeusia*, *hypogeusia* and *ageusia*) based on the impairment level of taste sensation (Schiffman, 2009). The prevalence of these taste abnormalities is low in the general population (0.93%), but increases with aging to 5.1% among people aged 60–69 (see review by Bergdahl & Bergdahl, 2002; Hoffman, Cruickshanks, & Davis, 2009; Imoscopi et al., 2012). For hospitalized patients (aged 56 ± 19 years) exposed to a variety of drugs and diseases, the prevalence increases to about 14% (Imoscopi et al., 2012; Kettaneh et al., 2005). In elderly nursing home residents, it ranges from 14% to 22% (Imoscopi et al., 2012).

2.1.1. Taste perception changes

A variety of studies indicated gustatory sensitivity declined with aging (Kremer et al., 2007; Mojet, Heidema, & Christ-Hazelhof, 2003; Schiffman, 2008). Compared to younger people, older individuals have been found to have greater difficulty in detection of tastants dissolved in water (Mojet et al., 2003; Schiffman, 2008; Stevens, Cain, Demarque, & Ruthruff, 1991), or tended to perceive the tastes as less intense (Murphy, 1993). Nevertheless, when tastants are dissolved in real foods, the influences of aging on the taste sensation became more inconsistent (De Graaf, Polet, & van Staveren, 1994; Kremer et al., 2007), which presumably because of "mixture suppression" of tastes in real food systems.

2.1.1.1. Saltiness. A variety of studies using salt solutions showed significant decreases or a flattened downward slope in saltiness perception with aging (Mojet et al., 2003; Schiffman, Crumbliss, Warwick, & Graham, 1990; Stevens et al., 1991). Stevens et al. (1991) indicated that threshold of sodium chloride solution increased with age. Mojet et al. (2003) reported decreased intensity ratings with aging when salty tastants dissolved in both product and water. However, some studies suggested that little or no effect of age was found when the perceived saltiness of real foods (chicken broth and mashed potatoes) was measured (Drewnowski, Henderson, Driscoll, & Rolls, 1996; Zallen, Hooks, & O'Brien, 1990).

2.1.1.2. Sweetness. Sweetness perception is affected by the aging process negatively, but relatively less influenced compared to other basic taste senses (Murphy & Gilmore, 1989; Schiffman, 2008). Schiffman (2008) reported that the elderly's sweetness detection threshold was 2.7 times higher than the young. However, some studies reported no decrease in sweetness sensation for older adults (De Jong, De Graaf, & Van Staveren, 1996; Gilmore & Murphy, 1989; Mojet et al., 2003).

2.1.1.3. Sourness. Studies using citric acid water solution or beverage showed decrease in sourness intensity perception with age (Murphy & Gilmore, 1989; Zandstra & De Graaf, 1998). However, as for saltiness, when the perceived sourness was studied in real foods, instead of water solutions, some studies found little or no effect with elderly (Stevens & Lawless, 1981).

2.1.1.4. Bitterness. A majority of studies have reported a decline in the bitterness sensitivity of many bitter tastants of older adults, compared to the young (Gilmore & Murphy, 1989; Schiffman et al., 1994). However, the effect appears to be dependent on the specific tastant, e.g., it holds true for quinine but not for urea (Cowart, Yokomukai, & Beauchamp, 1994).

2.1.1.5. Umami. Compared to the other basic tastes, only a few studies have investigated whether age affects umami perception.

Table 1
Age-related orosensory perception changes and effects of compensatory strategies on elderly's food preferences. Please refer to footnotes for details.

Elderly's dependence level & food systems	Elderly population			Decline/impairment of orosensory perception[1]			Compensatory strategies and their preference effects[2]							
	Sample size	Age	Specific group characteristics	Taste	Odor	Oral touch	Flavor enhancement		Flavor enrichment		Irritant addition		Texture change	
Dependent living condition														
Liquid														
Functional red fruit drink[a]	N = 76	64–97	Residents from Clinical Rehabilitation Institute	Yes	Yes	–	Higher sweetness, lower sourness	○		–		–		–
Orange lemonade[c]	N = 29	79 ± 6	Senior homes	Yes	–	–	Sweetness	↑ & ↓[3]		–		–		–
Peach juice[o]	N = 36	82.8 (F) 78.8 (M)[4]	Nursing home	Yes	Yes	–	Sweetness	↑		–		–		–
							Peach aroma	↑		–		–		–
Tomato soup[h]	N = 20	60–90	From the geriatric unit of Academic Hospital	–	–	–	Soup flavor	↑		–		–		–
Semi-solid														
Grain porridge[c]	N = 29	79 ± 6	Senior homes	Yes	–	–	Sweetness	↑ & ○[3]		–		–		–
Strawberry jam[c]	N = 29	79 ± 6	Senior homes	No	–	–	Sweetness	↑ & ↓[3]		–		–		–
Strawberry yogurt[c]	N = 29	79 ± 6	Senior homes	Yes	–	–	Sweetness	↑ & ○[3]		–		–		–
Chocolate spread[c]	N = 29	79 ± 6	Senior homes	Yes	–	–	Sweetness	↑ & ↓[3]		–		–		–
Yoghurt[h]	N = 20	60–90	From the geriatric unit of Academic Hospital	–	–	–	Cherry flavor	↑		–		–		–
Solid														
Mashed potatoes[f]	N = 33	65+	Nursing home	Yes	Yes[5]	–		–	MSG	↑ & ○[5]		–		–
Spinach[f]	N = 33	65+	Nursing home	Yes	Yes[5]	–		–	MSG	○		–		–
Ground beef[f]	N = 33	65+	Nursing home	Yes	Yes[5]	–		–	MSG	↑		–		–
Quorn® (meat substitute)[h]	N = 20	60–90	From the geriatric unit of Academic Hospital	–	–	–	Chicken spices, marjoram and chicken flavor	↑		–		–		–
Broth with pasta[o]	N = 36	82.8 (F) 78.8 (M)[4]	Nursing home	Yes	Yes	–	Vegetable extract	↑				–		–
Pasta with tomato sauce[o]	N = 36	82.8 (F) 78.8 (M)[4]	Nursing home	Yes	Yes	–		–	Capers and oregano	↑		–		–
Vegetable puree[o]	N = 36	82.8 (F) 78.8 (M)[4]	Nursing home	Yes	Yes	–		–	Pesto sauce	↑		–		–
Rice with butter[o]	N = 36	82.8 (F) 78.8 (M)[4]	Nursing home	Yes	Yes	–		–	Sage and rosemary	↑		–		–
Bread with aubergine spread[s]	N = 104	79–101	Nursing home, 32 subjects had dementia	–	–	–	Lemon, garlic, salt and pepper	↑		–		–		–
Independent living condition														
Liquid														
Chicken broth[d]	N = 25	60–75	Healthy, institutionalized elderly were excluded	No[6]	–	–	Saltiness	↑ & ↓[6]		–		–		–
Tomato soup[e]	N = 120	72 ± 6	Living independently	Yes & No[7]	Yes & No[7]	–	MSG & celery powder	○[7]		–		–		–
Vegetable soup[g]	N = 30	73.6 ± 5.78	Living independently	–	–	–		–		–	White pepper (2 levels)	↓	Thickness	○
Gravy[i]	N = 43[8]	68.5 ± 5.9	Living independently, healthy	–	Yes	–	Overall taste intensity	↑		–		–	Thickness	↑
	N = 41	65.1 ± 5.2	Living independently, healthy	–	No	–	Overall taste intensity	↑		–		–	Thickness	↑
Tomato drink[k]	N = 52	60–85	Living independently	–	Yes	–		–	Lemon flavor	↓	Capsaicin	○ & ↓[9]		–

(continued on next page)

Table 1 (*continued*)

Elderly's dependence level & food systems	Elderly population			Decline/impairment of orosensory perception[1]			Compensatory strategies and their preference effects[2]							
	Sample size	Age	Specific group characteristics	Taste	Odor	Oral touch	Flavor enhancement		Flavor enrichment		Irritant addition		Texture change	
White cream soup[l]	N = 15	60–84	Healthy, community dwelling	No[10]	Yes & No[10]	Yes[10]		–	Mushroom	○		–	Addition of potato starch	↓
													Milk (replace water)	↓
Sweet vanilla waffle[j]	N = 22	60–85	Healthy, community dwelling	–	Yes & No[11]	Yes & No[11]	Vanilla	○		–		–	Decreased fattiness, increased elasticity & dryness[11]	↓
Savory cheese waffle[j]	N = 22	60–85	Healthy, community dwelling	–	Yes & No[11]	Yes & No[11]	Cheese	↑		–		–	Decreased fattiness & airiness, increased dyrness[11]	↓
Ice tea[r]	N = 21	60–75	Living independently, healthy	Yes	–	–	Sweetness	↑ & ↓[12]		–		–		–
Chocolate drink[r]	N = 21	60–75	Living independently, healthy	Yes	–	–	Bitterness	↓ & ○[12]		–		–		–
Tomato soup[r]	N = 21	60–75	Living independently, healthy	Yes	–	–	Saltiness	↓		–		–		–
Borth[r]	N = 21	60–75	Living independently, healthy	Yes	–	–	Umami	○		–		–		–
Semi-solid														
Yogurt-like fermented oat bran product[m]	N = 50	63–85	Living independently	–	Yes	–	Red currant aroma	↓		–		–		–
Mayonnaise[r]	N = 21	60–75	Living independently, healthy	Yes	–	–	Sourness	○		–		–		–
Solid														
Cheese-flavored waffle[g]	N = 26	73.6 ± 4.5	Living independently	–	–	–		–		–	Capsaicin (2 levels)	○	Thickness	○
Custard dessert[k]	N = 52	60–85	Living independently	–	Yes	–	Cream flavor	↓	Cherry flavor	○		–	Creaminess	↑
Mashed potatoes[i]	N = 43[8]	68.5 ± 5.9	Living independently, healthy	–	Yes	–		–	Celery leaves[8]	↑		–		–
	N = 41	65.1 ± 5.2	Living independently, healthy	–	No	–		–	Celery leaves[8]	↑		–		–
Stew[i]	N = 43[8]	68.5 ± 5.9	Living independently, healthy	–	Yes	–		–	Beer and gingerbread	○		–		–
	N = 41	65.1 ± 5.2	Living independently, healthy	–	No	–		–	Beer and gingerbread	○		–		–
Jam-filled cakes[p]	N = 107	61+	Participated in their own food choice, healthy	–	–	–		–		–		–	Soft vs. hard	○
Dependence level not available														
Liquid														
Orange lemonade[b]	N = 31	67–86	Residents in service apartments	Yes	–	–	Lemonade concentration	↑ & ○[13]		–		–		–
Tomato soup[b]	N = 31	67–86	Residents in service apartments	No	–	–	Tomato and bouillon	↑ & ↓[13]		–		–		–
Bouillon[b]	N = 31	67–86	Residents in service apartments	No	–	–	Bouillon concentration	↑ & ↓[13]		–		–		–
Apple juice[n]	N = 35	59–88	Having no serious health problems	–	–	–	Sweetness	↑ & ↓[14]		–		–		–
Solid														
Chocolate custard[b]	N = 31	67–86	Residents in service apartments	No	–	–	Cacao concentration	↑ & ↓[13]		–		–		–
Deep fried peanut[q]	N = 113	50–79	Food-allergy-free	–	–	–		–		–		–	Increased brittleness	↑

Notes.

1. The decline of orosensory perception in this table include age-related decline of taste, odor and oral texture perception, perceived intensity, detection ability and/or discrimination ability of reference stimuli etc. in the corresponding cited study. The orosensory perception also includes chewing efficiency, oral stereognosis, etc. "Yes" represent there is a significant or slight decline of the sensitivity among the elderly subjects in the cited study. "No" represent there is no change of orosensor perception among the elderly participants in the cited study. – represents not available.

2. ↑, ↓, ○ represent the compensatory strategy had a positive, negative or no influence on elderly's food preference, acceptance, appreciation or liking. − represents not available.
3. In this study, pleasantness rating of the orange lemonade increased with the increase of sucrose concentration from 0 to 15% and decreased when sucrose level increased from 15% to 37.6%. For grain porridge, increase of sucrose concentration from 0 to 1.9% affected the elderly's pleasantness positively; increase of sucrose level from 1.9% to 29.2% had no effect on food preference. For strawberry jam, increase of sucrose levels from 0 to 154% affected the elderly's pleasantness positively, increase of sucrose level from 154% to 308% affected food preference negatively. For strawberry yoghurt, increase of sucrose concentration from 0 to 20% affected the elderly's pleasantness positively; increase of sucrose level from 20% to 50% had no effect on food preference. For chocolate spread, increase of sucrose concentration from 0 to 165.2% affected the elderly's pleasantness positively; increase of sucrose level from 165.2% to 330.4% had no effect on food preference.
4. "F" represents mean age of female participants; "M" represents mean age of male participants.
5. The average ETOC score of all elderly participants was lower than the young (N = 29, <30 years old). There were 33% of the elderly participants had normal ETOC score. The pleasantness of mashed potatoes increased with increasing of MSG from 0% to 0.5%, and kept stable from 0.5% MSG to 2.0% MSG.
6. In this study, salt taste sensation of the elderly was evaluated. The elderly had increased preference when salt concentration increased from 0.04 mol/L to 0.24 mol/L, and had decreased preference when salt concentration increased from 0.24 mol/L to 0.68 mol/L.
7. Among the 120 elderly participants, 61 subjects had taste impairment, 72 had smell impairment and the rest had normal taste and smell perception.
8. In this study, participants were divided into two subgroups: 41 elderly without olfactory impairment and 43 elderly with impaired olfaction. The addition of celery leaves is a multisensory strategy, which is not only flavor enrichment but also visual enrichment.
9. In this study, low irritate addition had no influence on elderly's food preference, high irritant addition had negative influence on elderly's food preference.
10. All the elderly had normal taste sensation, 9 of them with normal smell. They perceived creaminess, chicken and mushroom flavor as less intense, compared to the young (aged 18–29).
11. In this study, olfactory performance was evaluated among the elderly participants only, among which 45.5% had good performance, 54.5% had poor performance. Texture changes were accomplished by replacement of 25% wheat flour by potato starch. The elderly had decreased chewing efficiency and letter recognition ability, but their sugar particle size detection ability did not differ from the young (aged 18–35).
12. In this study, increased sucrose or aspartame content in ice tea increased male participants' preference and had no effect on preference of female participants. Increased caffeine content decreased participants' preference for the chocolate drink, while increased quinine content had no effect on preference of participants.
13. Pleasantness of four products were increased when the flavor concentration of each product increased from 1st to 3rd level and decreased/kept stable when the flavor concentration increased from 3rd to 5th level.
14. In this study, pleasantness ratings of apple juice increased with the increase of sucrose concentration from 0 to 4% and decreased when sucrose level increased from 4% to 10%. Compared to the young (N = 33, aged 20–30), the elderly preferred higher level of sucrose.
References. a: Arganini, Donini, Peparaio, & Sinesio, 2014; b: De Graaf et al., 1996; c: De Jong et al., 1996; d: Drewnowski et al., 1996; e: Essed, Kleikers, et al., 2009; f: Essed, Oerlemans, et al., 2009; g: Forde & Delahunty, 2002; h: Griep, Mets, & Massart, 1997; i: Kremer et al., 2014; j: Kremer, Mojet, & Kroeze, 2007; k: Kremer, Bult, Mojet, & Kroeze, 2007a; l: Kremer et al., 2005; m: Koskinen et al., 2003; n: Kozlowska et al., 2003; o: Laureati, Pagliarini, & Calcinoni, 2008; p: Michon, O'Sullivan, Sheehan, Delahunty, & Kerry, 2010; q: Miyagi & Ogaki, 2014; r: Mojet et al., 2005; s: Pouyet, Cuvelier, Benattar, & Giboreau, 2015.

According to the little evidence available, a decrease in sensitivity in older people may also be found for umami (Sasano, Satoh-Kuriwada, & Shoji, 2015; Schiffman, Frey, Luboski, Foster, & Erickson, 1991). Schiffman et al. (1991) found that compared to the young participants (aged 26 ± 5 years), elderly participants (aged 87 ± 4 years) rated the suprathreshold concentration of an umami tastant (MSG) water solution as less intense. Sasano et al. (2015) indicated age-related decline of umami taste perception.

2.1.1.6. Astringency. Astringency, described as "a dry puckering sensation", can activate both the taste sense and the trigeminal system in the mouth (Gibbins & Carpenter, 2013; Schöbel et al., 2014). Astringent compounds, e.g. tannins, tartaric acid, potassium alum and polyphenols, are existing in a number of beverages and natural foods (Gibbins & Carpenter, 2013; Schiffman, 2008). Schiffman (2008) compared the DT (detection thresholds) and RT (recognition thresholds) of six astringent stimuli between young and old participants. The DTs of elderly were up to four times of the young's, and RTs of elderly were up to six times of young's, suggesting a decrease of the astringency sensation with age.

The above studies indicate some varying results depending on the experimental approach and possibly group of elderly investigated. In particular, a large variation was observed with regards to perceptual aspects evaluated (thresholds, suprathreshold intensities, etc.), the methods, target compounds, concentration ranges, media in which compounds were presented, which may partly explains the inconsistencies. Likewise, differences in participants' dependence level, health status as well as the reliance on small number of participants are also part of the problems (Mojet et al., 2003; Sulmont-Rossé et al., 2015). Furthermore, when real foods were used to dissolve the tastants, individual olfactory impairment in various levels may also have affect the taste perception to some extent differently (Mojet, Christ-Hazelhof, & Heidema, 2005).

2.1.2. Causes of taste impairment in the elderly

Besides the aging process itself, many other factors may contribute to taste impairment among the elderly. Medications, particularly interactions between drugs, contribute significantly to olfactory changes among older adults (Schiffman, 2009). Among the wide range of medications associated with taste disturbances, antimicrobials such as ampicillin and pentamidine can decrease saltiness perception (Doty, Shah, & Bromley, 2008), and cardiovascular drugs, like captopril used in treatment of hypertension, often are associated with loss of taste (Doty et al., 2008; Imoscopi et al., 2012). Drugs can impair taste acuity through affecting the function of the taste buds or the related neurons (Doty et al., 2008). Age-associated physiological function decline in the oral cavity which affects the taste sensitivity significantly (Imoscopi et al., 2012). Moreover, oral and systemic diseases, nutritional deficiencies and poor lifestyle also impact the sense of taste negatively (Imoscopi et al., 2012). Age-related decline in gustatory sensation can likewise be associated with reduced food appreciation, intake and thus nutrition condition (Olde & Rigaud, 2003). It in turn may even impair gustatory sensitivity further (Mattes, 2002).

2.2. Smell

Decreased olfactory sensation is more common among the elderly than decreased sense of taste. It is present in over 50% of the elderly aged between 65 and 80 and around 75% of the population older than 80 (Doty & Kamath, 2014a, b). Because of olfactory impairment, the elderly can have decreased enjoyment of foods that may initiate malnourishment, and hazardous risks such as failure to detect spoiled foods or leaking gas (Santos, Reiter, DiNardo, & Costanzo, 2004).

A variety of studies confirmed age-associated smell impairment for various odorants and functions, e.g. deficits in odor detection, decline in odor intensity perception, difficulties in odor discrimination, and enhanced adaption with slower recovery ability (De

Graaf et al., 1994; Kremer et al., 2007a; Kremer et al., 2007; Lehrner, Glück, & Laska, 1999; Thomas-Danguin et al., 2003; Wysocki & Gilbert, 1989). It was reported that older people aged 63–85 years tended to rate odors as less intense than the young group aged 18–34 (Koskinen, Kälviäinen, & Tuorila, 2003).

The olfactory loss with age may due to multiple factors, such as increased possibility of getting nasal disease and losses of selectivity of receptors to olfactory stimuli etc. (see review by Doty & Kamath, 2014a, b). Uses of some medications also contribute to olfactory losses (Tepper & Genillard-Stoerr, 1991). Moreover, a decreased olfactory function may be a sign of neurodegenerative diseases, e.g. Alzheimer's and Parkinson's, in the early stage (Doty & Kamath, 2014a, b). It has even been reported that there could be a link between deficits of olfactory identification and increased mortality (Devanand et al., 2015).

2.3. Trigeminality

The trigeminal sense is an integral part of the human somatosensory system, which detects chemosensory irritants in the nasal cavity, mouth, throat and eyes (Frasnelli & Hummel, 2005; Møller, 2014). It is not a component of the gustatory or olfactory system, but contributes to the orosensation as a separate sense (Møller, 2014). Most odorants can generate both smell and trigeminal sensations depending on their concentrations (Frasnelli & Hummel, 2005). Astringent compounds with "oral pungency" can activate the trigeminal sense in the oral cavity (Møller, 2014; Schöbel et al. 2014). Trigeminal mediated sensations mainly include pungency, warmth, cooling and tingle (Frasnelli & Hummel, 2005; Møller, 2014).

Age-related decline of trigeminal sensation has been reported, especially in people older than 60 years (Hummel, Futschik, Frasnelli, & Hüttenbrink, 2003; Wysocki, Cowart, & Radil, 2003). Moreover, many studies showed that trigeminal sensation is correlated with olfactory perception (Frasnelli, Schuster, & Hummel, 2010). Laska (2001) reported that even though impairment of the trigeminal system may be observed with age, it still can contribute to the orosensory perception significantly.

2.4. Oral touch

Oral texture perception is determined by many factors, such as vibratory sensation, thermal sensation, somesthetic sensitivity, etc. (Calhoun, Gibson, Hartley, Minton, & Hokanson, 1992). It encompasses various components of the masticatory system, which involves the lips, cheeks, teeth, tongue and saliva etc. (Mioche, 2004).

Age-associated changes in oral physiology can contribute to the impaired food texture perception in the elderly, such as impaired dental and oral health status, reduced masticatory efficiency and increased swallowing difficulties (dysphagia) (Mioche, 2004; Mishellany-Dutour, Renaud, Peyron, Rimek, & Woda, 2008; Ship, 1999).

Many studies reported age-related loss of texture sensation (Kremer et al., 2007; 2005) and ultimately texture preference changes (Forde & Delahunty, 2002; Ship, 1999). It was reported that the elderly aged 60–85 perceived elasticity of sweet waffle as less intense compared to young subjects aged 18–35 (Kremer et al., 2007). Another study by Kremer et al. (2005) showed older adults aged 60–84 perceived the creaminess of a cream soup as less intense compared to young participants aged 18–29.

Furthermore, one should be aware that texture perception to some extent has effects on taste and olfactory perception, since chewing-up and mixing of foods in oral cavity are important for flavor release (Forde & Delahunty, 2002; van Ruth, O'Connor, & Delahunty, 2000).

2.5. Orosensory changes are not uniform across the senses and individuals

In general, age-related decline of orosensory perception appears to be non-uniform across all sensations (Kremer, Bult, Mojet, & Kroeze, 2007b; Popper & Kroll, 2003). Saltiness and bitterness perceptions appeared to be more affected by age whereas sweetness and astringency perceptions showed smaller decline with age (Murphy & Gilmore, 1989; Schiffman, 2008). Moreover, the olfactory changes with aging are larger than the gustatory (Boyce & Shone, 2006; Popper & Kroll, 2003; Stevens, Bartoshuk, & Cain, 1984).

In addition, higher variability of orosensory perception may be observed among older adults compared to the young (Kremer et al., 2007b; Stevens et al., 1984). Stevens et al. (1984) indicated that the odor deficit was lesser for the young-old group (aged 65–78 year) compared to the old-old group (aged 80–95 year). Koskinen et al. (2003) reported that the variation in the scores of ETOC (European Test of Olfactory Capabilities) was grater among the elderly aged 63–85 than the young aged 18–34. This is mainly because the variability in interindividual orosensory impairment of older adults is not only increased with age, but also associated to age-related events. Sulmont-Rossé et al., (2015) reported that there is a link between dependence level in the elderly's living condition and orosensory abilities. A decreased self-reliance in the elderly's living condition is due to many factors e.g. poor health, medication and cognitive dysfunction and so on, which are associated with a general decline in orosensory acuity. This to some extent explained why some older adults have a declined orosensory perception, while some healthy and independent living elderly have identical acuity compared with younger people (Koskinen et al., 2003; Kremer et al., 2007b; Thomas-Danguin et al., 2003).

3. Sensory food preferences among the elderly

Orosensory impairment associated with aging is a significant factor which affects food appreciation and food intake among the elderly (Brownie, 2006; Popper & Kroll, 2003). Therefore a thorough understanding of how age affects food preferences is important for food and beverage development targeted at older people (WHO, 2015).

There is a long standing assumption in the food industry that the elderly prefer food products with enhanced flavor or modified-texture, in order to compensate for their reduced orosensory perception. Flavor enhancement (e.g. increasing concentration of an already existed flavor of the product), flavor enrichment (e.g. with an additional new flavor), irritant addition (e.g. addition of capsaicin, pepper, etc.) and texture changes (e.g. increase of creaminess) are the four most commonly used compensation strategies at present for age-related orosensory losses (Kremer et al., 2007a).

Table 1 shows the actual evidence in support/opposite of this long standing assumption. It provides a list of most representative and relevant previous research on the effects of the four main compensatory strategies on elderly's preferences of a number of foods and beverages within last two decades.

In each study, the specific characteristics of the elderly participants are also listed, since their food preferences and compensatory needs were rather heterogynous due to differences in dependence level, health status and social living conditions (Table 1). All studies could be divided into three subgroups based on the dependence level of the subjects; 1) the dependent on caring subgroup, 2) the free living, independent subgroup and 3) a subgroup with the level of dependence defined less clearly. The criterion for independence was that participants should be community dwelling and able to participate in food choice and/or prepare foods by themselves. In each subgroup, food systems were segmented in the order of liquid, semi-solid and solid (Table 1).

3.1. Age-related changes of flavor preferences and elderly's preferences of flavor modified foods

Focusing only on the basic tastes, the common assumption has been that elderly people suffering from loss of taste prefer greater taste intensities than younger people. Some studies supported this assumption. For instance, De Jong et al. (1996) noted that older adults (aged 73–85) from senior homes preferred orange beverage with higher sucrose content. However, Drewnowski et al. (1996) indicated that healthy, independent-living elderly (aged 60–75) preferred lower saltiness of chicken soup, compared to young participants. Mojet, Heidema, and Christ-Hazelhof (2004) reported that saltiness enhancement in tomato soup, umami enhancement in broth, bitter taste enhancement in chocolate drink, and sourness enhancement in Mayonnaise all had no positive effect on 60–75 years old healthy, independent elderly's preferences. Only the sweetness enhancement of ice tea increased the appreciation among the male participants.

For flavors a similar picture may be seen. De Graaf, van Staveren, and Burema (1996) had elderly residents in service apartment who were less independent (aged 67–86) and healthy young subjects (aged 20–30) evaluate different foods. These contained tomato soup, bouillon, orange lemonade and chocolate custard, in which the flavor concentration was varied by changing the product/water ratio. Older adults preferred higher flavor levels compared to the young, and the difference may mainly due to the decline in perceived intensity for the elderly group. Kremer, Holthuysen, and Boesveldt (2014) reported that the celery flavor enrichment improved healthy, living independently elderly's (aged 60–85) preferences to mashed potatoes. On the other hand, Kremer et al. (2007) studied sweet vanilla waffles and found that vanilla flavor enhancement had no effect on the independent elderly's preference (aged 60–85). Similarly, Koskinen et al. (2003) reported that flavor enhancement did not enhance the liking of a yogurt-like fermented food product among the healthy, independent older adults (aged 63–85). Lemon flavor enrichment decreased independent elderly's (aged 60–85) preference of a tomato drink (Kremer et al., 2007a).

The addition of one or more irritant at around threshold level has been advised as a potential counteraction strategy. The belief is that the irritant enrichment can provide more dimensions to people's eating experience (Laska, 2001). However, this may not be a very sufficient strategy based on existing studies. It was reported that the addition of two levels of irritant (0.9 and 1.8 ppm capsicum solution) to cheese flavored waffle both had no influence on the elderly's preferences (Forde & Delahunty, 2002), higher irritant addition can in some case even decrease preference for most elderly (Kremer et al., 2007a).

These results indicate that the effect of flavor enhancement by increasing concentrations of existing basic tastes or flavors in a product will be rather product and individual dependent (Popper & Kroll, 2003). Accordingly, flavor enhancement is far from a "one-size-fits-all" solution that it was originally believed to be (Essed, Kleikers, van Staveren, Kok, & De Graaf, 2009). However, in most cases, flavor enhancement strategies had positive effects on food preferences of unhealthy, dependent older adults living in hospitals and nursing homes etc. (Table 1). In contrast, for independent and healthy elderly, flavor enhancement or enrichment strategies had no or even negative effects on their food preferences (Table 1). Therefore, the effects of adding or increasing certain flavors have shown nonconsistency when preference of different flavor levels were evaluated among elderly with different dependence and health levels (Koskinen et al., 2003; Kremer et al., 2007a; Mojet et al., 2005). A possible explanation is that the increased dependence is usually associated with poorer health, combined with more severe impairment of the ability to perceive flavor (Essed, Kleikers, et al., 2009), which explained why flavor modification might be regarded as an improvement by some elderly, and an overpowering amplification by some other older adults (Popper & Kroll, 2003).

3.2. Age-related changes of texture preferences and elderly's preferences of texture-modified foods

Compared to the chemical senses, a smaller number of studies investigated texture preferences among the elderly, and most evaluated the effects of texture modification on the food acceptability in healthy independent elderly (Table 1).

Because of the age-related impaired oral physiology (discussed at Section 2.4), it is assumed that older adults may prefer foods with textures which are easier to breakdown and swallow (Popper & Kroll, 2003). Moreover, to some elderly segments, texture-modified foods (TMF) are more like necessity, rather than a preference or choice (Cichero, 2015). Wright, Cotter, Hickson, and Frost (2005) summarized two main reasons for prescribing TMF, which are dysphagia (80%) and poor dental status (20%). The prevalence of dysphagia among institutional or hospitalized elderly has been estimated up to 50% and even higher in very old adults (above 85 years old) (Rothenberg & Wendin, 2015).

A common compensatory strategy for dysphagia is texture modification (Rothenberg & Wendin, 2015). Successful TMF should provide the elderly with pleasurable experiences and safe consumption. There are typically three levels of food texture modification offered to people with dysphagia. They move from soften foods, through chopped and minced foods, to pureed foods (Cichero, 2015).

Again, the acceptance of texture changes seems to be highly segment dependent, as different groups of elderly react differently to texture changes. For example, pureed foods were preferred by older consumers of pureed foods from care homes or hospitals, compared to healthy older adults (aged above 65) living independently without dysphagia (Ettinger, Keller, & Duizer, 2014). This difference in response might be partly due to the variation in chewing and swallowing deficiencies among the two groups.

Even within the group of healthy, independent older people, the influence of specific texture modifications on food preferences have shown to be highly variable. For example, for a white cream soup, increased thickness had negative influence on hedonic ratings of healthy elderly aged 60–84 (Kremer et al., 2005). Forde and Delahunty (2002) reported that increasing the textural thickness in a vegetable soup had no effect on food preferences of elderly living independently (aged 68–79). A positive effect of increased thickness was shown for other liquid product matrices, e.g. gravy (Kremer et al., 2014).

Thus, the effects of the textural characteristics on elderly's preferences appear to be both product- and segment-dependent. The segment of elderly with dysphagia is a rather large and has greatest need for TMF. It is important for food catering industry, especially the home meal service and meal providers for nursing homes and hospitals to be aware of this when developing TMF targeted at the elderly. Likewise the flavor release pattern is often very different in texture-modified foods, especially in gelatin gel-based foods. Thus, one significant challenge for the food industry is to develop formulated flavors that can compensate for the different release patterns observed in, for instance, gelatin gel-based foods.

3.3. The relative contribution of flavor and texture for food preference of older people

According to some studies, the relative contribution of flavor and texture to the pleasantness of food changes with aging (Forde & Delahunty, 2002, 2004; Kälviäinen, Roininen, & Tuorila, 2003). The proposed explanation is that when sensitivity in some senses is lost due to aging, less affected senses can compensate for the losses (Forde & Delahunty, 2004; Kälviäinen et al., 2003).

In some cases, texture is becoming a more important factor which affects food and beverage appreciation among the elderly (Forde & Delahunty, 2002, 2004; Szczesniak, 2002). For instance, the elderly aged above 60 were found to be more affected by the pulpiness texture in their liking ratings of orange juices compared to the younger adults aged 20–50 (Forde & Delahunty, 2004).

Oppositely, Kälviäinen et al. (2003) indicated that for a yogurt-type snack food the effects of taste on preference was more pronounced than the limited effect of texture in older adults (variations in smoothness). Another study by Kremer et al. (2005) found that older people aged 60–84 and the young group aged 18–29 had no significant differences across their pleasantness ratings for flavor, texture and solvents (water or milk) of a white cream soup. Again, heterogeneity among participants included in these studies may possibly explain the diverse findings.

Understanding the contribution of different senses to target consumers' food appreciation plays an important role in leading the modification directions during product development. For example, food appreciation of an older adult with olfactory losses may depend more on the oral somatosensory feelings of some products (Forde & Delahunty, 2004), thus, texture modifications can be the primary task which deserves more efforts during product development for this specific consumer subgroup.

3.4. Explanations for compensatory strategies with no effect

There are many studies on compensatory strategies on foods for different segments of elderly. Although, some general trends can be drawn, there are also some results that point in different directions. Four possible reasons may explain why in some cases a single compensatory strategy or a combination of several either had no effect or even had a negative influence on older people's food preferences.

Firstly, awareness of their own diminished orosensory changes varied among older people, since the deterioration of orosensory systems occurs gradually as people age and some elderly can habituate to sensory losses continuously (Nordin et al., 1995; Wysocki & Pelchat, 1993). The older people may counteract the losses with the help of former food experience, mental images and related-memory (Mojet et al., 2005). Moreover, detection of novelty and change based on their own food memory ("misfit") might even influence their acceptance of sensory modified foods negatively (Köster, Møller, & Mojet, 2014; Morin-Audebrand et al., 2012).

Secondly, there are differences in the selection criteria of participants in the various studies, which include health condition, age range, dependence level, social interaction/loneliness, nutritional status, cognitive condition, familiarity with the tested products, etc. For example, Kremer et al., (2005) only accepted participants who passed screening tests, to exclude the elderly with abnormalities in gustatory and olfactory. Furthermore, within one study with the same participants, elderly could be segmented into different segments based on their health and dependence levels and may react significant differently towards compensatory product changes. For example, one study showed that the subgroup with dental defects preferred muesli oat flakes with a more fragile texture, compared to older people without missing teeth (Kälviäinen et al., 2003).

Thirdly, impairment of sensory capabilities among the elderly is one important factor which affects food appreciation. However, social circumstances, external product information, dietary habits and food culture may also affect food appetite in a broader perspective. This will be further discussed in Section 4.2.

Fourth, the variety in the influences of strategies on elderly's food preferences can be due to the various food systems used in different cases. From an applied perspective, this suggests caution in generalizing results from one product category to another in product development and optimization efforts.

4. Future perspectives

4.1. Multisensory compensatory strategies to increase elderly food preferences

Although this review has focused on orosensation, people's perception towards food and beverages is not only a combining of smell, taste or somatic cues, but also influenced by what the food looks like and what it sounds like during biting and chewing in the mouth. Both vision and audition contribute greatly to the multisensory perception of foods and affect foods appreciation (Murray, Wallace, Zampini, & Spence, 2012; Philipsen, Clydesdale, Griffin, & Stern, 1995; Spence, Levitan, Shankar, & Zampini, 2010). Past research on compensatory strategies has mainly focused on addition of taste stimuli and odors or texture-modifications. The single sensory compensation not only had restricted effects on the improvement of elderly's food preferences, but may also have potential negative influences on the health of some elderly. For instance, increased salt intake may lead to higher blood pressure (He & MacGregor, 2002). In contrast, taste enhancement with umami substances allowed a far less amount of salt used during food preparation and can even benefit human's health through many pathways (Jinap & Hajeb, 2010). Hence, food modifications should be made not only with a focus on increasing the food appetite, both also consider possible influences on the target segments' health status.

Based on above challenges, multisensory compensatory strategies may be recommended to be considered in future studies about improvement of food appreciation. Murray et al. (2012) reported that appreciation of chips and sparking water were influenced by manipulated the sound level. A study by Philipsen et al. (1995) showed that amplification of color intensity improved the perceived flavor intensity among older adults aged 60–75. These studies showed that multisensory strategies have potential in promoting elderly's food appreciation, and warrant further research.

4.2. Other factors affect food appetite in a broader perspective

It is known that except orosensory perception, the mental and physical environment, social circumstances and cultural aspects affects people's appetite as well (Gustafsson, Öström, Johansson, & Mossberg, 2006; Rothenberg & Wendin, 2015). A more comprehensive view is needed where these aspects are also taken into account, combined with multisensory modified food products to meet elderly needs and preference (Keller et al., 2014; Rothenberg & Wendin, 2015).

For example, the room and table settings, the meal time environment, the accompany from family or friends and the external product information provided all have great impact on elderly's food preferences (Gustafsson et al., 2006; Keller et al., 2014; Rothenberg & Wendin, 2015). Nijs, De Graaf, Kok, and van Staveren (2006) reported that family-style meals can stimulate food appetites and intake in nursing homes. Moreover, Kremer et al. (2014) reported that the elderly increased the liking ratings of meatballs when information of salt reduction provided. It would be another interesting area for future research to quantify the relative contribution of all these different factors to affect food appreciation.

4.3. Development of standard evaluation methods for orosensory changes and assessment of foods sensory modification

This literature review emphasizes the need for standard evaluation methods to assess orosensory changes and the level of sensory impairment. At present, comparison of the various results from different studies about age-related orosensory changes is difficult, because of the highly heterogeneous evaluation methods, stimuli and media type reported in the literature. Developing standards will enable for a more valid comparison across different studies between different segments of older adults, e.g. different age groups, level of dependence, health status and so on. For instance, elderly with different levels of cognitive abilities should not use methods which much relied on verbalization because of the possible biased results (Maitre, Symoneaux, & Sulmont-Rosse, 2015). When selecting the optimal modified foods for patients with different levels of dysphagia, it would be helpful to build a relation between the dysphagia level and texture scale (Rothenberg & Wendin, 2015).

4.4. Development of functional foods targeted at older adults

Developing functional food for the elderly is a way by which the food researchers and industry can contribute to meet older consumers nutritional needs. Both the worldwide aging of population and the increasing awareness of the association between nutrition and health status are in favor of the expanding market of functional food for senior citizens (Siro, Kapolna, Kapolna, & Lugasi, 2008).

Taste expectations and experiences were reported as extremely important factors which determined consumers' acceptance of such product. However, functional foods, containing extra health-promoting ingredients, are often associated with unpleasant flavor and even texture changes compared to conventional foods (Luckow & Delahunty, 2004). It is one of the great problems that the functional food developers have to solve. For example, whey protein is expected to be beneficial to older people with *sarcopenia* due to its great efficiency in muscle build-up and maintenance (Burd et al., 2012), but whey protein enrichment alters the sensory characteristics of foods, e.g. a bitter taste due to the increased presence of smaller peptides and a dry, grainy or crumbly texture in some food matrices due to its high water binding capacity.

Furthermore, it is unwise and risky to count on consumers' willingness to compromise on the appetite for health while consuming functional foods (Verbeke, 2006). Functional food developers need to explore orosensory compensatory strategies not only to cope with the unpleasant character changes due to the addition of functional ingredient, but also to meet the appetite needs from elderly with impaired orosensations, which will be much more complex compared to the development of conventional sensory modified foods for the elderly.

5. Conclusions

Taken collectively, the large body of literature reviewed in this paper clearly shows that orosensory perception and food preferences are influenced by various age-related physiological changes associated. While influences of aging on orosensory changes have been widely reported, the type, direction and magnitude of effects are different depending on the product and the specific subgroup of elderly under consideration. The inter-individual variability in orosensation impairment among the elderly population is not only related to aging itself, but also to events that are associated with aging. For example, increased dependence with aging caused by poor health, consumption of medication and deterioration in cognitive status, also lead to the impairment in orosensory perception. This can explain, to some extent, why sensory acuity of some elderly declined, while some healthy and independent elderly have equal acuity with younger adults (Kremer et al., 2007).

Most studies about age-related sensory changes focused on orosensory perception, while less attention has been given to its relationship with elderly's food preferences. Changes of flavor and texture preferences with aging varied across individuals and products. In some cases, different elderly segments' preferences may even be negatively affected by high-flavor or texture changes. In general, flavor and texture modification are of great importance for enhancing the food appreciation among the less dependent elderly with poorer health and the very old independent elderly Therefore, in future studies, food researchers and professionals in the food industry (product developers, home meal service, food provider of nursing homes, large scale catering etc.) should consider targeting these specific subgroups of elderly while exploring a well-balanced flavor and texture framework for specific food systems.

The relative influence of flavor and texture on food preference changes with aging. In cases where the perception of flavor is compromised, texture appears to become an increasingly important attribute affecting elderly's preferences. Moreover, flavor enhancement/enrichment and texture change are far from the one-size-fits-all solution in increasing the elderly's food appreciation, the development of multisensory compensation strategies for increasing food appeal is highly recommended for further investigation in the future.

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