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Ágrip á íslensku:	Þessi skýrsla er heimildaritgerð um bragð- og lyktarskynjun. Á bak við bragðskynjun liggur flókin blanda margra lífeðlisfræðilegra og sálfræðilegra þátta. Bragð, lykt, áferð og erting eru megin lífeðlisfræðilegu þættirnir. Sálfræðileg skynjun bragðs er jafn mikilvæg lífeðlisfræðilegri skynjun og hefur verið rannsökuð mikið. Ljóst er að mörg skynfæri spila saman til að framkalla mismunandi bragðskynjun eftir því hvert samhengið er og að einstaklingsmunur ríkir við skynjun bragðs. Ástæður þessa mismunar eru hins vegar ekki að fullu ljósar. Fiskbragð og lykt eru margbrotið samspil rokgjarnra efna, sem eru mismunandi milli tegunda og breytast við geymslu fisks. Nokkur megineinkenni fiskbragðs í ferskvatnsfiski og sjávarfiski eru rakin hér ásamt stuttri kenningu um afstöðu neytenda til fisks.		
Lykilorð á íslensku:	Bragðskynjun, fiskbragð, einstaklingsmunur		
Summary in English:	This report is a literature review of taste, aroma, and flavor perception. Behind flavor perception lies a complex combination of several physiological and psychological responses. Taste, aroma, texture, and irritation are the main senses involved on the physiological level. The psychological, or cognitive, level of flavor perception is just as important as the physiological and has been researched extensively. It is clear that many senses interact to produce different flavor responses depending on the context and that great individual differences exist. The reasons behind these differences, however, are not clearly understood. Fish flavor is a complex mixture of several aroma compounds and varies between species, and changes during storage of fish. Some of the main characteristics of fish flavor in freshwater and saltwater species are discussed herein, along with a short theory on the consumers attitude towards fish.		
English keywords:	Flavor perception, fish flavor, individual differences		

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Department of Food Science
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FLAVOR PERCEPTION AND VOLATILE COMPOUNDS IN FISH

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1. INTRODUCTION

Flavor perception has been researched widely throughout the years, yet is still not fully understood. It is clear that flavor perception begins with the eyesight, as soon as food is seen. Sending a message to the brain, the eyes tell whether a food looks palatable and should be tasted. Touch will usually come next, either with the hands or with some utensil, such as a fork or a spoon. The touch gives an idea about the texture, if the food is hard or soft, course or fine, etc. Sniffing follows and the aroma will give a hint of the flavor. Taking a bite starts many simultaneous processes, taste buds tell if the food is bitter, sweet, salty, or sour or perhaps some combination, tongue and teeth assess the texture, and aroma is perceived through the retronasal route, all determining the flavor of the food. Based upon that determination a decision whether to take another bite is made. Taste and aroma perception, like many other physical processes, begin at a chemical level, with compounds reacting with certain receptors to elicit a neurological response. This physiological response along with the chemical reactions can be referred to as the sense level of perception. What the brain does with the information received - identifying tastes and odors, perhaps remembering similar odors and even connecting them to memories from childhood - is the cognitive level and can be researched from a psychological point of view.

In this paper the physiological processes of tasting and smelling will be addressed, but the main focus will be on the psychology of these processes. Fish flavors will then be discussed in particular and some consumer studies on fish consumption. The psychology of flavor perception will then be used to try to explain consumer responses to fish flavors.

2. TASTE PERCEPTION

2.1. Tastants

Four basic tastes have generally been agreed upon: sweet, sour, salty, and bitter. Simple carbohydrates, such as glucose and fructose, have a sweet taste due to specific binding of the molecules to so-called AH-B glycophore receptors. H^+ ions from acids elicit a sour taste and anions and cations from NaCl and other salts produce a salty taste (Shallenberger, 1996). The binding sites for bitter tastes are not known, but quinine and caffeine are known to cause bitterness (Kandel and Schwartz, 1991). In past years umami, the taste of monosodiumglutamate, has been added, constituting the fifth basic taste. It has a "mouth-filling" taste and has long been used in cooking to enhance flavor. Not everyone agrees on the 4-5 basic tastes. Delwiche (1996) argues that since the substances used to test taste sensitivity are usually representative of the basic tastes, new descriptors of tastes are not found. He cites research where subjects were given various tastants and asked to group them qualitatively. If they were not given labels before grouping, the groups would be as many as the tastants, but if asked to classify according to the basic tastes and "other" fewer groups were obtained. For practical purposes most sensory scientists use the four basic tastes and umami, whether or not they agree with Delwiche's arguments.

Different food constituents have different tastes. Carbohydrates generally taste sweet. Fats have little taste, but contribute mouthfeel and carry odorants (4.2.). Amino acids have the most variation in taste and the effect of amino acids and peptides on food taste has been researched extensively. According to Kirimura *et al*. (1969) arginine is bitter and slightly sweet, serine is sweet with some sour and umami, glutamic acid is sour and umami, and alanine is sweet with slight umami. Generally amino acids have more than one taste character, but can still be divided into three basic groups: sweet amino acids, sour and umami-like amino acids, and bitter amino acids. Except for the bitter ones, most amino acids have two or three tastes. Peptides are generally not as strong tasting as amino acids. Some amino acids are the dominant contributors of taste in a foodstuff while others intensify taste or add to mouthfeel.

2.2. Physiology

Taste involves substances binding to receptors on the tongue and in the back of the throat. A food cannot be tasted without being put in the mouth cavity. Five or more pathways are involved in taste perception. Sugars and sweetening agents bind to special receptor proteins activating two pathways, bitter substances bind to proteins and activate one pathway and salts and acids change the electrical status of receptor cells through ion channels in the cell membrane. Receptor proteins, which umami substances bind to and the following pathways are less known (Laing and Jinks, 1996). The receptor cells to which tastants bind are in the taste buds. They are modified epithelial cells and at the base is a nerve fiber, which is branched so that each nerve has many ends imbedded in different taste buds. Therefore the signal from each nerve fiber is from many receptors. The detailed mechanisms known for taste sensation are described in many texts, for example Lawless and Heyman (1998) and Kandel and Schwartz (1991). The function of the taste senses is not clearly understood, but some theorize that a sweet taste from carbohydrates signals an energy source, salty taste available nutrients, and basic and sour tastes could be to warn against dangerous acids and toxins (Lawless and Heyman, 1998).

2.3. Psychology

When chemical reactions have taken place at the taste receptors and neurological responses have been sent, the brain starts to process the messages and cognitive sensing begins. A sucrose solution is tasted. To some it has a very prominent sweet taste, to others it tastes slightly sweet, and still others do not perceive sweetness. Taste thresholds of tastants seem to be highly individual and might be both physiological and psychological. Several factors affect the simple phenomena of how strong a taste is perceived to be and how mixtures of tastants interact. A few studies are described below.

It is clear that individual differences in taste perception exist and they can effect results when using sensory panels or consumers to test certain foods. Obvious sources, such as age, gender, and background have been shown to affect perception, but personality traits can also affect taste perception. For instance, private body consciousness (PBC), the sensitivity people have towards changes in body temperature, internal tensions, heart rate, dryness of mouth and throat, etc., affects perception of different concentrations of, for example, salt in a soup. People with high PBC perceive changes more clearly than people with low PBC. Studying all the factors which can influence taste perception is a large task, but clearly these factors must be taken into consideration when performing studies based on sensory or consumer panels, especially if unexplained variation in results is high (Stevens, 1996).

Tuorila *et al*. (1996) studied memory of taste intensities of sweet and salty foods on groups receiving minimal training and more extensive training. By waiting 1 hour, 1 day, 1 week, and 6 weeks from training to ask subjects to recall intensities it was found that taste intensities were recalled to be higher than they actually were after waiting 1 day and more. For more trained subjects this was not as marked.

Vanne *et al*. (1998) investigated the ability of subjects to reproduce sucrose concentrations after a certain time from first tasting them. Three different concentrations of sucrose were used in four different media: water and standard solutions of NaCl, citric acid, and caffeine. Each group of subjects used only one medium. 12 minutes, 1, 5, 25, and 125 hours after tasting the subjects were asked to reproduce the sweetness intensity by mixing 0 M and 1 M solutions of sucrose and tasting and retasting until they were satisfied. In all cases the produced sucrose concentration increased from the first session to 125 hours. Low concentrations of sucrose had a larger difference than high concentrations. The added tastants, NaCl, citric acid, and caffeine did not seem to affect this result. These findings are similar to those of Tuorila *et al*. (1996) in that intensities were recalled to be higher than they actually were and demonstrate that sensory memory for tastes can be a large bias in sensory food research.

Stevens (1996) studied the effect of aging on taste thresholds and masking effects of other tastants. He found that in older subjects thresholds were always higher than in younger subjects, both in pure solution and with another compound. Detection of a taste, for example sweet, in the presence of another taste, e.g. sour, is impaired, and as the concentration of the masking substance (2. tastant) increases so does the taste threshold for the masked substance (1. tastant). This is true for young and old subjects. The threshold is higher to begin with in old subjects and stays higher throughout and usually the masking for young and old subjects has a similar slope, with the older subjects having higher thresholds overall.

Nakagawa *et al*. (1996) found that inducing physical or mental stress on subjects before tasting sweet, bitter, and sour solutions altered taste perception somewhat, although differently. It seemed the only taste perception affected by physical stress was that of sour taste, where the duration of sour after-taste was shortened after exercise, and research indicated that physical exercise might affect the buffering capacity of saliva, thus altering sour taste perception. Mental stress had a larger effect on taste perception, perceived duration of all three tastes was shorter after completing mental tasks and total amount perceived was reduced. Mood tests indicated higher tension and fatigue after the mental stress, indicating that mood might affect taste perception.

Horio and Kawamura (1998) studied the effect of physical exercise on preference for sweet, salty, sour, bitter, and umami taste. Subjecting students to vigorous exercise for more than 30 minutes and using non-exercise control subjects they evaluated the preference for NaCl, sucrose, citric acid, caffeine, and monosodiumglutamate (MSG) solutions. Preference for the sweet and sour solutions increased after exercise, but no effect was seen with salty, bitter, and umami solutions. Since exercise uses glucose in the body it may be only natural for exercisers to have a higher preference for sugary solutions after exercising.

Lavin *et al*. (1998) found that adults rated a dark red strawberry beverage sweeter than a light red one and a light green key-lime beverage sweeter than a dark green one. Children aged 5-7 and 8-10 did not rate one or the other color significantly sweeter. Children 11-14 years old did not discriminate between the green beverages but found the light red strawberry beverage to be sweeter than dark red. These findings suggest that connecting colors to sweetness is a learned, rather than inherent, association.

The effect of adding vanilla to milk was also studied by Lavin *et al*. (1998) and all age groups found the vanilla flavored milk to be significantly sweeter and trending towards creamier, though only 8-10 year olds and adults found it to be significantly creamier. There was also a definite trend towards higher liking of the flavored milk.

Taste and aroma are generally the most important contributors to flavor. Their interactions can stem from physical, physiological, cognitive, or psychological effects. Salts and acids will for example generally increase the headspace concentration of nonpolar volatiles, thus increasing the intensity of the aroma contributed by them. It is unlikely that interactions are occurring at the receptors, since receptors for taste and aroma are generally different. These interactions could be at the central processing level, thus being a function of cognition. Fruitlike aromas have been reported to increase when sugar is added to a solution and then tasted, likely because the added sweetness indicates added fruitiness. Many odorants, added to sweet solutions, have also been known to increase perceived sweetness. (Noble, 1996)

3. AROMA PERCEPTION

3.1. Odorants

Odorants are small molecules, usually less than 1 kDa. They are light enough to be breathed into the nose but heavy enough to be recognized by receptors. Almost all aromas are a result of various such odorants, usually several hundred. Even though a few substances in an aroma may be the key contributors it is still comprised of all the odorants. The human brain is able to recognize a large number of odorants, possibly up to 10.000. Millions of olfactory receptors are at work when a food is smelled and they send messages to the brain, which then processes them and delivers identification of the aroma. It is not yet known whether each odorant has its own receptor, but it is considered likely in light of the fact that these receptors are very many, likely 1.000-10.000. Before reaching the receptor, an odorant must travel through the olfactory mucus, covering the olfactory epithelium. The odorant might take part in many reactions before binding to the receptor cell (Bell, 1996).

3.2. Physiology

Receptor cells in the nose contain proteins, which odorants bind to. 1.000 types of receptor proteins are believed to exist, and one or few proteins are in each receptor cell. Receptor proteins in the receptor cell membrane capture the odorants, and that seems to initiate a structural change starting a chain of events. This chain reaction results in the depolarization of the cell membrane and thus a nerve signal travels down the axon of the olfactory cell. When an odorant binds to a protein chemical energy becomes electrical energy, through one of two pathways: the cAMP or Inositol triphosphate pathways. The pathways open ion channels in the cell membrane resulting in a flow of charged ions across the membrane and an electrical signal being sent to the brain. The signal will give an idea of the amount of odorant and its identity (Laing and Jinks, 1996).

Volatile compounds can enter the nasal cavity and produce odors in two ways. From outside the body, that is the environment, and through the nostrils, called the orthonasal route. And from the oral cavity, when swallowing or exhaling, through the retronasal route. Several experiments where subjects were trained in recognizing odorants orthonasally and then trying to identify them retronasally and vice versa showed that when trained orthonasally subjects would identify almost 100% of samples orthonasally and 80% retronasally. Retronasally trained subjects correctly identified 92% of the samples during retronasal testing. Retronasal identification seems inferior to orthonasal and the routes seem to be related (Pierce and Halpern, 1996).

3.3. Psychology

As in the case of taste, the cognitive processing of odor signals has a large impact on odor perception. Odor perception seems to be particularly linked with memories from long ago, more so than other types of sensory perception (Lawless and Heyman, 1998). The reasons for this are not understood, but it seems clear that training of odor recognition is no replacement for experience with odors. Lesschaeve and Issanchou (1996) found that odor memory is more related to previous experience of a subject with an odor than with training a subject to recognize an odor. Panel training for a short time under laboratory conditions is not sufficient for subjects to create strong associations to odors. The more deeply in memory the odor information is stored, the more easily it is retrieved in a recognition task. Sensory training enhances the ability of people to accurately verbalize odorants.

Pointer and Bond (1998) investigated whether an odor can function as a retrieval cue for memorizing prose. Subjects were exposed to odor or color while learning a prose passage by using either scented (peppermint) paper or colored (yellow) paper. Recollection of the prose was then tested under the original learning context and without it. Results were that while color had negligible effect on quantity and quality of recall of the prose, both quantity and quality of recall were significantly better for subjects who had scented paper when recalling. The fact that odor assisted in remembering the prose supports theories of people being able to recall certain autobiographical events when smelling an odor that was in the atmosphere when the events occurred.

A study of odor perception and beliefs about risk revealed that if people are told that an unfamiliar odor is natural or healthy they will show adaptation effects to that odor and if they are told the odor is hazardous they show sensitization. In cases where people did not receive information about the healthfulness of odors adaptation and sensitization occurred about evenly. Several subjects who were told the odors were hazardous also spontaneously reported headaches, lethargy, dizziness, or irritation from exposure to the odorants. These results are connected to other results indicating that exposure to an unpleasant odor or an odor thought to be hazardous often does not lead to adaptation, but to sensitization and reports of health symptoms as mentioned above (Dalton, 1996).

In a review article Elmes (1998) discusses the possibility of an "inner nose". An inner eye is used to describe the phenomenon when a person can visualize something without actually seeing it. The inner nose would enable a person to smell or remember the smell of something without it being present. Although many researchers vote against the inner nose, Elmes gathered data that suggest that people can more easily identify an odor if they have been told beforehand to picture it in their nose. Also he describes an experiment where people were told what an odor is before smelling it in a mixture with others at low concentrations, resulting in them profiling the mixture as the single odor. Evidence suggests that an inner nose does exist, even if it is not as clear as the inner eye or inner ear.

Hulshoff *et al*. (1998) tested the effect of sniffing a weak or strong odor on perception of odor strength 25 minutes later. Subjects who smelled weak odors 25 minutes before smelling the reference odor overestimated its intensity but not those who smelled strong odors, and they did not underestimate odor intensity. Since recovery from adaptation is thought to take 15-20 minutes this effect must involve a central process, not only the senses.

Cain *et al*. (1998) performed several studies on odor identification. They found that the ability to identify odors could change from day to day, and presenting people with the same odors day after day seemed to improve their identification abilities, even though they received no feedback. When given 146 descriptors of odors that had previously been described correctly, incorrectly, or nearly correctly, subjects generally did not improve their description. The fact that so many choices were given and that the subjects were not told to use these words to identify the odors could have affected the results. When given several choices, one of which is the right one, to name 7 odors previously not recognized, subjects got correct answers on average for 3,6. To compare the same thing was done with trivia questions and correct answers were 3,4. However, the subjects had been asked before reviewing the multiple choices, to rate their likely success in getting the right answer and there was little correlation between that and the actual right answers. When subjects received feedback on their responses in identifying odors and subsequently did another round of sniffing their identification success improved from 38 to 59%, indicating that feedback has a large effect on odor identification.

Subjects who were trained for a short time in identification of certain odors performed markedly better after training than before, identifying 81% after five sessions compared to only 44% in the first session. A non-trained control group showed an improvement from 48% identification to 54% in 5 sessions (Cain *et al*. 1998).

Ayabe-Kanamura *et al*. (1998) demonstrated that the perception of German and Japanese women of the same odorants in the same concentrations differed. For 11 of 18 odorants tested a significant difference in the use of descriptors was detected. In

13 odorants pleasantness ratings differed significantly. Odors familiar to the subjects were more often judged pleasant and except in the case of perfume, pleasant odors were thought to indicate edibility.

These studies demonstrate that odor perception is highly complex and is affected by individual and intercultural differences. The study by Pointer and Bond (1998) where odor functioned as a memory enhancer, and other observations about odor memory are very interesting and should be studied further. Physiologists need to figure out how and why odor and memory are linked and perhaps this can later be used to explain consumer behavior and as a study tool for students.

4. FLAVORS

Flavor is often defined as the sensation arising from the interplay of signals produced as a consequence of sensing smell, taste, and irritating stimuli from a foodstuff (Laing and Jinks, 1996). Taste and smell have been covered and irritants are addressed below (4.1.). Flavor is generally thought to consist of the volatile components sensed in the nose, both through the nostrils (orthonasally) and from inside the mouth (retronasally), nonvolatile compounds sensed on the tongue, and compounds that are perceived in the mouth as texture or mouthfeel. Aroma is considered more important than taste in determining flavor. Flavor analysis has typically focused on measuring volatile compounds, for example by gas chromatography-mass spectroscopy (GC-MS) and GC-olfactory methods. But changes in composition occur during eating, through mastication of the food by the teeth and dilution of some component by saliva. Measuring those changes is more difficult. The change a food undergoes is different for each type of food, an aqueous beverage will for example change little as passing through the mouth, while a fat-based food will undergo melting of the fat, temperature changes, and possibly emulsion changes (water-in-oil to oil-in-water), which all cause changes in the release of volatiles (Taylor and Linforth, 1996).

Why do we have this complicated flavor perception system? And why do some substances taste good and some bad? Since many poisons have a bitter taste, and even a foul smell, it has been suggested by many that this is our way of limiting what we put in our mouth. Although today, food is clearly marked as such in most surroundings, our forefathers did not have that luxury, and depended on sight, smell, and taste to decide whether something was edible or not. Several studies, old and new, also suggest that food flavors play an important role in food digestion. The flavor of food alone, without swallowing, can cause secretion of saliva, gastric acid, enzymes from the exocrine pancreas, and hormones from the endocrine pancreas. Furthermore, a patient lacking an esophagus, whose food was inserted into the stomach through an artificial opening, needed to also put food in his mouth and taste and chew it in order to gain weight and feel satisfied (Teff, 1996).

4.1. Trigeminal sensing

Burn of peppers and mustards, tingle of carbonation, and coolness of peppermint are all phenomena associated with trigeminal sensing or chemesthesis. Peppermint gives sensations of coolness and sting because menthol stimulates cold fibers and pain fibers and chili peppers evoke burning sensations because capsaicin stimulates heat sensitive pain fibers (Green, 1996).

The irritants, which produce feelings of pungency, tickling, sting, burn, and cooling, are believed to interact with free nerve endings in the epithelium of the mouth and nose by altering Ca^{+2} conductance of nerves. Three classes of these irritants have been proposed: those interacting with nucleophilic groups (HO, H_2N, HS), those that break disulfide bonds (ammonia), and short-chain aliphatic and aromatic alcohols, esters, acids, and monoterpenes, giving e.g. burning and cooling sensations (Laing and Jinks, 1996).

CO_2 affects trigeminal sensing, producing a tingling or tickling effect, but it can also affect the taste qualities of solutions (Cowart, 1998). A trial where 15 subjects rated solutions of sucrose, NaCl, citric acid, and quinine sulfate, both uncarbonated and carbonated, showed that sweetness was reduced by carbonation and sourness increased in a sucrose solution. In NaCl solution, saltiness decreased and sourness increased. Cowart speculates that this might not be a taste-trigeminal interaction, but a taste-taste interaction, since carbonated water may have a slightly sour taste, although some have reported it to be tasteless.

4.2. Effect of different food constituents on flavor

The main components in foods, carbohydrates, proteins, and lipids all have roles in flavor generation and perception. The taste of amino acids and peptides was discussed above (2.1.) and peptides have also been reported to influence flavor and some peptides have their own flavor. A beef peptide, said to be present naturally in beef, is responsible for flavor enhancing properties similar to those of MSG. The predominant influence of proteins on flavor perception is by interactions between flavor components and protein macromolecules. Proteins can bind various aromatic substances or tastants, depending on their polarity and structure, and thus influence flavor release from the foodstuff (Fischer and Widder, 1997).

Lipids have an effect on flavor perception, stability, and generation. A flavor substance may be hydrophilic or lipophilic. When a food contains little or no lipids, a high concentration of lipophilic compounds will be in the air above the food, since it cannot bind to lipids in the food. If lipid content of a food is higher, most of the lipophilic flavorants will be bound to lipids in the food and the concentration in the air above the food is much lower. The headspace concentration of hydrophilic flavorants is not affected as much by the lipid content. Studies have shown that an increase in fat content (for example by adding oil to an aqueous solution of flavorants) results in a decrease of flavor strength and changes the flavor pattern. Flavor release in the mouth from the lipid phase of foods is slower than from the water phase, so the maximum flavor intensity is perceived later than that of hydrophilic flavorants. Lipids in food also affect the stability of flavors. Reduction in fat content means higher flavor loss during processing and storage because of the higher volatility of flavorants (De Roos, 1997).

Carbohydrates affect food flavors in different ways. They give food sweetness, they undergo reactions that form flavor compounds and they interact with flavor molecules, changing their volatility and consequently the sensory perception of the food. Hundreds of chemicals seem to have the structure required to impart sweetness, but only few of these are used in foods. Fructose and xylitol are the only food carbohydrates that are sweeter than sucrose, commonly used as a reference of sweetness. Maillard browning, the reaction of an amino acid with a reducing sugar, produces flavor in foods both through volatile aromatics formed and bitter-tasting polymers. The flavors produced are typically described as caramelized, bready, nutty, roasted, or meaty. Gums and other thickeners have the effect of reducing sweetness, since the perceived sweetness intensity of sucrose decreases after a certain viscosity is reached. Viscosity affects the diffusion of molecules in a mixture, and altering the viscosity (for example by switching thickeners in a formula) may alter the flavor profile of a food since molecules will reach the retronasal cavity at a different time.

Generally carbohydrates decrease slightly the volatility of flavor compounds in water. A few carbohydrates have the opposite effect, especially mono- and disaccharides (Godshall, 1997).

4.3. Individual differences in flavor perception

Individual differences in flavor perception are regarded as noise by some researchers, but are actually very real and can tell us many things about people as instruments. They can be genetical, for example inherited color-blindness, ability to taste phenylthiocarbamide, etc. They can be physiological, for example saliva production and perhaps differences in brain neurology. Differences because of personality can perhaps be divided in two groups, first perceptual differences connected to personality traits, such as very efficient and accurate people being better able to discriminate between samples; second response differences, or how the personality of a person can affect their responses to perception, that is shyness of using the scales, or willingness to please, thus giving higher responses. People can also differ in the way they interpret certain words, so when using people as instruments it is important for researchers to be clear in the meaning of words (Pangborn, 1981).

De Graaf *et al*. (1996) found that age affects flavor perception. A group of elderly people needed a higher concentration of some foodstuffs to report the same flavor intensity as a group of young people and the elderly also had a higher concentration for optimal preferred perceived intensity, that is the concentration where they liked the flavor best.

Food acceptance is of course mainly related to hedonics, at least in the Western world. Flavor is usually more important in determining consumer acceptance of foods than appearance or texture. Generally sweet and salty tastes seem to increase liking and sour and bitter taste decrease it. Age usually raises preferred concentrations of sweet and salty tastes. Odor is not as clear, but it seems that exposure to odors modifies liking and age raises preferred concentrations. Trigeminal stimulation is generally unpleasant, but seems to grow more desirable with increased exposure, as is well known with chili pepper. The majority of food preferences seem to develop in the first few years of life, when children are exposed to the food practices of their family and culture. In the modern world, preferences change more during adulthood than in traditional communities and are effected by e.g. health concerns and exposure. Exposure to a taste or odor definitely seems to increase liking as has been seen through research on infants, children, and young adults. Sour and bitter tastes have not shown the same trend with adults, where repeated exposure did not increase liking.

When a substance in food is in its natural state, increasing concentrations usually increase hedonic response, up to a point where it starts decreasing again. With irritants and trigeminal stimulants, increasing concentrations usually decree decreasing hedonic response (Tuorila, 1996).

Studies have shown that elderly people prefer foods with stronger flavor, while young subjects preferred lower flavored versions of the same foods. Odor perception is known to diminish with age and it is theorized that by adding flavorants and/or odorants to foods, elderly people will eat more of them because of higher preference, diminishing the likelihood of malnutrition (Griep *et al.*, 1997).

Cross-cultural differences in flavor perception are of particular interest to many researchers. It seems clear that different cultures have different food traditions, and ingredients and spices that are part of everyday life for one country are completely foreign and unpalatable to people from another country. Adaptation effects are probably part of the explanation, since people are used to a certain flavor from childhood. Also supporting that theory is the fact that when people are introduced to new foods they may not like them at first, but that changes when they adapt to them. One of the main reason researchers focus on cross-cultural differences is to see if a food sold in one country is marketable in another country.

Japanese and Australian consumer panels evaluated orange juice, cornflakes, and ice cream at four different sucrose levels each. Sweetness intensity, sweetness liking, sweetness just right, and overall liking were among factors rated. Few differences were between panels in perception of taste and flavor intensities. Australians rated creaminess of ice cream and flavor intensity of orange juice greater than Japanese and saltiness intensity of cornflakes lower. No differences were in perceived sweetness intensity. Both cultures liked the same concentrations of sugar in orange juice best and the same least, although Japanese had higher hedonic rating for sweeter samples than Australians. Australians, on the other hand, gave higher hedonic ratings to all sweetness levels of cornflakes, but both liked the same concentration best. Both groups liked highest sweetness best. Japanese had higher liking of all sweetness levels in ice cream, but optimal sweetness was similar for both. The effect of liking of sweetness on overall liking of a product was different. For the Japanese panel sweetness was important in overall liking of cornflakes, but saltiness for Australians (Prescott *et al*., 1997).

Japanese and Australian consumer panels also evaluated orange juice and salad dressing in which citric acid concentration had been manipulated, grapefruit juice with manipulated caffeine concentration, and cornflakes with manipulated sodium chloride concentration. Ratings were given for intensity, liking, just right, and a variety of sensory attributes. The panels gave similar intensity ratings for sourness in orange juice and salad dressing, bitterness in grapefruit juice, and saltiness in cornflakes. Both panels rated the same level of citric acid in orange juice as optimal, but Japanese gave higher hedonic ratings to high levels than Australians did. Increasing bitterness in grapefruit juice by adding caffeine had similar effects on both panels, liking decreased as bitterness increased. Australians liking for cornflakes decreased as the salt above normal levels increased, but no marked difference for liking was seen among Japanese. The optimal level of salt was the same for both panels, and Australians gave higher overall ratings. One of the most prominent cross-cultural differences detected in this study was that the Japanese panel seemed to be more tolerant of variations in taste intensities. This could be because of different rating behavior, that is constantly giving higher ratings, or because of an unwillingness to give critical ratings (Prescott *et al*., 1998).

Flavor perception is of course strongly related to odor perception, since odors are a large part of flavors. Similarities in the psychology are therefore seen. Cultural differences in flavor perception are known to occur, and perhaps particularly in hedonic rating and general liking of different foods. Flavor perception also changes with age and not only is perceived intensity lowered but optimal intensity is raised (De Graaf *et al*., 1996).

5. FISH AROMAS AND FLAVORS

Fish flavors are mainly characterized by the volatile compounds in fish. Ólafsdóttir and Fleurence (1998) present a good review on the main groups of fish odors. These are species related fresh fish odor, microbial spoilage odor, oxidized odor, environmentally derived odor, and processing odor. The last is not of interest when dealing with fresh fish, but is relevant for example in ripening of herring and anchovies. The fresh fish odor is prevalent during the first few days after catching. After that oxidation products and microbial metabolites dominate the aroma of fish.

The compounds associated with fresh fish flavors are mostly 6-, 8-, and 9-carbon aldehydes, ketones and alcohols derived from the unsaturated fatty acids characteristic of fish by lipoxygenase activities. Six carbon compounds (hexanal, *trans*-2-hexenal, *cis*-3-hexenal) provide green plant-like aromas. They are connected to freshwater fish and are usually not found in saltwater species. Eight carbon compounds (1-octen-3-ol, 1-octen-3-one, 1-*cis*-5-octadien-3-ol, 1-*cis*-5-octadien-3-one) seem to occur in most types of fish and seafood and contribute heavy plant-like odors and metallic-like flavors. The nine carbon compounds (3,6-nonadienal, 2,6-nonadienal, 3,6-nonadienal) contribute fresh, green, cucumber-like odors and flavors and are found in some fish species, particularly freshwater species. These fresh fish compounds are similar to those found in some vegetables, as can be seen from their typical aromas. They are produced by lipoxygenases in plants as well as in fish, though the pathways are somewhat different. The eight carbon alcohols and ketones, which are found in all fish that have been surveyed, are also found in mushrooms. These compounds alone have mushroom or geranium-like aromas, but in freshly harvested fish they contribute heavy plant-like aromas. The nine carbon compounds are found in cucumber and melons and contribute a cucumber and melon-like aroma to the fish in which they are present. Hexanal and 2-hexenal contribute green-plant-like aldehyde aromas. They are found in all freshwater fish and hexanal has been found in 5-6 days old saltwater fish. Table 1 summarizes these compounds and the aroma and aroma thresholds for some of them.

It has been found that saltwater fish contain bromophenols, but they are scarce in freshwater species. If low concentrations of bromophenols are mixed into freshwater fish muscle tissue the resulting flavor is marine-like, salty, shrimpy, and iodine-like. Iodine-like off flavors in shrimp have been connected to abnormally high levels of 2,6-dibromophenol (Lindsay, 1990). 2,6-Dibromophenol and 2,4,6-tribromophenol provide iodine-, shrimp-, crab-, and sea salt-like flavor to fish and shrimp muscle tissue and oil matrices. Monobromophenols (2-, 3-, 4-) enhance sweet seafood-like flavor in the same matrices. In water solutions all the bromophenols are iodine-like, phenolic or medicinal. Since these chemicals have not been detected in freshwater fish they are believed to be derived from dietary or environmental sources in the ocean (Boyle *et al.*, 1992). Research on wild and cultivated prawns in Australia

(Whitfield *et al.*, 1997) further demonstrated that the bromophenols must be derived from the diet of these animals. Total bromophenol content varied in three different wild species from 9,5 to 1114 ng/g, but in the cultivated species it was less than 1 ng/g. Sensory analysis of these prawns showed that the meat of the wild animals had briny, ocean-like, and prawn-like flavors, while the cultivated prawns were bland. For these Australian prawns, the major dietary components of wild prawn are crustaceans, molluscs, protozoans, and marine worms (polychaetes). Small quantities of nematodes and algae and sea grass are also eaten. Of these, only the algae and marine worms are known to synthesize bromophenols. The cultivated prawns feed on fish meal, plant material, prawn meal, and squid meal. The prawn meal is likely the major contributor of bromophenols in the diet, but it is in much lower concentrations than in the marine worms.

Table 1: Some carbonyls and alcohols reported in fresh fish and their aroma

	Concentration	Threshold	Aroma[#]
1-Penten-3-ol	3-30 ppb	400 ppb	
3-Hexen-1-ol	1-10 ppb		
Hexanal	10-100 ppb		heavy, green, aldehyde
2-Hexenal	1-10 ppb	120 ppb*	green, stinkbug-like
1-Octen-3-ol	10-100 ppb	10 ppb	raw mushrooms
1,5-Octadein-3-ol	10-100 ppb	10 ppb	heavy, earthy, green, mushroom
2-Octen-1-ol	1-20 ppb		
2,5-Octadien-1-ol	1-20 ppb		
1-Octen-3-one	0,1-10 ppb	0,005 ppb	cooked mushrooms
1,5-Octadien-3-one	0,1-5 ppb	0,001 ppb	crushed geranium leaves
2-Octenal	0,1-5 ppb	9,1 ppb*	
6-Nonen-1-ol	0-15 ppb		
3,6-Nonadien-1-ol	0-15 ppb	10 ppb	
2-Nonenal	0-25 ppb	0,08 ppb	
2,6-Nonadienal	0-35 ppb	0,01 ppb	cucumber-like
6-Nonenal	trace		
3,6-Nonadienal	trace		

Josephson and Lindsay (1986), #Lindsay (1990), *Hall and Andersson (1983)

During storage the compounds responsible for the very fresh fish flavors deteriorate through autolytic and microbial reactions. The fresh, planty, and metallic flavors disappear and are replaced with a neutral, flat flavor. When microbes start growing rapidly sulfur compounds, phenols, and certain fatty acids give spoiled and putrid aromas and flavors. Through microbial breakdown of trimethylamine oxide (TMAO) trimethylamine (TMA) is formed and the resulting odor is fishy in a negative way, reminiscent of old, stale fish or dried fish. Freshwater fish generally do not contain TMAO and TMA is not present in freshly harvested marine fish. When high concentrations of TMA have been formed the fish is very undesirable for consumption. TMAO seems to serve an osmoregulatory function in saltwater fish and is normally not found in freshwater fish above trace amounts. Dimethylamine, which has an ammoniacal aroma, is formed along with formaldehyde from enzymatic activity in fish muscle. It is formed in frozen fish rather than TMA, which is dominantly formed in storage above freezing temperatures. The enzymatic activity is also associated with toughening of fish muscle. It appears that the formaldehyde crosslinks with proteins, thus changing the texture.

Dimethyl sulfide and methyl mercaptan have both been reported to contribute off-odors and flavors in fish and are usually formed microbially.

Autoxidation of fish lipids during storage gives off undesirable flavors. *cis*-4-Heptenal is formed through degradation of *trans*-2,*cis*-6-nonadienal by autoxidizing lipid systems. It has been reported to have putty, painty and linseed oil-like aromas at high concentrations, cardboardy at lower concentrations and to posses a cold boiled potato aroma. It does not seem to contribute fishy flavors, but enhances burnt, fishy cod liver oil-like flavors from 2,4,7-decatrienals (Josephson *et al.*, 1983; Josephson *et al.*, 1984; Lindsay *et al*., 1986; Lindsay, 1990; Kawai, 1996).

The major volatile compounds found in the headspace of some tropical prawns after less than 8 days storage on ice were trimethylamine, 2-methyl-2-propanamine, o-3-methylbutyl hydroxylamine, o-2-methylpropyl hydroxylamine, methyl disulfide, carbon disulfide, methyl (methyl thio) methyl sulfide, and ethyl butyrate. Most of these compounds are formed through bacterial breakdown of amino acids and other bioavailable compounds in the shrimp (Chinivasagam *et al*., 1998).

Prell and Sawyer (1988) documented the flavor profiles of 17 ocean fish species. They classified the species in a tree diagram according to dominant characteristics and found that haddock, wolffish, tilefish, pollock, cod (market), flounder, and cusk formed one branch, all having relatively low total flavor intensity and fresh fish note and slight sweet, salty, and sour notes. All except flounder also had a slight shellfish flavor. Whiting, white hake, and cod (scrod) formed a second branch, similar to the first but lacking the shellfish flavor and possessing instead an earthy note. Halibut, weakfish, and striped bass had a moderate flavor intensity, and distinctive fish oil, gamey, and sour notes. These comprised the third branch. The fourth branch contained bluefish and mackerel with high flavor intensity, fish oil, and sour notes and low gamey notes. Monkfish (low flavor intensity, full, shellfish, salty, fresh fish, and sweet), Grouper (low flavor intensity, slight fresh fish, sour and shellfish, sweet and salty, sour), and Swordfish (low flavor intensity, sweet, fresh fish, shellfish, full, nutty-buttery, fish oil) did not seem to fit into any branch and did not make up a branch of their own, suggesting independent flavor groups for these species.

Chambers and Robel (1993) documented flavor profiles of 11 freshwater species. In these species saltiness is much lower than in ocean fish and many have a white meat (as cooked chicken breast) characteristic not noted in ocean fish. Many attributes are similar, for example metallic, bitter, and sour tastes. Fresh fish aftertastes were common in both studies and white meat, metallic, and astringent aftertastes for the freshwater species. In the ocean species a sour aftertaste was often noted.

6. CONSUMER PERCEPTION OF FISH FLAVORS

Even though fish and fish products are an important source of nutrients in many countries, and health professionals encourage more fish consumption, research on consumer perception of fish seems to be scant. Many consumers in the Western world feel they should eat more fish and are certain that fish is healthy. Sörensen *et al*. (1996) tried to connect consumers' attitudes to their likelihood of buying and liking fresh fish in connection with some other products. Most consumers perceived the fresh fish to be healthy and promote well being, but that did not affect their likelihood of buying the fish. The main predictors of buying less fresh fish were the negative consequences associated with fish: that buying it was complicated as it required a trip to the fishmongers and that preparing and eating it was too time consuming and difficult.

Many people also associate fish with "fishy" odors and the smell of TMA and do not like the flavor of fish. In parts of the world far away from the ocean fresh saltwater fish is rare and the "fresh" fish is often close to two weeks old when the consumers see it, not helping these assumptions. In an experiment that had the main objective to asses the theory of planned behavior (Bredahl and Grunert, 1997) some conclusions about the behavioral pattern of buying and consumption of fish could be drawn about the Danish consumer. Taste was by far the most influential factor and the consumers' belief of getting a light feeling of satiety was also important. The perceived healthiness was important for deciding to buy frozen fish or shrimp, but not fresh fish. Price and nutritional value had little effect, but the perceived ability to prepare a tasty dish from the raw material was important. The main conclusions of the experiments were that marketing strategies for seafood need to focus less on the health aspects, which consumers seem to be aware of already, and more on making the preparation of seafood meals easy and desirable.

Hamilton and Bennet (1983) used small (21-34) groups of consumers with little training to evaluate nine fish species. Whiting, cod, plaice, haddock, ling, dab, blue whiting, saithe, and lemon sole were evaluated. The consumers could clearly discriminate between all the species and in paired preference tests consumers usually demonstrated a preference for one sample, although it was not significant in most cases. Appearance, texture, flavor and acceptability were rated on a 5 point hedonic scale and regression tests performed to see which factors were most important in determining acceptability. Texture and flavor turned out to be highly correlated and both correlated strongly with acceptability, indicating that flavor alone was enough to model both. Appearance was somewhat correlated to acceptability, but after removing two species appearance had little affect. The strength of preference was not high, indicating that consumers would not react adversely to changing of species, especially in products such as fish fingers.

7. CONCLUSIONS

Fish is an important source of protein and other nutrients in many parts of the world and some countries (including Iceland) rely heavily on fish export for their income. Research and reports on fishing practices, fish storage, and fish quality are abundant, most performed with the fish processing factories and distributors in mind. On the other end of the chain, the health sector has performed extensive research on the healthiness of fish and fish oils and encourages consumers to eat more fish, fresh or frozen. Sadly, little research seems to be done on how to entice the consumers to buy and prepare fish and on their perception of fish as food. In Iceland haddock is the fish most eaten, and it is usually boiled or fried and eaten with potatoes and butter. In southern Europe fish is seen in many delightful preparations, especially salted cod, or baccalao. The trend in countries not adjacent to the sea seems to be to "disguise" the fish with batter and sauces, so it can hardly be tasted. This usually means deep-frying the fish in batter, thus increasing the fat content, so the fish is not as healthy. In many countries fish consumption is decreasing in the younger generations. Understanding the needs of consumers as those who buy and prepare fish could help the marketing of fish.

In this paper several psychological factors that are at work in odor and flavor perception have been mentioned. Many of these can surely be connected to consumers' attitudes towards fish. Perhaps some negative attitudes towards fish and the automatic connection of fish to "fishy", TMA-like odors can be attributed to negative memories from childhood. "Eat your fish, it's healthy" is a sentence many young adults of today may have heard as children. The fish may not have been as fresh as it should be so the smell of fish is connected to nagging parents and other bad memories.

The easy availability of other food and "fast-food", "TV-dinners", and other quickly prepared combinations also contribute to the decline in fish consumption. Understanding the needs of consumers and preparing easy to make fish dishes is important to increase fish consumption. The fish industry research should start focusing not only on the processors and distributors but more on consumers and on making the buying and preparing of fish easy for them.

8. REFERENCES

Ayabe-Kanamura, S., Schicker, I., Laska, M., Hudson, R., Distel, H., Kobayakawa T., Saito, S., 1998. Differences in perception of everyday odors: a Japanese-German cross-cultural study. *Chem. Senses* 23: 31-38.

Bell, G.A., 1996. Molecular mechanisms of olfactory perception: Their potential for future technologies. *Trends Food Sci. Techn.*, vol. 7.

Boyle, J.L., Lindsay, R.C., Stuiber, D.A., 1992. Contributions of Bromophenols to marine-associated flavors of fish and seafoods. *J. Aq. Food Prod. Techn*., vol. 1(3/4).

Bredahl, L., Grunert, K.G., 1997. An application of the theory of planned behavior to explain consumption of fish and shellfish in Denmark. The Aarhus school of business, center for market surveillance, research and strategy for the food sector, MAPP working paper no. 44.

Cain, W.S., de Wijk, R., Lulejian, C., Schiet, F., See, L., 1998. Odor identification: perceptual and semantic dimensions. *Chem. Senses* 23: 309-326.

Chambers, E., Robel, A., 1993. Sensory characteristics of selected species of freshwater fish in retail distribution. *J. Food Sci*., vol. 58, no. 3.

Chinivasagam, H.N., Bremner, H.A., Wood, A.F., Nottingham, S.M., 1998. Volatile components associated with bacterial spoilage of tropical prawns. International Journal of Food Microbiology, 42, 45-55.

Cowart, B.J., 1998. The addition of CO2 to traditional taste solutions alters taste quality. *Chem. Senses* 23: 397-402.

Dalton, P., 1996. Odor perception and beliefs about risk. *Chem. Senses* 21: 447-458.

De Graaf, C., van Staveren, W., Burema, J., 1996. Psychophysical and psychohedonic functions of four common food flavours in elderly subjects. *Chem. Senses*, 21: 293-302.

De Roos, K.B., 1997. How Lipids Influence Food Flavor. *Food Techn.*, vol.51, no.1.

Delwiche, J., 1996. Are there "basic" tastes? *Trends Food Sci. Techn.,* vol. 7.

Elmes, D.G., 1998. Is there an inner nose? *Chem. Senses* 23: 443-445.

Fischer, N., Widder, S., 1997. How Proteins influence food flavor. *Food Techn*., vol. 51, no.1.

Godshall, M.A., 1997. How Carbohydrates Influence Food Flavor. *Food Techn.*, vol.51, no.1.

Griep, M.I., Mets, T.F., Massart, D.L., 1997. Different effects of flavor amplification of nutrient dense foods on preference and consumption in young and elderly subjects. *Food Quality and Pref.*, 8, 2 p. 151-6.

Green, B.G., 1996. Chemesthesis: Pungency as a component of flavor. *Trends Food Sci. Techn.*, vol. 7.

Hall, G., Andersson, J., 1983. Volatile fat oxidation products I. Determination of odour thresholds and odour intensity functions by dynamic olfactometry. Lebensm. -Wiss. u. -technol., 16, 354-361.

Hamilton, M., Bennett, R., 1983. An investigation into consumer preferences for nine fresh white fish species and the sensory attributes which determine acceptability. *J. Food Techn.* 18, 75-84.

Horia, T., Kawamura, Y., 1998. Influence of physical exercise on human preferences for various taste solutions. *Chem. Senses 23*: 417-421.

Hulshoff Pol, H.E., Hijman, R., Baaré, W.F.C., van Ree, J.M., 1998. Effects of context on judgements of odor intensities in humans. *Chem. Senses*, 23: 131-135.

Josephson, D.B., Lindsay, R.C., Stuiber, D.A., 1983. Identification of compounds characterizing the aroma of fresh whitefish (*coregonus clupeaformis*). *J. Agric. Food Chem.*, 31, 326-330.

Josephson, D.B., Lindsay, R.C., Stuiber, D.A., 1984. Variations in the occurrences of enzymically derived volatile aroma compounds in salt- and freshwater fish. *J. Agric. Food Chem*., 32, 1344-1347.

Josephson, D.B., Lindsay, R.C., 1986. Enzymic generation of volatile aroma compounds from fresh fish. In*: Biogeneration of aromas*, American Chemical society, 201-219.

Kandel, E.R., Schwartz, J.H., 1991. Principles of Neural Science, 2nd edition, chapter 32, Elsevier, New York.

Kawai, T., 1996. Fish Flavor. *Crit. Rev. in Food Sci. and Nutr*., 36(3), 257-298.

Kirimura, J., Shimizu, A., Kimizuka, A., Ninomiya, T., Katsuya, N., 1969. The contribution of peptides and amino acids to the taste of foodstuffs. *J. Agr. Food Chem*., Vol. 17, no.4.

Laing, D.G., Jinks, A., 1996. Flavour perception mechanisms. *Trends Food Sci. Techn.*, vol. 7.

Lavin J.G., Lawless, H.T., 1998. Effects of color and odor on judgments of sweetness among children and adults. *Food Qual. Pref.*, vol.9, no.4, pp. 283-289.

Lawless, H.T., Heymann, H., 1998. Physiological and psychological foundations of sensory function, chapter 2, Sensory evaluation of food - principles and practices, Chapman and Hall, New York.

Lesschaeve, I., Issanchou, S., 1996. Effects of panel experience on olfactory memory performance: influence of stimuli familiarity and labeling ability of subjects. *Chem. Senses* 21: 699-709.

Lindsay, R.C., Josephson, D.B., Olafsdottir, G., 1986. Chemical and biochemical indices for assessing the quality of fish packaged in controlled atmospheres. In: *Seafood Quality Determination*, Proceedings of an international symposium coordinated by the University of Alaska sea grant college program, Kramer, D.E., Liston, J., (ed), Elsevier, Amsterdam, 221-234.

Lindsay, R.C., 1990. Fish Flavors, *Food Rev. Int.*, 6(4), 437-455.

Nakagawa, M., Mizuma, K., Inui, T., 1996. Changes in taste perception following mental or physical stress, *Chem. Senses* 21: 195-200.

Noble, A.C., 1996. Taste-aroma interactions, *Trends Food Sci. Techn.*, vol. 7.

Ólafsdóttir, G., Fleurence, J., 1998. Evaluation of fish freshness using volatile compounds- Classification of volatile compounds in fish. In: *Methods to Determine the Freshness of Fish in Research and Industry*, Proceedings of the Final meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3 CT94 2283. Nantes Nov 12-14, 1997. International Institute of Refrigeration, 55-69.

Pangborn, R., 1981. Individuality in responses to sensory stimuli, *In:* Criteria of food acceptance, *J. Solms, R.L. Hall* (ed), Forster Publishing Ltd, Switzerland, p. 177-219.

Pierce, J., Halpern, B.P., 1996. Orthonasal and retronasal odorant identification based upon vapor phase input from common substances, *Chem. Senses* 21: 529-543.

Pointer, S.C., Bond, N.W., 1998. Context-dependent memory: colour versus odour, *Chem. Senses* 23: 359-362.

Prell, P.A., Sawyer, F.M., 1988. Flavor profiles of 17 species of north Atlantic fish, *J. Food Sci*., vol. 53. no.4.

Prescott, J., Bell, G.A., Gillmore, R., Yoshida, M., O'Sullivan, M., Korac, S., Allen, S., Yamazaki, K., 1997. Cross-cultural comparisons of Japanese and Australian responses to manipulations of sweetness in foods, *Food Qual. Pref.*, vol. 8, no. 1. 45-55.

Prescott, J., Bell, G.A., Gillmore, R., Yoshida, M., O'Sullivan, M., Korac, S., Allen, S., Yamazaki, K., 1998. Cross-cultural comparisons of Japanese and Australian responses to manipulations of sourness, saltiness and bitterness in foods, *Food Quality and Pref.*, 9, 1/2, pp 53-66.

Shallenberger, R.S., 1996. The AH, B glycophore and general taste chemistry. *Food Chem.*, 56, 3, 209-214.
Stevens, D.A., 1996. Individual differences in taste perception, *Food Chem.*, Vol. 56, No.3. 303-311.

Stevens, J.C., 1996. Detection of tastes in mixture with other tastes: issues of masking and aging, *Chem. Senses* 21: 211-221.

Sörensen, E., Grunert, K.G., Nielsen, N.A., 1996. The impact of product experience, product involvement and verbal processing style on consumers' cognitive structures with regard to fresh fish, The Aarhus school of business, center for market surveillance, research and strategy for the food sector, MAPP working paper no. 42.

Taylor, A.J., Linforth, R.S.T., 1996. Flavour release in the mouth, *Trends Food Sci. Techn.*, vol. 7.

Teff, K.L., 1996. Physiological effects of flavor perception, *Trends Food Sci. Techn.*, vol. 7.

Tuorila, H., 1996. Hedonic responses to flavor and their implications for food acceptance, *Trends Food Sci. Techn.*, vol. 7.

Tuorila, H., Theunissen, M.J.M., Ahlström, R., 1996. Recalling taste intensities in sweetened and salted liquids, *Chem. Senses* 21: 29-34.

Vanne, M., Tuorila, H., Laurinen, P., 1998. Recalling sweet taste intensities in the presence and absence of other tastes. *Chem. Senses* 23: 295-301.

Whitfield, F.B., Helidoniotis, F., Shaw, K.J., Svoronos, D., 1997. Distribution of bromophenols in Australian wild-harvested and cultivated prawns (shrimp), *J. Agric. Food Chem.* 45, 4398-4405.