DOCTORAL THESES IN FOOD SCIENCES AT THE UNIVERSITY OF TURKU

The Importance of Natural Colors in Food for the Visual Attractiveness of Everyday Lunch

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To my grandchildren

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ABSTRACT

Food is always seen to possess colors. Colors are one of the first sensory stimuli in the perception of food, and color cues are utilized to imagine the expected taste, flavor and liking of food. Although the importance of visual signals and aesthetics at the buying stage of products has been recognized, the color-related determinants of visual attractiveness of everyday food is an under-investigated theme.

The aim of this thesis was to investigate the influence of natural colors and color combinations on the visual attractiveness of food. The focus was on typical foodstuffs (vegetables having a wide range of colors) consumed at Finnish everyday lunches. In the experiments, both quantitative consumer studies and qualitative interviews were conducted. Food components' color values (L^*, a^*, b^*) were measured by digital image analysis and different color dimensions were calculated to describe color combinations in food. In addition, the interdependence of the color-related attractiveness of food and individual attitudes was investigated.

Colors and color combinations in food were found to influence the visual attractiveness of food by contributing to the identification of food components, generating expectations about taste, freshness and quality of food, and influencing the overall attractiveness of appearance. In general, colorful, typical, bright, and vivid colors in lunch food were found attractive. Color contrasts and color variation were found to increase the impression of variety, and consequently the preferred complexity of food. In addition, colors were used to estimate the degree of freshness, also associated with attractiveness.

The influence of colors on the visual attractiveness of food was found to be important but unconscious, difficult to verbalize, and individual-dependent. Visually attractive and aesthetically pleasing lunch food was described as easy to identify and recognize (perceptual fluency). Consequently, the presence of clear and typical colors in food that improved the easy and quick observation and identification of food components were preferred. At workday lunches, pleasantness, fluency, functionality, and tidiness were found to be the color-related determinants of aesthetic pleasure. Color is one part of the holistic multisensory experience of food, and it is preferred that every part of the experience is in congruence.

This study focused on the Finnish everyday lunch context, and the results can be utilized to improve the visual attractiveness of food, and consequently, to nudge people to select a healthier diet with more vegetables. The results and the tools used in this thesis can be applied in further research to investigate the color-related determinants of visual attractiveness and aesthetic pleasure in food in various contexts.

TIIVISTELMÄ

Ruoka nähdään aina väreissä. Tyypillisessä arkipäivän ruokailutilanteessa ruoan värit ovat yksi ensimmäisistä ruoasta havaittavista ominaisuuksista ja niiden avulla voidaan arvioida ruoan odotettavissa olevaa makua, flavoria ja ruoasta pitämistä. Vaikka visuaalisten signaalien ja estetiikan tärkeys tuotteiden ostohetkellä on yleisesti tunnustettu, arkiruoan värien merkitystä visuaalisessa houkuttelevuudessa on tutkittu vain vähän.

Tämän väitöskirjan tavoitteena oli tutkia ruoan luonnollisten värien ja väriyhdistelmien vaikutusta ruoan visuaaliseen houkuttelevuuteen. Tutkimuksessa keskityttiin tyypillisiin suomalaisella arkilounaalla tarjolla oleviin elintarvikkeisiin (värikkäisiin kasviksiin). Tutkimusmenetelminä olivat sekä kvantitatiiviset kuluttajatutkimusmenetelmät että kvalitatiiviset haastattelumenetelmät. Ruoka-aineiden väriarvot (L^*, a^*, b^*) mitattiin digitaalisen kuva-analyysin avulla, ja väriarvojen perusteella laskettiin erilaisia väriyhdistelmiä kuvaavia muuttujia. Lisäksi tutkittiin, miten henkilökohtaiset asenteet vaikuttavat arvioitaessa väreihin liittyvää ruoan houkuttelevuutta.

Ruoan värien ja väriyhdistelmien todettiin vaikuttavan ruoan ulkonäön houkuttelevuuteen. Ruoan värit helpottivat ruokakomponenttien tunnistamista ja aikaansaivat ennakko-odotuksia ruoan mausta, tuoreudesta ja laadusta. Värikkäitä, kirkkaita, vahvoja ja kullekin ruoalla tyypillisiä värejä pidettiin lounasruoassa houkuttelevina. Värikontrastien ja värien moninaisuuden todettiin lisäävän vaikutelmaa ruoan vaihtelevuudesta ja kompleksisuudesta, joita yleensä pidettiin toivottuina ominaisuuksina ruoassa.

Ruoan värien vaikutus ruoan visuaaliseen houkuttelevuuteen arvioitiin tärkeäksi, mutta tiedostamattomaksi, vaikeaksi sanallistaa ja yksilökohtaiseksi. Visuaalisesti houkutteleva ja esteettisesti miellyttävä lounasruoka kuvailtiin yleensä helposti tunnistettavaksi ja sujuvasti havaittavaksi. Ruoalle tyypillisiä ja selkeitä värejä, jotka edistivät helppoa ja nopeaa ruoan havainnointia ja ruokakomponenttien tunnistamista, pidettiin houkuttelevina. Lounasruoan väreistä saatavaan esteettiseen mielihyvään liittyviksi tekijöiksi todettiin miellyttävyys, sujuvuus, funktionaalisuus ja siisteys. Ruoan värit koettiin yhdeksi osaksi moniaistista ruokakokemusta, jossa kaikkien osa-alueiden toivottiin olevan keskenään yhteensopivia.

Tämä tutkimus keskittyi suomalaiseen arkipäivälounaaseen ja tutkimuksen tuloksia voidaan käyttää hyväksi parannettaessa ruoan visuaalista houkuttelevuutta, jonka avulla kuluttajat voidaan saada valitsemaan terveellisempää, enemmän kasviksia sisältävää ruokaa. Tämän väitöskirjan tuloksia ja menetelmiä voidaan hyödyntää ja soveltaa tutkittaessa ruoan visuaaliseen houkuttelevuuteen ja esteettiseen miellyttävyyteen liittyviä väritekijöitä erilaisissa konteksteissa.

LIST OF ABBREVIATIONS

*a**	CIE color value for green to red
ANOVA	analysis of variance
ASTM	American Society for Testing and Materials
*b**	CIE color value for blue to yellow
*C**	color dimension for chroma
CIE	Commission Internationale d'Eclairage
CIELAB	color space (using values *L**, *a** and *b**) standardized by CIE
CVPA	centrality of visual product aesthetics
CVS	computer vision system
*D**	color dimension for depth
DIN	Deutsche Institut für Normung
ΔE	total color difference
FNS	food neophobia scale
GHI	general health interest
*h**	color dimension for hue angle
HSD	honestly significant difference
HSV	hue, saturation, value
*L**	CIE color value for lightness
PAD	pleasure, arousal, dominance
PLS	partial least square
PROP	6-n-propylthiouracil
RGB	red, green, blue
S^+	color dimension for saturation
USC	University of Southern California
*V**	color dimension for vividness
VIMAP	the Vienna integrated model of top-down and bottom-up processes in art perception
λ	wavelength

LIST OF ORIGINAL PUBLICATIONS

I. Paakki, M., Sandell, M., & Hopia, A. (2016). Consumer's reactions to natural, atypically colored foods: an investigation using blue potatoes. *Journal of Sensory Studies,* 31, 78–89.

II. Paakki, M., Sandell, M., & Hopia, A. (2019). Visual attractiveness depends on colorfulness and color contrasts in mixed salads. *Food Quality and Preference,* 76, 81–90.

III. Paakki, M., Aaltojärvi, I., Sandell, M. & Hopia, A. (2019). The importance of the visual aesthetics of colours in food at a workday lunch. *International Journal of Gastronomy and Food Science,* 16, 100131.

1 INTRODUCTION

"We eat with our eyes first" – this saying indicates the importance of visual stimuli in the perception of food. In ordinary eating situations when food is looked at before eaten, the interaction with food usually begins with vision, and visual signals are utilized to imagine the expected taste and flavor and the expectations of liking and palatability (e.g., Cornell et al., 1989; Hurling & Shepherd, 2003; Spence et al., 2010; Wadhera & Capaldi-Phillips, 2014). At the buying stage of products in general, when most attention is usually paid to visual properties, vision is considered the most important modality (e.g., Schifferstein et al., 2013; Fenko et al., 2010). In contrast, at the buying stage of food products, taste is usually rated as the most important argument even though the food products are not actually tasted (Schifferstein et al., 2013). However, this even highlights the significance of visual signals, because the-taste-without-tasting refers to the expectation of taste that is mostly based on the visual appearance. The entirety of the visual appearance of food consists of many different attributes, such as color, gloss, texture, shape, and size, of which color is one of the most obvious visual cues (Delwiche, 2012). In normal lighting conditions, food products are always seen to possess colors, and color is an intrinsic attribute of appearance (e.g., Francis 1995; Cardello, 1996; Hutchings, 1999; Spence et al., 2010).

In everyday life, colors in food are mostly associated with colors in vegetables, fruits or berries, due to the wide range of colors and colorfulness in these foodstuffs. At the same time, vegetables, fruits and berries form an essential part of a healthy diet due to their content of useful compounds, such as fiber, vitamins, minerals etc. The recommended consumption of vegetables, fruits and berries in a healthy diet is five portions (about 500 g) per day (Finnish Nutrition Recommendations by National Nutrition Council, 2014; World Health Organization, 2015). In addition to nutritional reasons, more vegetables, fruits and berries in the diet also means more sustainable eating. Unfortunately, their actual consumption often remains below these recommendations. In Finland, only 14% of men and 22% of women eat in line with the recommendations (Valsta et al., 2019) although they are quite well informed about the benefits of consuming more vegetables, fruits and berries. It has become evident that rational information alone is not enough to motivate people to eat healthily (Kleef & Trijp, 2018). It has been believed that consumer judgments are based mainly on cognitive processes and objective decision-making, and usability and efficiency perspectives have dominated. Today, it is supposed that visual appeal, aesthetics, and emotions have at least an equally important impact on the evaluation of products (e.g., Bhandari et al., 2019; Wiedmann et al., 2019). In 2008, a method called "nudging" was introduced to effect consumers' choices by means of subtle guiding (Thaler & Sunstein, 2008). For food choices, Spence (2020), for example, has stated that enhancing the appeal of leafy greens could nudge people towards consuming more salads and consequently towards a healthier diet. Walmsley et al. (2018) found layout changes in grocery stores nudged people to purchase more fruits and vegetables, and they considered nudging an effective tool to promote healthy behaviors. Nudging is considered to be an appropriate method especially in the situations when there is no immediate feedback, such as a health benefit that is positioned far in the future (Kleef & Trijp, 2018).

Colors, being an intrinsic part of visual information, are also an essential part of visual aesthetics. In aesthetic science, visual attractiveness has been found to be based on the balance and harmony of colors and color combinations (e.g., Hård & Sivik, 2001). Commonly, many everyday judgments and decisions are based on aesthetic responses to products (e.g., Palmer et al., 2013). For example, people may choose one product instead of another according to a preference for its color and consequently for its more aesthetically pleasing appearance, although they seldom think over what their preferences are or why they have them (Palmer et al., 2013). Over the last ten years, marketers have recognized the importance of aesthetic appeal (Patrick, 2016). Further, food liking and eating satisfaction are found to depend on visual factors such as aesthetics, variety, and attractive presentation (e.g., Carins et al., 2020; Michel et al., 2015; Rowley & Spence, 2018; Zellner et al., 2014a). However, investigations related to the colors and aesthetics of food have concentrated on the visuality of plating, and especially on fine dining (e.g. Spence et al., 2014; Velasco et al., 2016; Zellner et al., 2010), and the color-related aesthetics of everyday food itself is an under-investigated theme.

The overall aim of this thesis was to obtain a more profound understanding of the meaning of colors in food and of the influence of natural colors and color combinations on the visual attractiveness of food in an everyday lunch. Due to the multifaceted nature (both conscious and unconscious) of the meaning of colors, both quantitative and qualitative studies were conducted. In addition, CIELAB color values were measured to calculate different color dimensions to describe colors and color combinations in food and to research the relationship between color dimensions and attractiveness. The workday lunch (eaten in a restaurant or similar) is selected as a research context because of its importance in the Finnish diet. Lunch accounts for almost a quarter of the daily energy intake in Finland, and more than 20% of men and about 25% of women have their daily workday lunch at a staff canteen (Valsta et al., 2019). At a Finnish lunch, the quality of food has been found to be the most important criterion for the selection of the restaurant (Varjonen & Peltoniemi, 2012), and the food itself has been found to be one of the key elements for a successful lunch experience (Ala-Harja et al., 2019). In this study, the focus was on the naturally colorful and typical vegetables served at Finnish workday lunches. No modified lighting or artificial dyes were used in order to avoid their potentially negative influence on consumers, especially artificial colorings (e.g., Shim et al., 2011; Song & Im, 2018; Román et al., 2017). In everyday eating situations, such as workday lunches, the presentation of food typically consists of non-colored plates, containers, and cutlery, and consequently the colors of foodstuffs play a significant role in visual attractiveness. Consequently, the focus of this thesis was on colors and the color combinations in food itself.

In the literature review, the center of interest was on color meaning and the different roles of colors in food. In addition, research concerning the role of colors and color combinations in visual aesthetics, attractiveness, and pleasantness of food are reviewed.

The experimental part of the thesis consisted of three studies with the following aims: to investigate the influence of an atypical color in food on consumers' response and choice (Study I), to investigate the impact of different color attributes and different dimensions of color combinations on the visual attractiveness of food (Study II), and to investigate the color-related aesthetic pleasure in food at workday lunches (Study III).

The data for the thesis was gathered during following research projects: 1. New Flavor Possibilities of Vegetable Foods (funded by Tekes – the Finnish Funding Agency for Technology and Innovation; current name Business Finland) (Study I); 2. The Impact of a Dining Environment on Making Healthy Food Choices (funded by the Finnish Cultural Foundation) (Study II); and 3. Health Supporting Multisensory Food Environment (funded by Business Finland) (Study III).

2 REVIEW OF THE LITERATURE

2.1 Color in food

In everyday talk, “color in food” usually refers to the visible hues of the surfaces, for example red tomatoes, green salads, orange carrots, etc. seen through the eyes of an observer. Color is typically regarded as a characteristic of the object. However, it is obvious that color is not a constant and measurable property like weight or shape. For example, the shape of the object does not vary due to the circumstances like illumination, but illumination has a remarkable effect on colors – in dim lighting all the colors are seen as gray.

Robertson (1992) introduced two different color concepts: 1) perceived color as “the aspect of a visual perceptual phenomenon – distinct from form, shape, size, position, gloss or texture – that enabled a person to distinguish between elements of the visual field and to characterize the elements by color names such as white, black, yellow, red, blue, green, gray, brown, orange, pink, purple and so on,” and 2) psychophysical color as “a characteristic of visible radiation by which an observer may distinguish such differences between fields of view of the same shape, size, position and structure as may be caused by differences in the spectral composition of the radiation.” Psychophysical color is usually specified using quantitatively measured terms like “tristimulus values.”

Both these aspects of color, color perception and the physical appearance of color, are discussed in the following sections (2.1.1 and 2.1.2). A third meaning of the word “color” refers to the colorants. In edible plants, the natural colors derive from special chemical compounds called color pigments. The most common color pigments are introduced in the final section (2.1.3).

2.1.1 Color perception

Color is the perception in the brain resulting from the detection of light after it has interacted with an object (Lawless & Heymann, 2010). Color perception depends both on the observer and the conditions under which the color is observed (Pathare et al., 2013). The basic color sensation of an object is composed of the spectral composition of light, the physical and chemical composition of the object, and the spectral sensitivity of the eye of the observer. The color sensations are processed in the brain to compose the actual color perception (Lübbe, 2008). The term ‘perception’ involves the interpretation of sensations, giving them meaning and organization, whereas ‘sensation’ is defined as referring to the functioning of sensory systems (Foley & Matlin, 2016).

The visual perception of color arises from stimulation of photoreceptors in the retina by light in greater intensities at some wavelengths than others in the visible region (380-770 nm) of the electromagnetic spectrum (Lawless & Heymann, 2010). The light striking an object may be absorbed, reflected, refracted, or transmitted by that object. After the interaction with the object, the light falls on the eye of the viewer, and goes through cornea, aqueous humor, lens, and vitreous humor to the retina of the eye (Packer & Williams, 2003). The visual receptors are located in the retina. These receptors contain light-sensitive pigments. Stimulated by light energy, these pigments generate electrical nerve impulses that travel along the optic nerves to the brain. Although the stimulus that enters a human eye can be measured and described in physical terms, the actual color perception is the result of the complex processing in the mind (Robertson, 1992; Hutchings, 1999; Lübbe, 2008).

There are two kind of visual receptors in the retina: rods and cones. The rods yield achromatic information and they are capable of operating at low light intensities. The cones operate at higher light intensities and provide chromatic information. The cones are concentrated in fovea (diameter 2 mm) on the retina, where the highest color resolution occurs. There are three different cone types: cones with absorption maxima in long (565- 566 nm), middle (535 - 541 nm) and short (430 – 441 nm) wavelength regions, called S-, M- and L-cones respectively (Lee, 1998; Conway et al., 2018). Traditionally these cones are referred to using the color names red (R), green (G) and blue (B), but actually the colors are the output of the visual system, not the input (Conway et al., 2018). The cone responses represent the initial encoding of color. The second stage of encoding is done by cone-opponent channels called the 'red'-'green' and 'blue'-'yellow' channels (Hurlbert & Ling, 2017). In the 'red'-'green' channel, the L-cone signal is compared with the M-cone signal, whereas in the 'blue'-'yellow' channel, the S cone signal is compared with the combined L- and M-cone signals.

In addition to the instantaneous cone responses, the colors seen are determined by the cone responses that have preceded them in time and that are surrounding them in space (Hurlbert & Ling, 2017). Chromatic adaptation contributes to colored afterimages and the phenomenon of color constancy, for example. keeping object colors constant in changing illumination. Simultaneous chromatic contrast enables better detection of the object by enhancing the apparent differences between object and background.

How color is encoded in the cortex is still a challenging scientific question – for example, it is not fully known which neural regions compute conscious hue experiences (Brogaard & Gatzia, 2017; Conway et al. 2018). According to Brogaard and Gatzia (2017), in passive and relatively inattentive viewing, only general features of the color stimulus (e.g., approximate wavelength and relative local contrast) are determined, whereas the determination of a specific hue is a result of attention-demanding post-perceptual processing in higher neural regions.

2.1.2 Description of color

In spite of the fact that the actual color is a perception, the colors of the object (the physical appearance of colors) can be described by physical dimensions. The color of the object can vary in three dimensions: hue, lightness and saturation (or chroma or purity) (Lawless & Heymann, 2010). These physical dimensions are also called objective or psychophysical color terms (Hunt, 1978).

Hue (red, blue, green, etc.) is the attribute most commonly discussed in everyday discussions when describing colors. Hue is the aspect of the percept that differentiates it from white (Shevell, 2003). According to Hunt and Pointer (2011), hue is the attribute of a visual perception according to which an area appears to be similar to one, or to proportions of two, of the perceived colors red, yellow, green, and blue. Monochromatic light (light of a single wavelength) has a characteristic hue. Typical descriptions of hue are violet for 400–450 nm; blue near 470 nm; blue–green for 480–495 nm; green near 500 nm; yellow–green for 520–560 nm; yellow near 580 nm; orange for 600–630 nm; and red for 640–700 nm (Shevell, 2003).

The lightness (or value) of the perceived color of an object indicates the relationship between reflected and absorbed light with no regard to specific wavelength(s) involved (Lawless & Heymann, 2010). According to Shevell (2003), lightness is "the perceived level of emitted light relative to light from a region that appears white." The term 'brightness' is also used quite commonly. The sensation of brightness increases with increase in the level of illumination. Brightness is the perceived overall level of emitted light, whereas lightness describes the brightness of objects relative to that of a similarly illuminated white (Hunt & Pointer, 2011). Lightness is said to be relative brightness and it is unaffected by illumination level (MacDougall, 2002).

Chroma is the degree of difference of a hue in comparison to a grey color with the same lightness (Pathare et al., 2013). Chroma is a relative value between a color and an achromatic percept of the same lightness, while saturation is the perceived difference between a color and white regardless of lightness (or brightness) (Shevell, 2003). According to Cho et al. (2017), chroma has relatively poor consistency in visual perceptions, and saturation is the term more familiar to ordinary viewers. Saturation is defined as "the proportion of pure chromatic color in the total color sensation (Lübbe, 2013)." The color intensity is related to the chroma values and human perception: The higher the chroma values, the higher is the color intensity of samples perceived by humans (Pathare et al., 2013). The color purity refers to color saturation: a pure color is fully saturated. The color purity represents the proportion of one monochromatic component (consisting of a single wavelength of light) to the total color mixture (Pridmore, 2007).

In addition, Berns (2014) introduced the following color attributes: vividness (the degree of departure of the color from a neutral black color), depth (the degree of departure of the color from a neutral white color), and clarity (the degree of departure of the color from its background color). According to Berns's definition, high values of vividness correspond to 'clean' and 'bright' colors, and low values to 'dull' and 'dirty' ones. The term 'depth' is associated with the strength of the color, higher values of depth representing 'stronger' colors and lower values 'weaker' and 'paler' colors.

2.1.3 Color pigments in plants

The colors of natural plants typically derive from four classes of chemical compounds: chlorophylls, carotenoids, anthocyanins, and betalains. These colored compounds selectively absorb wavelengths of light in the visible region. The most common feature in the molecular structure of these color pigments is the presence of double bonds, either in hydrocarbon chains or in ring structures (Moss, 2002).

The number and quality of the color pigments, and consequently the color of the plants, change during the growth and ripening of the plants. In addition, food processing modifies the compounds and their colors. The most common color pigments in plants and their color changes are discussed in the following sections.

2.1.3.1 Chlorophylls

Chlorophylls are widely distributed natural pigments essential in photosynthesis, a process converting carbon dioxide and water to glucose and oxygen using sunlight. Structurally, chlorophylls are porphyrins with four tetrapyrrole derivatives co-ordinated with magnesium and having an esterified 20-carbon monounsaturated phytol group as a side chain. Chlorophylls, as well as their degradation products pheophytins, are lipophilic due to the presence of the phytol group (Belitz et al., 2009).

The green color of plants derives from chlorophylls *a* and *b* (**Figure 1**). Chlorophyll *a* is blue-green (absorption peak at 663 nm), and chlorophyll *b* is yellow-green (absorption peak at 645 nm) (Timberlake & Henry, 1986; Barrett et al., 2010; Mazzeo et al., 2011). Typically, both chlorophylls *a* and *b* occur together in a ratio varying between 5:1 – 2:1 in favor of chlorophyll *a*. (Belitz et al., 2009).

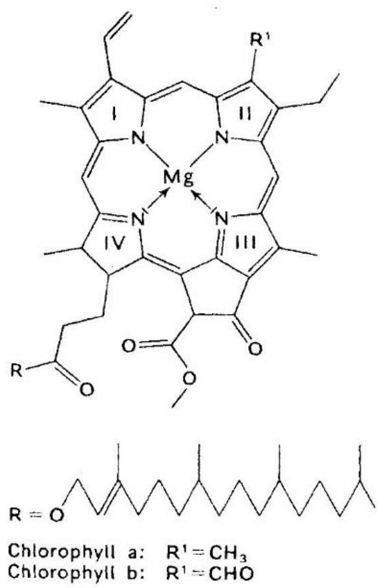

Figure 1. Chlorophylls *a* and *b* (Belitz et al., 2009). Reprinted with permission from Springer Nature.

During ripening and maturation, the green color of the plants often changes to yellow or red. This change is due partly to the degradation of the chlorophylls and partly to the revealing of the hidden pigments (e.g., carotenoids). Color changes due to chlorophyll degradation also occur during food processing. The chlorophylls are sensitive to both heat and acid (Barrett et al., 2010).

Degradation products of chlorophylls are pheophytins, chlorophyllides and pheophorbides. Olive-brown pheophytins *a* and *b* are composed by removing magnesium from the chlorophylls *a* and *b*. Pheophytins can be hydrolyzed to yield pheophorbides *a* and *b* (Belitz et al., 2009). The color change due to the conversion of chlorophylls to pheophytins occurs readily upon heating plant material in a weakly acidic solution; in pH 7 the reaction occurs less readily (Belitz et al., 2009). Replacing magnesium ion with metal ions such as Sn^{2+} or Fe^{3+} yields greyish-brown compounds (Belitz et al., 2009). If Mg^{2+} is replaced by Zn^{2+} and Cu^{2+} (weight ratio 10:1), a stable green-colored complex is formed (Belitz et al., 2009). In addition to chemical reactions, chlorophylls are also degraded by enzymatic reactions. Magnesium dechelatase enzyme converts chlorophylls to pheophytins, and chlorophyllase enzyme removes the phytol group from the chlorophyll molecule, yielding chlorophyllides (Toivonen & Brummell, 2008). Pheophorbides are formed either from pheophytins by chlorophyllase enzyme activity or from chlorophyllides by magnesium dechelatase activity (Toivonen & Brummell, 2008). The enzymes are mostly inactivated when vegetables are blanched, hence chlorophyllides and pheophorbides are rarely detected (Belitz et al., 2009). However, it has been noted that the conversion of chlorophylls to pheophytins continues in blanched vegetables even during frozen storage (Belitz et al., 2009).

Miglio et al. (2008) stated that the green color maintenance of boiled green vegetables derives from changes in surface reflectance and in the depth of light penetration into tissues. This was due to the replacement of air and other dissolved gases in cells by cooking water and cell juices released by membrane deterioration during cooking. However, after prolonged heating, the greenness decreased due to chlorophyll degradation.

2.1.3.2 Carotenoids

Carotenoids provide the yellow, orange or red color of many foods of plant origin (Belitz et al., 2009). In green plants, carotenoids are masked by chlorophylls and when chlorophylls are degraded, the colors of the carotenoids are revealed. In addition, the color changes during ripening can be due to the synthesis of pigments, for example the carotenoid (lycopene) content of the tomato increases greatly during ripening (Belitz et al., 2009). Carotenoids are lipophilic polyene hydrocarbons having a 40-carbon skeleton (**Figure 2**) (Belitz et al., 2009). The color of carotenoids derives from the conjugated double bond system in the molecules. At least 7 conjugated double bonds are needed for a carotenoid to have perceptible color (Meléndez-Martínez et al., 2007; Rodriguez-Amaya, 2016). The absorption peak wavelength depends on the number of conjugated double bonds in the molecule. In addition, the methyl and oxo groups shift the absorption wavelengths (Belitz et al., 2009).

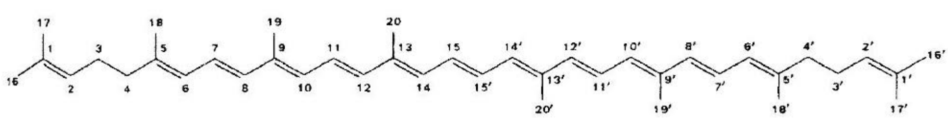

Figure 2. The general structure of carotenoids (Belitz et al., 2009). Reprinted with permission from Springer Nature.

Carotenoids can be divided into two structural classes: carotenes and xanthophylls. Carotenes are pure polyene hydrocarbons (acyclic, monocyclic, or bicyclic carotenes), and xanthophylls contain oxygen in the form of hydroxy, epoxy or oxo groups (**Figure 3**).

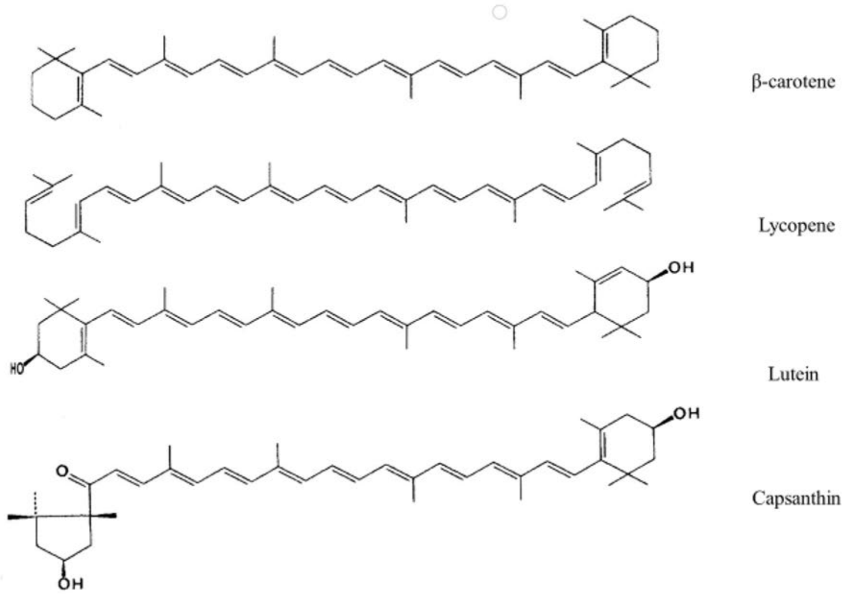

Figure 3. Structures of some carotenoids; carotenes (β-carotene and lycopene) and xanthophylls (lutein and capsanthin) (Belitz et al., 2009). Reprinted by permission from Springer Nature.

Carotenoids are highly sensitive to oxygen and light, but relative stable regarding heat (Belitz et al., 2009; Barrett et al., 2010). Although both enzymatic and nonenzymatic degradation occurs, the primary cause of carotenoid degradation and subsequent color changes during processing and storage of foods is oxidation (Rodriguez-Amaya, 2016; Belitz et al., 2009). For example, the bleaching of carotenoids may be due to the lipoxygenase enzyme, which catalyzes the oxidation of lipid compounds (Barrett et al., 2010). In addition, color changes of carotenoids may be due to nonenzymatic browning reactions such as the Maillard reaction (Belitz et al., 2009; Talcott & Howard, 1999).

2.1.3.3 Anthocyanins

Red, blue and violet colors in plants are typically due to anthocyanins. Anthocyanins are water-soluble pigments occurring in the form of glycosides composed of aglycone (anthocyanidin) and a sugar moiety. Anthocyanidins are phenolic compounds belonging to the group of flavonoids (Belitz et al., 2009) (**Figure 4**). The structure of anthocyanidins differs in their hydroxylation and methoxylation patterns producing different color shades from orange-red to violet-blue (Stintzing & Carle, 2004). The sugar residues (glucose, galactose, arabinose or rutinose) of the anthocyanins are most frequently attached to the hydroxyl group at position 3 of the anthocyanidin; the additional sugar groups occupy positions 5 or 7, or less frequently 3' and 5' (Veberic et al., 2015). Increasing hydroxylation and acylation results in a shift towards a blue color, whereas glycosylation results in a shift towards a red color (Belitz et al., 2009; Liu et al., 2018; Stintzing & Carle, 2004).

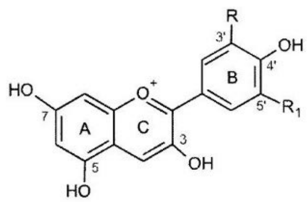

Figure 4. General structure of anthocyanidins (reprinted from Veberic et al., 2015, with permission from Elsevier).

During plant development, anthocyanin levels increase to their maximum level, and then decrease as ripening progresses. The fading of the color in plants can be due to either reduced biosynthesis of anthocyanins or increased degradation of anthocyanins, or a combination of both (Liu et al., 2018). In addition, the transition of green color in plants to another color is due to the degradation of chlorophyll and the appearance of concealed pigments. The formation of anthocyanins is enhanced by light, and both light intensity and light quality (spectrum) are found to have an influence on anthocyanin biosynthesis (Belitz et al., 2009; Liu et al., 2018).

Anthocyanins change color according to the pH of the medium. A change in pH from acidic to neutral begins a reversible discoloration of anthocyanins from red to colorless, and at pH 6-8 the color of anthocyanins is purple or blue (Belitz et al., 2009; Liu et al., 2018). Anthocyanins can exist in different pH-dependent forms: red flavylium cation at very low pH levels, colorless chromenol at pH 4-5, purple and deep blue quinoidal and ionic anhydro base at pH 6 – 8, and yellow or colorless chalcone at high pH (Belitz et al., 2009; Timberlake & Henry, 1986). In addition, the appearance and color of plant tissues may vary according to the anatomical modifications, like the shape of the epidermal cells, the number of epidermal cell layers, the size of the vacuoles, the ratio of pigmented and non-pigmented cells, and pigment trapping by vacuolar protein-anthocyanin complexes (Stintzing & Carle, 2004).

Anthocyanins are relatively unstable and easily degraded during food processing and storage because they are sensitive to pH, heat and light (Barrett et al., 2010). Additionally, in food processing, anthocyanins may cause discoloration by the formation of metal complexes (Belitz et al., 2009). Undesired brown colors can be formed due to enzymatic reactions. Anthocyanins are phenolic compounds, which are substrates for polyphenol oxidases. Polyphenol oxidase enzymes catalyze hydroxylation and oxidation reactions that generate brown colors in plants (Belitz et al. 2009). To avoid enzymatic discoloration, enzymes can be inactivated by heating, by using reductive agents such as SO_2, or by removing available oxygen (Belitz et al., 2009).

2.1.3.4 Betalains

In plants, the colors purple, blue or red primarily derive from either anthocyanins or betalains, but not from both. Anthocyanins and betalains have never been found together in the same plant (Stintzing & Carle, 2004). However, both anthocyanins and betalains are found together with carotenoids and chlorophylls to create varying colors in plants. Betalains are water-soluble pigments consisting of red-violet betacyanins ($\lambda_{max} \sim 540$ nm) and yellow betaxanthins ($\lambda_{max} \sim 480$ nm) (Timberlake & Henry, 1986; Belitz et al., 2009) (**Figure 5**). The overall tissue appearance is influenced by the mixtures of betacyanins and betaxanthins at varying concentrations (Stintzing & Carle, 2004). Most of the betalains have acylated sugar moiety; betacyanins are derived from two aglycones, betanidin and isobetanidin, whereas the structural features of betaxanthins are more variable (Belitz et al., 2009). One of the most common betalains is betanin, which is the main pigment of red beet (Stintzing & Carle, 2004).

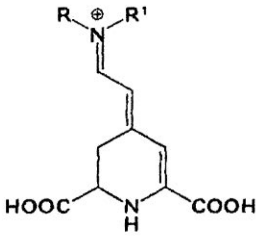

Figure 5. General structure of betalains (Belitz et al., 2009). Reprinted by permission from Springer Nature.

Betalains are sensitive to heat, but stable over the pH range from 3 to 7 (Barrett et al., 2010; Stintzing & Carle, 2004). During food processing and storage, enzymes (polyphenoloxidases, β-glucosidases, peroxidases) too may promote betalain degradation, the resulting degradation products being similar to those of thermal, acidic or alkaline degradation (Stintzing & Carle, 2004). Betacyanins are found to degrade by exposure to heat or acid through isomerization, decarboxylation or cleavage (Stintzing & Carle, 2004). The red betanin of red beet is found to decompose hydrolytically into colorless and yellow compounds. This reaction is reversible because betanin is partly regenerated at higher temperatures (Belitz et al., 2009).

2.2 Color experience in food and eating context

Experience is defined as "the fact or state of having been affected by or gained knowledge through direct observation or participation (Merriam-Webster)," or "the apprehension of an object, thought, or emotion through the senses or mind (Free Dictionary)." The experience is always influenced by the characteristics of the individual (e.g., personality, cultural values, skills, background, motives), those of the product (e.g., color, shape, texture), and the context (e.g., physical, social, economic) (Desmet & Hekkert, 2007). Experience is specifically personal, something having an effect on an individual. The effect can be either cognitive or emotional or both, and subjective experiences are considered to be multisensory in nature (Faivre et al., 2017). In addition to the actual perception of the sensory product properties, product experience is influenced by individual's pre-existing attitudes and beliefs about a product (Schifferstein et al., 2013). According to Thomson et al. (2010), "when we experience a product, we don't just react to the product itself but also to the associated conceptualizations."

Color is an intrinsic visual property of an object, and consequently objects could not be experienced without experiencing colors. Color experience is not only a perception of spectral properties of the object but depends on a variety of factors including the environment, the background of the object, prior encounters with the object, etc. (Brogaard & Gatzia, 2017). Colors have both symbolic meanings and emotional cues, and color experiences are linked to previous experiences (Manav, 2017). Color symbolizes different, even opposite, things to various cultures and countries, for example in Japan, green is connected with love and happiness but in Anglo-Saxon countries with envy (Aslam, 2006). Color-emotion associations and color-induced emotions have been investigated in numerous studies. The results are quite varied due to differing measuring methods and populations. For example, in Turkey Manav (2007) found green and yellow to be associated with sadness, and pink and green to romance, whereas in studies of Gilbert et al., (2016) in the USA black and blue were associated with sadness, and bright pink and red with romance. Moreover, the effect of colors on emotions was noticed to be heavily dependent upon experimental conditions, such as stimulation duration and size of the stimulus (Hanada, 2018). In addition to the color itself, the object on which the color is perceived influences both the associations and the preferences one has regarding the color, and furthermore, the context in which the color is viewed has an influence on color meanings and corresponding effects (Elliot & Maier, 2012).

In the following sections, the focus is on the colors in food and their importance in the multisensory eating experience (section 2.2.1). The individual differences between color experiences are discussed in section 2.2.2, and the influence of surrounding colors (from the color of the plate to the entire context) is examined in section 2.2.3.

2.2.1 Multisensory experience of food

Eating is considered as one of the most multisensory experiences in everyday life (e.g., Spence, 2015a; Velasco et al., 2018). Food experience is a dynamic and complex combination including multisensory perception, aesthetics, meaning, and emotions (Schifferstein, 2016). Each of the five senses – sight, smell, hearing, touch and taste – is employed to explore and experience food. Formerly, different senses have been considered to be isolated modalities separated from each other, and the information received through different senses has been supposed to be processed separately in different brain areas. However, it has been confirmed that the information received about the same objects or events through different senses is combined in the brain to yield multimodally determined percepts (e.g., Driver & Spence, 2000: Auvray & Spence, 2008). The ability of the brain to process and successfully integrate information from different senses is essential for conducting everyday tasks (Love et al., 2012). The majority of research on multisensory flavor perception has focused on the moment of consumption. However, the experience of eating often lasts for a much longer time period, from the anticipation of consumption to the subsequent memories associated with consumption (Spence, 2015a).The exact role of the senses in the interaction with food highly depends on the particular food product, but generally, the first exploration at a distance is made by vision (Schifferstein, 2016). According to Turk (2014), people employ multiple senses both in parallel and sequentially to explore the environment, to confirm expectations and to perceive new information.

Cross-modality is the ability to integrate information acquired through separate senses. Cross-modal sensory interaction occurs when the interpretation of data in one sensory modality is influenced by the data in another sensory modality (Bertelson & De Gelder, 2004). In eating, cross-modal interactions, for example between colors and tastes, and between colors and odors, are very common (Nehmé et al., 2016). In synesthesia, the presentation of one sensory feature in one modality elicits a conscious experience in another, nonstimulated modality; colored-hearing is one example of synesthesia (Deroy & Spence, 2013). The prevalence of synesthesia in the population is quite rare, about 4% (Newell & Mitchell, 2016). More common is the phenomenon called crossmodal correspondences, referring to "the systematic associations often found across seemingly unrelated sensory features from different sensory modalities (Parise, 2016)." Crossmodal correspondences refer to tendencies to match sensory features across sensory modalities (Deroy & Spence, 2013), for example crossmodal correspondences between tastes and colors. Spence et al. (2015b) stated that the majority of people match the taste of salt with white and blue, sweetness with red and pink, sourness with green and yellow, and bitterness with browny-black and violet/purple. Spence (2011) categorized crossmodal correspondences as structural, statistical or semantic. Structural crossmodal correspondences arise from the intrinsic organization of the perceptual system and they might be innate, for example colors and odors can be associated if they share a feature such as intensity or magnitude; statistical correspondences reflect the frequency of encounters between stimulus attributes, for example the odor of lemon is associated with yellow because of repeated co-perception of the yellow lemon and its odor, and semantic correspondences refer to sharing of identity or meaning between stimuli, for example both the odor and color of the lemon are associated with the verbal term "yellow" (Spence, 2011; Goubet et al., 2018). Crossmodal correspondences modulate multisensory integration at both the perceptual and decisional levels (Spence, 2011). For example, Hidaka & Shimoda (2014) investigated the effect of color on taste and found cognitive/decisional processes based on memory and/or knowledge play a key role in color-taste linkages, but interaction between perceptual and cognitive/decisional processes was also found to be important. Nehmé et al. (2016) conducted a cross-cultural study to investigate the nature of crossmodal correspondences between colors and odors and found both the perceptual and semantic factors influence odor-color associations in different countries. According to Chylinski et al. (2015), the cross-modal interaction between color and texture was found to be automatic and unlearned.

According to Spence (2019), crossmodal correspondences are considered to be bidirectional, but typically the research concerning colors and tastes has been about the effects of vision on taste, not the effects of taste on color perception or expectation. The results of research showing the crossmodal influence of vision on tasting to be much stronger than crossmodal effects in the opposite direction (effects of taste on color perception) indicate visual dominance, for example rounded shapes enhanced sweetness sensitivity (Liang et al., 2016). Much research has found that vision dominates other sensory modalities. For example, Morrot et al. (2001) found olfactory information could be discounted due to visual information (a white wine artificially colored red with an odorless dye was olfactorily described as a red wine); Hecht and Reiner (2009) found vision dominated auditory and haptic sensory modalities; and Li et al., (2017) investigated the neurological correlates of the Colavita visual dominance effect (dominance of vision over audition) and found visual information had a prioritizing role in activating response preparation in the motor system.

Schifferstein (2006) has investigated the importance of sensory modalities in everyday experiences of different products. On average, people were found to judge vision to be the most important modality for the evaluation of products, but the degree of importance was dependent upon the product. For foods and drinks, taste was the most important modality (mean importance rating 4.86 on a 5-point category scale from 1='very unimportant' to 5='very important'), and smell and vision the second most important (4.21 for smell, and 4.20 for vision). Vision was judged more important for product groups "fashion (4.56)," "home decoration (4.45)," and "vehicles (4.21)." The role of the senses is likely to depend on the products used, the frequency with which they are used, and the importance attached to the activities performed (Schifferstein, 2006). In Western countries, the importance of vision may have increased over time due to those products requiring major input from the visual modality in people's daily living, such as television and the Internet.

2.2.2 Individual differences in color experience

Although the physical dimensions of the light entering the eye after interaction with an object are identical for every observer, there are individual differences in the perception of the color of an object. The differences can be based on either the physiological or psychological features of an observer. Generally, people have three different kinds of cones in the eye to perceive red, green, and blue colors. In color vision deficiency, some types of these cones do not function normally. Color vision deficiencies can be divided into innate and acquired forms (Simunovic, 2010). Congenital color vision deficiencies are the result of genetic mutations affecting cone photoreceptors (Simunovic, 2010). Red-green color vision deficiency is the most common, affecting 2% (Africans) to 8% (Europeans) of males and 0.5% of females. Other color vision deficiencies, such as blue-yellow color vision deficiency, are less frequent (Simunovic, 2010). The acquired forms of color vision deficiency occur as a result of ocular, neurologic, or systemic disease (Simunovic, 2016).

In addition, responses to color alter with ageing (Dittmar, 2001; Manav 2007). With advancing age, color discrimination and visual imagery alter along with the yellowing of the crystalline lens in eyes and the decreased function of the blue cone mechanism in eye (Dittmar, 2001).

Results from studies investigating gender-based differences in color perception are contradictory. Jain et al. (2010) found females saw more shades of colors than males, whereas the results of the investigations by Miranda (2012) were contrary: men were more successful in discriminating shades. Da Silva et al. (2015) found no differences between the genders in the perception of colors. In the study by Hoppu et al. (2018), females were found to perceive a red color as the sweetest more often than males, whereas males perceived red more often as the healthiest and the most sour.

Perception and cognition are highly interrelated; perceptual information guides decisions and actions, and cognition influences perceptions (e.g., Tacca, 2011; Brewer & Lambert, 2001). Perceptual experiences, such as perceiving colors, can be influenced by cognitive states, for example thoughts, judgments, beliefs, intuitions, expectations, desires, mental images, and emotions. (Mroczko-Wąsowicz, 2016). According to Macpherson (2017), “perceptual experience refers to the conscious state that we typically go into when we perceive the world” and it has “a distinctive phenomenal character compared to typical beliefs or judgments about the world.” Two subjects, or one subject at different times, have different perceptual experiences due to their differing content of the states of their cognitive systems (Macpherson, 2017). However, this cognitive influence is still a matter of controversy. According to Firestone and Scholl (2016), there is no evidence for true top-down effects of cognition affecting perception.

Color can hold special meanings to different people (Elliot et al., 2007). Yokosawa et al. (2016) supposed that symbolic and conceptual associations between colors and objects may differ between cultures. Color preferences in particular were found to be influenced by culturally specific personal experiences during one's lifetime. Yokosawa et al. (2016) investigated cultural differences concerning the color preferences of Japanese and U.S. participants and found Japanese participants like lighter colors more and dark colors less than U.S. participants do. In their study, gender differences were also present in both cultures, but they tended to be smaller than the cultural effects. Goubet et al., (2018) found cultural differences between France and the U.S. when investigating odor-color associations. Odor-color associations were found to be dependent on cultural and developmental experience with odors. For example, U.S. participants associated methyl salicylate (an odor considered specific to U.S. cultural environment) with green across all ages, whereas French children did not show any significant color associations with methyl salicylate and French adults associated it with either green or brown.

2.2.3 The effect of visual surroundings

In addition to the color dimensions of the object, lighting and surrounding colors affect color perception (e.g., Piqueras-Fiszman et al., 2012; Hasenbeck et al., 2014). Stroebele and De Castro (2004) stated that the colors of an eating environment have an influence on human behavior such as food choice and preference. In addition, environmental colors may have influence on physiological or emotional states (Chylinski et al., 2015; Valdez & Mehrabian, 1994), and on people's feelings, mood, cognition and behaviors (Othman & Goodarzirad, 2013; Elliot & Maier, 2014; Stroebele & De Castro, 2004). In an environmental color study, a model by Mehrabian and Russell (1974) is widely used to assess environmental perception, experience, and psychological responses. The model explains the effect of the physical environment on human behavior by using three dimensions, pleasure (P), arousal (A), and dominance (D), to represent all emotions.

According to Stroebele and De Castro (2004), bright colors appear to arouse and stimulate, whereas dark colors seem to relax. Al-Ayash et al. (2016) found colors affect students' emotions and heart rates: blue increased relaxation and calmness feelings, and red and yellow increased heart rates. In the restaurant, red and black atmospheres may cause stress and excitement, whereas green created stimulation, warmth and happiness (Jacquier & Giboreau, 2012). Babin et al.

(2003) investigated the importance of colors and lighting in retail atmospherics and shopping reactions and found consumers processed atmospheric characteristics holistically, and also that the relationships between color and purchase intentions were complex and depended considerably on other moderating and mediating factors. Color meanings and effects are context specific, and the meaning of color is determined by its contextual surroundings (Elliot & Maier, 2012). In addition to physical environment, other contextual factors such as social context affect the experience of food (e.g., King et al., 2004).

2.2.4 The effect of visual appearance of food

The visual appearance of food consists of many different attributes such as color, shape, texture, surface structure, gloss, translucency (from transparency to opaqueness), size, uniformity and variety (e.g., Hutchings, 1999; Hunt & Pointer, 2011; Wadhera & Capaldi-Phillips, 2014). According to Lawless and Heymann (2010) "color is an appearance property of an object attributable to the spectral distribution of light emanating from that object. However, gloss, transparency, haziness, and turbidity are appearance properties of materials attributable to the geometric manner in which light is reflected and transmitted." Usually, the color of food is not uniform all over the product but varies according to translucency, surface texture and gloss, and all these attributes affect the appearance of the product (Hutchings et al., 2002). Light is reflected from the surface of a material both regularly (specularly) and diffusely and a surface having a high regular reflection appears glossy (Hutchings, 1999). An uneven (diffuse) reflection of light from a surface can make the object appear dull or matte (Lawless & Heymann, 2010). Light-scattering phenomena also contribute to powder reflectance properties such that color changes with particle size (Hutchings, 1999). Kono et al. (2017) have investigated the relationship between ice crystal size and the surface color of frozen salmon fillets and found numerous small ice crystals give the impression of color loss. According to Briones et al. (2006) the color perception of chocolate was affected by the structure of the surface (roughness) of chocolate. In addition to the surface properties, the translucency of the product affects the color of the product. A translucent material both transmits and scatters light, and consequently color and translucency are not independent (Hutchings, 1999). Investigations of interactions between color and translucency have indicated that color and translucency interactions change with sample depth or thickness (Hutchings, 1999). For example, the redness of a bacon slice depends on the thickness of the slice (MacDougall, 1971).

Mielby et al. (2018) highlighted the complex interaction between the extrinsic (such as the color or the shape of receptacle) and intrinsic (such as the color or the aroma of food) factors of the product. In general, table setting (tableware, plateware, cutlery, cups and glasses, bottles, and containers) influence the perception of food (Spence et al., 2012). For example, the color contrast between the color of the plate and the color of the food may affect the perceived color of the food (Spence et al., 2014). Piqueras-Fiszman et al. (2013) found the effect to be dependent on the type of food served: the color intensity of the desserts *fraisier* (yellow, white and red) and *vacherin* glacé (light pink, white and cream) was enhanced on the white plate compared to the black plate, whereas the color intensity of *fraicheur* (light brown, white and red) was not enhanced on the white plate. According to Schifferstein et al. (2017), the color of the background did not affect the direct color perception of vegetables but did affect their perceived attractiveness. Further, Spence (2018a) stated that the color of the plate, bowl, cup etc. against which a food is seen may influence how appealing a food looks, and even how much is consumed.

The color red in table settings has been noticed to influence consumers' reactions. Red plates were found to reduce consumption of food (e.g., Genschow et al., 2012; Bruno et al., 2013). The effect of the red color was presumed to be linked to danger and prohibition by culturally learned or biologically embedded associations. Reutner et al. (2015) found consumers reacted adaptively to the color red: the red plates reduced consumption only with unhealthy food, not with healthy food. The same kind of consumption-reducing effect of color red was achieved by marking the unhealthy foods with little red flags (Reutner et al., 2015). Mielby et al. (2018) found beverages in red receptacles to be rated as more carbonated than beverages in black receptacles.

2.3 Measurement of color

Physically, color is a characteristic of light and it can be measured in terms of intensity and wavelength. However, the actual perception of color is more complicated, depending also on the observer and the conditions under which the color is observed (Pathare et al., 2013). Various mathematical color spaces are developed to specify colors numerically, and those applied in food science are introduced in section 2.3.1. Section 2.3.2 deals with color measurements in food, and section 2.3.3 the comparisons between color measurements and color experiences.

2.3.1 Color spaces

Hue, brightness and saturation are the color dimensions commonly used to distinguish different colors from each other. Several color coordinate systems, or color spaces, have been developed to describe the color of an object. The various color spaces differ regarding the symmetry and the coordinate system used to define points within that space. Color space is defined as "a mathematical representation for associating tristimulus values with each color (Wu & Sun, 2013)." Tristimulus values represent the extent to which each of the three different cones (absorption maxima in the wavelength region of red, green, or blue) in the eye is stimulated. Wu and Sun (2013) grouped color spaces into following categories: hardware-oriented color spaces, for example RGB (Red-Green-Blue), human-oriented color spaces, for example HSV (Hue-Saturation-Value), and instrumental color spaces, for example CIELAB (using the color values L^*, a^* and b^*).

RGB (red, green, blue) is one of the most widely applied color systems used in color video monitors, image acquisition, storage and display (Pathare et al., 2013; Ibraheem et al., 2012). In RGB color space, colors are defined by coordinates on three axes representing red, green and blue (**Figure 6**). RGB is an additive color space where all colors can be created by mixing the primary colors: red, blue and green (Chavolla et al., 2018). However, RGB color space is not perceptually uniform and does not represent the colors perceived naturally by humans very well (Pathare et al., 2013). Additionally, illumination changes easily affect the color hue, and consequently complicate color tracking and analysis (Chavolla et al., 2018).

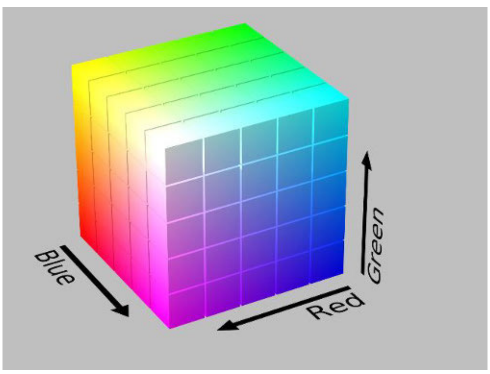

Figure 6. RGB Color space (https://commons.wikimedia.org/w/index.php?curid=9803320; 15.4.20).

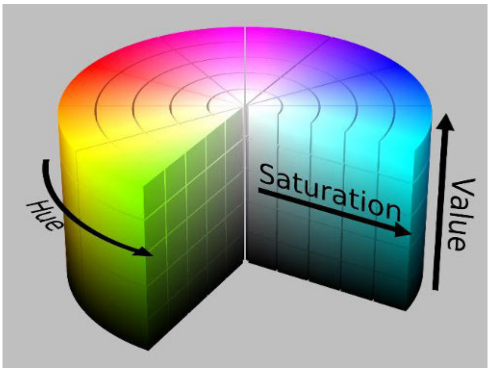

Figure 7. HSV Color space (https://commons.wikimedia.org/w/index.php?curid=9801673; 15.4.20).

HSV (hue, saturation, value) is an example of human-oriented color space or perceptual color space (Wu & Sun, 2013; Chavolla et al., 2018). HSV is based on the concept of visual perception in human eyes (Wu & Sun, 2013). HSV color space is defined using the cylindrical coordinates representing hue, saturation and brightness (or value) of the color (**Figure 7**). HSV color space is not sensitive to a small variation in color, and consequently it is not suitable for evaluating small changes in product color (Wu & Sun, 2013).

Instrumental color spaces used for color measuring instruments are commonly standardized by CIE (Commission Internationale d'Eclairage) (Wu & Sun, 2013). One of the first instrumental color spaces was created in 1931 and named CIE *XYZ*, where *Y* represented lightness, and *X* and *Z* were primary virtual components describing red-green and blue-yellow colors. This color space did not represent colors uniformly; therefore, the uniform color space CIE $L^*a^*b^*$ (or CIELAB) was developed in 1976. Today, CIELAB is the most frequently used instrumental color space in the color measurement of food (Wu & Sun, 2013). CIELAB is a uniform color space, where the distance between different colors corresponds approximately to the color difference perceived by the human eye (León et al., 2006; Hunt & Pointer, 2011; Wu & Sun, 2013). CIELAB expresses color as three values: L^* for the lightness from black (0) to white (100), a^* for green (-) to red (+), and b^* for blue (-) to yellow (+) (**Figure 8**).

The CIELAB color space has been created to be suitable for quantifying small color differences. The distance between the coordinates of any colors can predict the perceived color difference between them (Brainard, 2003).

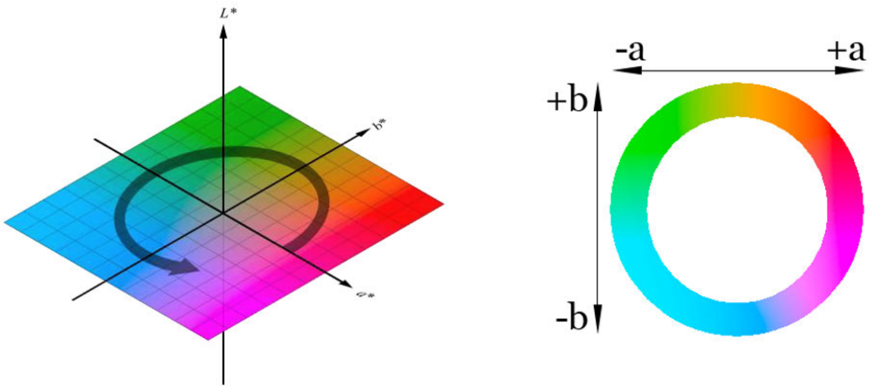

Figure 8. CIELAB Color Space
(hue angle: https://commons.wikimedia.org/w/index.php?curid=35029431; 15.4.20, color wheel: https://commons.wikimedia.org/w/index.php?curid=2565150; 15.4.20).

2.3.2 Measurement of color in food

Color measurements in food can be conducted either visually or instrumentally. Instrumental color measurements can be performed using instruments such as colorimeters, spectrophotometers or computer vision (Meléndez-Martínez et al., 2005; Wu & Sun, 2013; Pathare et al., 2013). Instrumental color measurements provide accurate, precise and objective results, and they are used specially to measure small differences between colors, for example in quality control (Barrett et al., 2010). Generally, instrumental color studies have concentrated on hues, while the other important dimensions of color, such as saturation or brightness, have been largely disregarded (Labrecque et al., 2013).

Colorimeters measure the color of light from both the primary (emitted light) and the secondary radiation sources (reflected or transmitted external light) in the tristimulus values *X, Y*, and *Z* (Pathare et al., 2013). In colorimeters, there are three filters (red, green, and blue) to spectrally emulate the response of the three types of cones in the human eyes (Mendoza et al., 2006). Spectrophotometers measure the spectral distribution of transmittance or reflectance of the sample wavelength-by-wavelength throughout the entire visible range (e.g., Pathare et al., 2013; Mendoza et al., 2006). The factors limiting the use of colorimeters and spectrophotometers are such that they provide average values of only small areas of the sample, they are unable to assess the color distribution and color uniformity measurements of entire foods, and they must be in contact with the sample (Mendoza et al., 2006; Goñi & Salvadori, 2017). In addition, the sample surfaces have to be uniform and homogenous, and the samples often need pretreatment such as grinding before color measurement (Manninen et al., 2015; León et al., 2006; Yam & Papadakis, 2004). Conventional color measurement methods were not originally designed for use with foods but with paints, photography, textiles, etc. and to measure samples that are flat, opaque and have uniformly colored surfaces whereas most foods are nonuniformly colored, have surface irregularity, and are translucent (Hutchings et al., 2002).

The use of digital images in food analysis has considerably increased in recent years (Goñi & Salvadori, 2017). In order to measure color from digital images in a standardized manner, a computer vision system (CVS) is required. CVS can analyze each pixel of the entire surface of the food sample (Pathare et al., 2013). CVS generally consists of five components: a controlled illumination system, a digital camera, an image capture board, and computer hardware and software to process the obtained information (Pathare et al., 2013; Quevedo et al., 2010; Goñi & Salvadori, 2017). Usually, color images taken by a digital camera are saved in the RGB color space and through a calibration process the CIELAB color parameters are obtained from common RGB images (Pathare et al., 2013; Goñi & Salvadori, 2017). This transformation is necessary because the RGB color space is not perceptually uniform and does not represent the colors perceived naturally by humans sufficiently enough (Pathare et al., 2013). The advantages of CVS over traditional colorimeters and spectrophotometers are that it does not require direct contact with the sample, both very small and very large samples can be processed, and it is possible to analyze each pixel of the entire surface of the sample (Goñi & Salvadori, 2017; Pathare et al., 2013). Computer vision systems have been used in color measurements of highly different foods, for example to analyze changes in surface colors of chocolate (Briones & Aguilera. 2005), to inspect the external quality of fruits and vegetables (Zhang et al., 2014), to measure the color of potato chips (Pedreschi et al., 2006), and to measure the color of salmon fillets (Quevedo et al., 2010).

Visual color measurements by humans are based on the fact that human color vision is a complex process through which humans see colors in terms of lightness, hue and chroma by integrating complex perceptions (Fernández-Vázquez et al., 2011). Typically, visual measurement of color involves observing the color of a sample and comparing it against defined color standards. The samples and color standards should be observed under identical and controlled conditions of illumination (Pathare et al., 2013). Visual color assessments are often made by means of color scales or atlases containing comparative standards. The main systems of color standards in food science are the Munsell System, the DIN (Deutsche Institut für Normung) system, and the USC (University of Southern California) system, of which the Munsell system is the most widely used in the food industry (Meléndez-Martínez et al., 2005). The Munsell color model is represented as a cylindrical shape in which colors are located as a function of value (clarity or lightness), hue and saturation (**Figure 9**) (Meléndez-Martínez et al., 2005; Ibraheem et al., 2012). All the colors are printed on cards which can be separated from the atlas and used as comparative standards in visual color measurements (Meléndez-Martínez et al., 2005). The disadvantages of visual color measurements are that they may vary considerably due to individual differences in perception and human error (Barrett et al., 2010).

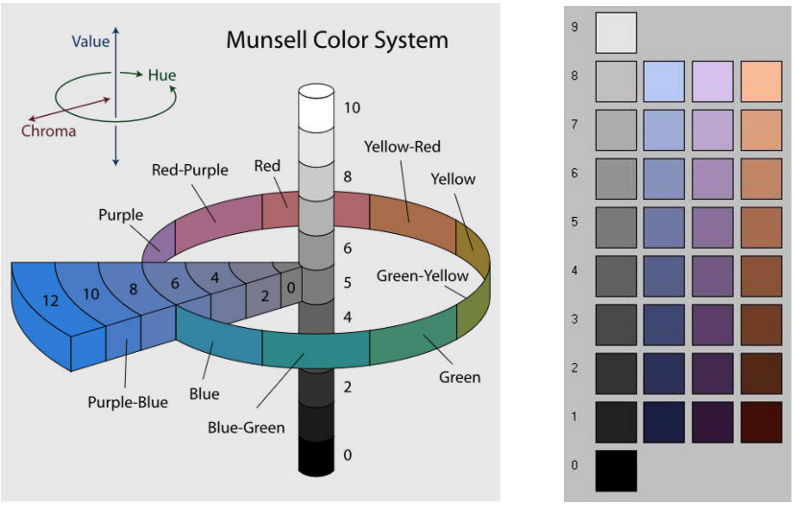

Figure 9. Munsell Color System
(color model: https://commons.wikimedia.org/w/index.php?curid=1955750; 15.4.20, color cards: https://commons.wikimedia.org/w/index.php?curid=2310280; 15.4.20).

2.3.3 Color measurement vs. color experience in food

The color of the light reaching the eye from the object can be instrumentally measured precisely and repeatably. However, although the measured color values and dimensions from two objects may be exactly the same, the perceived appearance of these two objects can be quite different (Brainard, 2003). One example of the effects influencing color perception is the influence of the background color as illustrated in **Figure 10**. The measurable color of both x-shaped intersections is precisely the same, while the perceived color of the intersections is quite different depending on the color of the background.

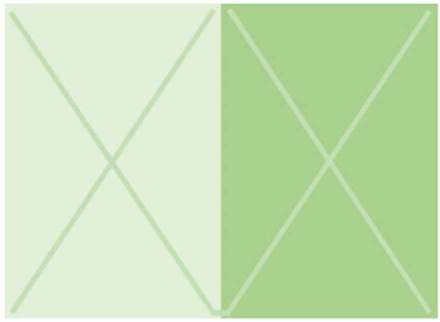

Figure 10. The influence of background color on the perceived color of x-shaped intersections. Both x-shaped intersections are of the same color.

Instrumental color measurements are best used to investigate the relationship between color dimensions and color assessments. For example, Khliji et al. (2010) found the $a*$ value (redness) to be related to consumers' assessment of meat color. Also, Holman et al. (2017) stated the $a*$ value to predict beef color acceptability. Fernández-Vázquez et al. (2011) investigated orange juice and found consumers' preference to correlate with orangish hue but not with the quantitative color attribute chroma; chroma was found to be difficult to evaluate visually. The aim of the study by Lee et al., (2013) was to determine appetite-promoting colors of various foods with different colors. They found the higher chroma values were preferred, especially for red and green foods. However, it is obvious that in addition to the color dimensions measured by instrumental methods, there are many other factors affecting color perception and experience, such as the adapted state of the observer, and the spatial and temporal structure of the stimulus (Brainard, 2003).

Typically, in earlier color research, visual stimuli were considered to be pure sensory phenomena and the cognitive influence was not recognized (Labrecque et al., 2013). Pelowski et al. (2017) have investigated the multiple ways by which people respond to the visual objects, especially art, in the environment. They developed a new model (VIMAP, The Vienna Integrated Model of top-down and bottom-up processes in Art Perception) to describe how people encounter and react to the environment, and stated that art experience is a combination of bottom-up (product-derived) processing of artwork features (form, attractiveness) with the top-down (viewer-centered) contribution of memory, personality, and context. The VIMAP model consists of seven stages: 1: Pre-classification, 2: Perceptual analysis, 3: Implicit memory integration, 4: Explicit classification, 5: Cognitive mastery, 6: Secondary control, and 7: Self-awareness with meta-cognitive assessment. Stages 1-4 consist of the bottom-up processing of art aspects and the following three stages consist of cognitive (top-down) processing. In this model, viewing art is positioned between stages 1 (the state prior to a meeting with art: context, expected stimuli, personality, etc.) and 2 (bottom-up inspection of an object: color, contrast, complexity, symmetry, etc.). During stage 3, the low-level features are segregated or grouped, and this processing contributes to general positive or negative assessments. The visual information is further processed in stage 4, sometimes called "late vision," involving focusing on more conceptual or artistic factors, such as style, and evaluating emotional valence. Pelowski et al. (2017) stated that in stage 5, "the perceptual and contextual elements uncovered in the bottom-up processing above are met with a more top-down executive consideration in which viewers attempt to locate and combine all information collected in the prior processing stages in order to form one coherent meaning, matching this to initial schema and expectations, and then attempt to formulate an appropriate evaluative or physical response, culminating in the creation of meaning, associations, evaluations and the model's first outcomes." Stages 6 and 7 in the model are reached only if there are both a discrepancy and high self-relevance in art processing. It is obvious that the conventional color measuring methods (both instrumental and sensory) used in food research have concentrated basically on the seeing of an object (between stages 1 and 2 in the VIMAP model) without considering the other stages of experience.

2.4 Roles of colors in food

The visual appearance is one of the first impressions a consumer notices in food, and color is regarded as an important attribute of a food product's appearance (e.g., Francis 1995; Cardello, 1996; Hutchings, 1999; Spence et al., 2010; Delwiche, 2012; Zellner, 2015). The role of color in food is particularly dependent on the type of food product. For example, brown is accepted in chocolate, but not in salad, whereas green is acceptable in salad but not in meat; yellow can be associated with sourness in lemon but greasiness in milk; red means unripeness in meat but ripeness in tomatoes, etc. The expectations induced by colors in food are discussed in general in section 2.4.1, the relationship between color and flavor in section 2.4.2, and the relationship between color and liking in section 2.4.3. The role of colors in the visual aesthetics of food, as well as the importance of color combinations in food are discussed in the following chapters, 2.5 and 2.6.

2.4.1 Color-induced expectations in food

Color in food is considered to be an important product-intrinsic (physically belonging to the product itself) sensory cue that influences the expectations that are generated in the mind of the taster (e.g., Spence, 2015b; Piqueras-Fiszman & Spence, 2015; Spence, 2019). Changing the hue or the saturation of the color in food item may exert a great impact on these expectations and consequently on the experiences of consumers (Spence, 2015b). In general, there are great dissimilarities between consumers' color-induced expectations. Expectations concerning different colors vary due to consumers' different backgrounds or culture, learned associations, expertise and experience with tasting a particular foodstuff, and their age (e.g., Spence et al., 2010; Shankar et al., 2010).

Color is used to judge the anticipated safety and quality of food. Learning of the association of certain acceptable (safeness to eat) colors regarding certain foods begins early in an individual's cognitive development (Clydesdale, 1993; Hutchings, 1999). The off-colors of food products may warn the would-be consumer of potential danger or at least of off-flavors, for example the blue or green mold on cheese, and the off-color of meats and fruits (Clydesdale, 1993). Colors suggesting that a food may have gone off can exert a particularly great effect on food avoidance behaviors (Spence & Piqueras-Fiszman, 2016). In the quality assessment of food, color indicates stages of ripening and cooking, as well as freshness (Hutchings, 1999). The results of the study by Schifferstein et al. (2019) using carrots as the sample material confirmed that browning decreases attractiveness and purchase intention ratings.

Color hue and saturation are found to affect consumers' expectations about sensory and functional properties, including freshness and nutritional value (Schifferstein et al., 2019). Zellner and Durlach (2003) found subjects to have color-induced expectations about the degree of refreshment of a solution. In their study, the participants rated the expected and actual taste of lemon and mint solutions with a brown color as less refreshing compared to the tastes of differently-colored solutions of the same flavor. This was caused by the fact that a brown color is not an appropriate color for either lemon or mint flavors. In the case of a vanilla flavored solution, brown is considered to be an appropriate color (vanilla extract is brown), and it was not expected to be less refreshing than other colors. Foroni et al., (2016) found red-brightness in food images to increase the arousal elicited and green colors to diminish it. Furthermore, they found greener food to be expected to have less energy. This derives from the argument that greener hues generally indicate lower energy levels in fruits and leaves. Although today food is often transformed and artificially colored, and therefore the calorie content is detached from its color, humans still may use colors in food for calorie estimation (Foroni et al., 2016).

In addition to generating expectations, colors in food have been observed to have a direct influence on humans' thermal perception. Suzuki et al. (2017) investigated the relationship between the color of food and thermal perception. They found a yellow color soup increased the postprandial peripheral (toe) temperature compared to white and blue soups. The blue color soup reduced the acceptability of hot soup (lower willingness to eat, palatability, pleasantness,warmth ratings, and higher anxiety ratings) compared to white and yellow soups, decreased the postprandial satiety ratings, and reduced the thermal sensation of the entire body compared to white and yellow soups.

2.4.2 Relationship between flavor and color in food

Multisensory flavor perception is a combination of all sensory inputs, but colors are not considered as constitutive of flavor. Flavor is defined as the combination of tastes (e.g., sweet, salty), smell (e.g., fruity, strawberry), and the chemical feeling factors or trigeminal sensations (ASTM International, 2009). However, in addition to these sensory systems (smell, taste, touch, trigeminal), food also stimulates vision and audition, and flavor is said to be an input from all of these senses (e.g., Delwiche, 2004; Auvray & Spence, 2008; Zellner, 2013). It has been stated that the experience of flavor is largely determined by the expectations generated (often automatically) prior to tasting (Spence, 2015b; Deliza & MacFie, 1996; Piqueras-Fiszman & Spence, 2015), and colors in food apparently create expectations.

Color-flavor interactions are said to be complex and even contradictory (Lawless & Heymann, 2010). Color's influence on taste and flavor perception is found to occur both in a bottom-up (processing sensory information as it is coming in) and top-down (perception driven by cognition) manner, but the relative importance of these manners is still under consideration (Spence, 2015b; Spence, 2019). Pelowski et al. (2017) introduced an integrated model of bottom-up and top-down processes. Bottom-up processing includes early vision and automatic processing of visual features below the level of awareness, whereas top-down processing includes the aspects of viewer cognition, memory, personality, and context. One example of the bottom-up influence of color is its crossmodal influence over taste and flavor perception (Spence, 2015b). For example, a white wine artificially colored red with an odorless dye is olfactorily described as a red wine (Morrot et al., 2001; Parr et al., 2003). An example of a top-down process is that descriptive information modifies the meaning of food color and consequently influences the perceived taste of food (Spence, 2015b).

Stevenson and Oaten (2008) found color effects manifested primarily via conceptual, rather than perceptual, means. They presented odor pairs either in their appropriate color (e.g., strawberry and cherry in red water) or in their inappropriate color (e.g., strawberry and cherry in green water), and found participants made more discriminative errors when the color was inappropriate. However, an articulatory suppression task (participants repeated the word “the” out loud during the experiment) significantly improved discrimination in the inappropriate color test by interfering with the participants’ focus on the color cue.

Certain tastes are commonly associated with specific colors. For example, Koch and Koch (2003) found positive color-taste associations between the color red and fruitiness, and the color yellow with sourness, citrusness, and fruitiness. Negative associations were found between the color blue and sourness, bitterness, saltiness, citrusness, and syrupiness, the color red with sourness, bitterness, and saltiness, and the color yellow with saltiness. O’Mahony (1983) reported people consistently matched the color red with sweetness, yellow with sourness, and white with saltiness, and Spence et al. (2015) stated people most often associated sweetness with red and pink, and sourness with green and yellow. The same kind of systematic associations between different colors in food and basic tastes have been reported by a large body of scientific research (Wang et al., 2019). Gender, age, body mass index and education were found to affect color-taste associations, for example women perceived red as the sweetest more often than men, and overweight subjects rated orange as the sweetest more often than normal weight subjects (Hoppu et al., 2018).

Although food color affects people’s ability to correctly identify the flavor of food, it must be noted that particular colors can be associated with different flavors by different individuals (Spence, 2019). Food colors are not associated with just one taste or flavor, for example red-colored solutions were not associated only with the flavor of strawberry but also the flavors of raspberry or cherry, while the grey-colored solutions were associated with the flavors of blackcurrant and liquorice (Zampini et al., 2007). Similar food colors may create different flavor expectations depending on the category of product under consideration (for example, the same colors in soft drinks, cakes, or noodles) (Spence, 2015b). Schifferstein et al. (2019) found the color of the carrots affected the associations; for example, red carrots were associated with red chili and radishes and were expected to be spicy, while yellow carrots were associated with yellow bell peppers or lemons, and sourness.

Although many studies have shown that color affects the ability to identify a food (e.g., Blackwell, 1995; Garber et al., 2000; Stillman,1993; Zellner et al., 1991), it is particularly the appropriateness of color that is important when identifying foodstuffs. People are more accurate at identifying appropriately colored foods and drinks than inappropriately colored or colorless ones. For example, the flavor of cherry is identified better in an appropriately-colored red solution smelling of cherry compared to an inappropriately-colored green solution smelling of cherry (Zellner et al., 1991; Stevenson & Oaten, 2008). In fact, if food is colored inappropriately, people tend to misidentify foods and drinks in a way that consistent with the color. For example, DuBose et al. (1980) found an orange-colored cherry-flavored beverage was misidentified as having an orange or apricot flavor, and Morrot et al. (2001) found subjects described red-colored white wine with descriptors generally used for red wine.

Although judgments of flavor identity are found to be influenced by a food's color, the influence of color on flavor intensity is more ambiguous (Spence et al., 2010). In general, the intensity of taste and/or flavor is said to increase as the color level increases (Delwiche, 2004). However, the psychological effects of changing the intensity of food coloring on the intensity of taste or flavor perception is not clear (Spence, 2015b). For basic taste perceptions (sweetness, sourness, bitterness and saltiness), the addition of food coloring is found to influence sensory thresholds (Maga, 1974), and particularly the saturation of the color red was positively associated with the perceived intensity of sweetness (Lavin & Lawless, 1998). Pangborn (1960) found a slight tendency for red coloring to enhance sweetness and flavor perception in a cherry-flavored solution, and orange coloring in an apricot-flavored solution. She found no effect for red, green or yellow colors on the discrimination of sweetness in an aqueous solution, but in green-colored samples of pear nectar a decrease in sweetness discrimination was noticed. Pangborn and Hansen (1963) found both sweet and sour discrimination to be diminished in colored (red, green, yellow, or blue) pear nectars compared to uncolored ones. Johnson et al. (1983) investigated strawberry-flavored sucrose solutions and found sweetness perception increased with increasing red color intensity. Further, Clydesdale et al. (1992) found that the reddest sample of the fruit flavored beverages received the highest or one of the highest sweetness responses, but the correlation was found only in the results from individual panels, not in the pooled data from all consumer panels. Schifferstein et al. (2019) investigated the relationship between taste intensity and color with carrots and found no correlation: taste intensity was identical for carrots with both a less or more saturated orange color.

Conserning the intensity of flavors, Calvo et al. (2001) found the intensity of color influenced perception of the intensity of fruit flavor in yoghurts: the greater the concentration of colorant, the greater was the intensity of fruit flavor perceived. Bayarri et al. (2001), too, noticed color affected the intensity of typical flavors in fruit drinks. In contrast, in the studies of Zampini et al. (2007), which used colored solutions with fruit flavors, increasing the intensity of the color of the solutions did not increase the participants' flavor intensity evaluations.

There may be many reasons for these contradictory results about the relationship between taste/flavor intensity and colors in food. Schifferstein et al. (2019) felt that in their investigations with carrots the relationship between taste intensity and color was not related to the saturation dimension of color vision, but to the lightness dimension: darker colors related to higher taste intensity. Zellner and Kautz (1990), Zellner and Whitten (1999), and Koza et al. (2005) found color enhanced odor intensity ratings when odorants were smelled orthonasally (i.e., through the nostrils), but to reduce odor intensity ratings when smelled retronasally (i.e., the solution was placed in the mouth). Bayarri et al. (2001) stated that the existence and the intensity of the effects between colors and flavor intensity depended on the product type and on the consumers' expectations derived from previous experience and knowledge. In addition, the PROP taster status (supertaster, medium taster, or non-taster of 6-n-propylthiouracil) can modulate the influence of color on individual's flavor perception. Zampini et al. (2008) have found that subjects more sensitive to PROP were less affected by the color of a drink than less sensitive subjects.

In addition to the color of food, the colors of plates, bowls, cups, etc. have a role on perceived taste (e.g., Wang et al., 2019; Piqueras-Fiszman et al., 2012; Piqueras-Fiszman & Spence, 2015). For example, Harrar et al. (2011) found salty popcorn tasted slightly sweeter when served in a red or blue bowl, and Piqueras-Fiszman et al. (2012) found red strawberry mousse tasted sweeter when served on a white plate compared to a black plate.

2.4.3 Relationship between liking and color in food

The visual attractiveness of food plating is found to affect liking for the flavor of food: it tastes as good as it looks (Zellner et al., 2014a). Food presentation creates expectations of a pleasurable eating experience (e.g., Namkung & Jang, 2007; Carins et al., 2020). According to Hutchings (1999), the appearance and color of a meal stimulates or depresses the appetite, and Garber et al. (2001) stated that there is a strong link between food color and palatability. Food pleasantness ratings seem to be influenced by colors, and consequently pleasantness has an effect on food selection (Stroebele & DeCastro, 2004).

Generally, color has to be within an expected range for food acceptance (Francis, 1995), and atypical colors in foods have a negative effect on acceptance (Cardello, 1996). Appropriately-colored foods are perceived to have better quality aroma and flavor, and they generally receive the highest hedonic response (Clydesdale 1993). Labrecque et al. (2013) stated that color preferences varied remarkably in different object contexts, for example brown hues are preferred for steaks and other meat dishes, whereas brown vegetables are not acceptable. According to the ecological valence theory (Palmer & Schloss, 2010), people like colors associated with objects they like (e.g., blue, associated with the sky), and dislike colors they associate with objects they do not like (e.g., brown, associated with rotten food). According to studies conducted in Europe and Asia, bright green and red hues are commonly considered to be the most preferred colors in food (Prokop & Fančovičová, 2011; Lee et al., 2013). However, general color preferences could not explain object-specific color preferences. For example, Jonauskaite et al. (2016) investigated color preferences in three context conditions: general, interior walls, and t-shirts, and found both the preferred color hues and the preferred color lightness varied widely between individuals and contexts, for example the preferred colors were lighter for walls and darker for t-shirts.

Color can be described in terms of hue, saturation and brightness (lightness), and all of these have been shown to affect preference judgements in complex ways (Crozier, 1999). In general contexts, Western adults prefer cool colors (e.g., blue) and colors of higher saturation to warm colors (e.g., red) and colors with lower saturation (Crozier, 1999; Palmer et al., 2013); however, in food, the color blue is rare and usually not liked, whereas the colors red, yellow, and green are the most common and most liked (Hutchings, 1999; Walsh et al., 1990; Spence, 2018b). Blue may be an innately disliked color in foods since there are few foods whose natural color is blue (Cardello 1996). On the other hand, the recent popularity of exotic and brightly colored foods and beverages, especially among children, suggests that innate color preferences for food are unlikely. It could be claimed that color preferences for foods are the result of experience, culture, conditioning, and learned associations rather than stem from inherent psychophysical characteristics (Clydesdale, 1993; Cardello, 1996).

Lee et al. (2013) have investigated human color preferences for vegetables and have found bright and vivid colors (colors with high chroma; saturated colors) to be preferred. The aim of that study was to determine the appetite-promoting colors of various foods with different colors. They found colors with high chroma values were preferred, especially in the red and green foods. The preference for high chromatic colors was supposed to have a significant association with a human's tendency to select fresher and non-contaminated foods. The memorized color or expected color for a food significantly influenced the hue and chroma preference for that food. However, color liking may not be a major driver of overall acceptance of food. In the studies by Leksrisompong et al. (2012) using sweet potatoes, the samples with unfamiliar colors were accepted by consumers as long as the other sensory characteristics (flavor, texture, aroma and taste) were well liked.

In food, expectations have been found to be set by colors, and the fulfilment or otherwise of these expectations greatly affects the liking of food (e.g., Spence, 2015b; Deliza & MacFie, 1996). According to Deliza and MacFie (1996), there are different psychological theories (assimilation theory, contrast theory, assimilation-contrast theory) to describe how the disconfirmation created by expectations influences the perception of product quality. According to the assimilation theory, any discrepancy between expectation and product performance will be minimized (or assimilated) by the consumer, and this can be done by changing his/her final perception to equal his/her expectation. The contrast theory assumes that when the expectations and the experiences are not matched, the consumer will evaluate the product less favorably than if he/she had no prior expectations of it. According to the assimilation-contrast theory there are certain limits of acceptance and rejection, and if the discrepancy between expectations and experiences is sufficiently small, the product is rated based on the assimilation theory, and if the discrepancy is large, on the contrast theory. Further, Spence (2019) stated that the degree of discrepancy between expectations and experiences is significant. Only when the degree of discrepancy is small does the expectation lead to an assimilation effect with regard to the experience. If the discrepancy is too large, visual cues are ignored as a predictor of the taste or flavor.

In addition to the degree of discrepancy, there are other factors determining whether assimilation or contrast will occur. Zellner et al. (2004) investigated the importance of the certainty of the expectation. Hedonic assimilation was found to occur when the subjects were told how other people have rated the stimulus (the expectation was certain), whereas hedonic contrast was found to occur when the subjects were uncertain about the hedonic expectation. Furthermore, Zellner et al. (2003) found hedonic contrast to be attenuated if samples were said to belong to different categories. All stimuli in their experiments were fruit juices, but the context stimuli ("good" version) were presented at full strength whereas the test stimuli ("poor" version) were presented diluted. The context stimuli were presented before test stimuli to create hedonic contrast. When all the stimuli (both context and test solutions) were called "fruit juices" (i.e., belonging to the same category) the test solutions were rated significantly lower compared to when the test solutions were called "commercial drinks" (i.e., belonging to a different category). Lahne et al. (2017) investigated the effect of category mismatch to hedonic contrast occurring between foods served in different courses within a meal. They found that if the appetizer and the main course did not cognitively fit into the same cuisine category (e.g., Italian or American cuisine) they are not compared, and hedonic contrast does not occur.

Particularly in food, expectations about flavor are found to modify the hedonic evaluation of a food (Deliza & MacFie, 1996; Yeomans et al., 2008). Preconceived expectations about the sensory or hedonic properties of food will affect subsequent perceptions of these properties and consequently food selection and consumption (Cardello 1994; Villegas et al., 2010). Fernández-Vázquez et al. (2013) investigated the expected liking and actual liking of orange juices with slight variations in color hues and found reddish orange juices to have the highest expected liking. However, after consumption the color hues did not affect the actual liking scores. Zellner et al. (2010) also found color to increase the attractiveness of food, but not the liking for the flavor of food. They supposed that once the food is tasted the sensory components in the mouth (e.g., taste, smell and texture) may override any effect of the initial visual components. Yeomans et al. (2008) investigated the importance of congruency between the expected flavor and actual sensory experience with highly novel foods. They found the contrast between expected and actual sensory qualities resulted in a strong negative affective response and enhancement of the unexpected sensory qualities.

2.5 Colors in visual aesthetics of food

Many everyday judgments and decisions are based on aesthetic responses to the world around (e.g., Naukkarinen, 2011; Palmer et al., 2013; Venkatesh & Meamber, 2008). Although cognitive processes and utilitarian values such as usability and efficiency have been used most frequently to explain consumers judgments, emotions arising from aesthetic-based factors can be at least equally important to explain consumers' higher order judgments such as quality perception and attractiveness (e.g., Bhandari et al., 2019). Wiedmann et al. (2019) have confirmed the importance of visual appeal and aesthetics in the context of industrial products. They propose that the impact of visual appeal and aesthetics is considerably higher than the impact of more rational concerns such as functionality. Bhandari et al. (2019) investigated the impact of perceived visual aesthetics on user evaluations using mobile apps as sample material. They found linkages between aesthetics and emotions and found affective responses to be as important as cognitive-based responses in decision-making. According to Creusen and Schoormans (2005), a product's appearance can have aesthetic, symbolic, functional (e.g., quality impression), and ergonomic (e.g., ease of use) value for consumers, and it can draw attention. They found that of these different product appearance roles, people most often mentioned the aesthetic and symbolic roles as influencing their product choice.

The term "aesthetics" is derived from the Greek word *aisthetikos*, (meaning 'pertaining to sense perception', 'things perceptible to the sense', or 'sensory impressions') and it relates to sense perceptions (Hoyer & Stokburger-Sauer, 2012). Aesthetics is a function of both the properties of an object and characteristics of a perceiver (e.g., Meshagen & Thielsch, 2010). Although aesthetics is commonly associated with the fine arts and concepts such as beauty, sublimity, the senses, the sensation of pleasantness, and artistic values (e.g., Augustin et al., 2012; Jacobsen, 2010; Charters & Pettigrew, 2005), aesthetics can also be considered to be any hedonic response (liked or not; interesting or not; to be approached or avoided) to a sensory experience (Shimamura, 2014). It is generally agreed that aesthetic experience is not solely sensory, but instead results from an interaction between perception, cognition, and emotion (e.g., Brachmann & Redies, 2017). According to Marković (2012), the aesthetic experience itself is pleasant, while the object of this experience can be either pleasant or unpleasant. However, for consumers, aesthetic experience is commonly equated with pleasure (Venkatesh & Meamber, 2008). The desire to experience aesthetic pleasure is the reason for designing products to delight one or more of the sensory modalities and consequently result in emotional responses (Desmet & Hekkert, 2007).

Traditionally, eating experiences have been excluded from aesthetic experiences because food and drink are considered to appeal mostly to appetite, pleasure and other utilitarian properties, and not to the disinterested appreciation of their properties (Spence et al., 2014; Charters & Pettigrew, 2005). In disinterested attention, the object is appreciated for its own sake without consideration of any extrinsic purpose it may serve (e.g., Charters & Pettigrew, 2005). Today, eating experiences are increasingly regarded as having aesthetic features, in spite of the utilitarian nature involved in eating. For example, Charters and Pettigrew (2005) found wine, like artworks, caused a sense of pleasure including both a hedonic and aesthetic experience. They defined hedonic experience as the general awareness of pleasure, and aesthetic experience as a deeper, more profound experience.

Although aesthetic perceptions are related to all senses, research on aesthetics is often focused on the visual domain (Hoyer & Stokburger-Sauer, 2012; Desmet & Hekkert, 2007). For example, Redies (2015) defined an aesthetic experience as consisting of an intense feeling of pleasure when viewing beautiful stimuli. Attributes such as ‘beautiful’, ‘attractive’, ‘pleasing to see’, ‘nice to see’, and ‘like to look at’ have been stated to be representative of aesthetic pleasure for designed artefacts (e.g., Blijlevens et al., 2017).

In the following sections, the branch of aesthetics called everyday aesthetics is introduced in section 2.5.1, and the theories used to explain aesthetic responses in section 2.5.2. Section 2.5.3 concentrates on research concerning visual aesthetics in food.

2.5.1 Everyday aesthetics

Everyday aesthetics has broadened the content of aesthetics to involve all everyday objects and activities, including food and eating, around us in our everyday life (e.g., Melchionne, 2013; Saito, 2001; Ratiu, 2013). ‘Everyday’ and ‘everyday aesthetics’ are characterized by attributes such as common, holistic, ongoing, temporal, functional, active, and informal (see discussions in Saito, 2001; Melchionne, 2013: Naukkarinen, 2013). Saito (2001) stated that “it is remarkable how much our seemingly nonaesthetic daily concerns are dominated by the aesthetic dimension.” According to Naukkarinen (2013) “whatever belongs to our everyday can be approached aesthetically or from the aesthetic point of view.” Vihalem (2016) stated that the aesthetic experience is a part of the general flow of everyday life, and aesthetic experiences cannot be separated from everyday life. Concerning everyday aesthetics, Saito (2015) pointed out the significance of bodily sensations as well as the fact that aesthetic responses guide people’s actions. If something is aesthetically appealing and attractive, people tend to purchase it, protect it, or try to maintain its aesthetic value (Saito, 2015).

There are different ways to describe what constitutes aesthetics in everyday life. It can be regarded as a special luxury interrupting the ordinary day (e.g., Haapala, 2010; Leddy, 2012), or it can be the ordinariness itself that is aesthetically desirable (e.g., Melchionne, 2013; Naukkarinen, 2011; Naukkarinen, 2013). The first point of view represents the traditional understanding of aesthetics concerning the fine arts, beauty and disinterestedness: aesthetics is something special, an unexpected experience that breaks the dullness of everyday life, and something we pay extra attention to. The second point of view highlights the commonness and the practical and functional purposes in aesthetics; according to Saito (2001), something cannot be beautiful if it is not useful.

According to Naukkarinen (2013) “if we approach something aesthetically, we typically pay attention to such issues as appearance, feel, look, touch, sound, and other perceivable qualities of the things we encounter and interact with: their emotional and sensory aspects.” Aesthetic judgment of an object has both emotional and cognitive perspectives because they can be made either spontaneously and quickly, or more extensively including the processes of reflection and elaboration (Graf & Landwehr, 2015).

2.5.2 Theories of aesthetic response

In everyday life, judgments and decisions are often based on internal aesthetic responses to aspects of the world around. The theories of aesthetic response have been categorized as: 1. mere exposure (people tend to like objects and images more as the frequency of seeing them increases), 2. arousal dynamics (pleasure is a matter of the viewer's degree of arousal), 3. prototype theory (people may prefer prototypical examples of categories to nonprototypical ones), 4. fluency theory (people prefer visual displays to the extent that they are processed more easily), and multicomponent theories (which concern especially aesthetic response to art) (Palmer et al., 2013). According to Palmer et al. (2013), the fluency theory is the single most general explanation of aesthetic preference. Both mere exposure and the prototype theory can be explained by fluency theory: the more often an object is seen, the more easily and fluently it will be processed and consequently more preferred; similarly, because prototypes are more easily and quickly processed, they are more preferred.

The key suggestions of fluency theory (Reber et al., 2004) are that "aesthetic pleasure is a function of the perceiver's processing dynamics: The more fluently the perceiver can process an object, the more positive is his/her aesthetic response," and "processing fluency is itself hedonically marked and high fluency is subjectively experienced as positive." According to Reber's fluency theory anything can be beautiful as long as it is found easy to process (Meshagen & Thielsch, 2010). Consequently, prototypical objects are generally preferred over nonprototypical objects, and repeated exposure to a stimulus enhances preference. Reber (2012) stated that visual stimuli that can be processed easily (fluently) yield a positive affective feeling, and this positive feeling can be attributed to the beauty and aesthetic pleasure of the visual stimuli. In addition to the visual quality of the object, prior exposure to the object affects the ease with which the stimulus can be processed (Reber, 2012). The product is found aesthetically more pleasant if it is familiar and easy to perceive and recognize. For example, fluency theory has been used to explain the role of colors in the product evaluation process in the context of consumer goods: a product with a fitting color leads to reduced mental perceptual effort and consequently a higher probability of being liked (Wiedmann et al., 2019; De Bock et al., 2013).

However, in contrast to the fluency theory, it has been noted that aesthetic liking may result from active elaboration of a stimulus (Graf & Landwehr, 2015). In the fluency theory, a perceiver is proposed to react passively to a stimulus, but in 'cognitive elaboration' a perceiver interacts actively with the stimulus to gain a deeper understanding of it (Graf & Landwehr, 2015). In the theory of arousal dynamics (Berlyne, 1970), pleasure is connected to the viewer's degree of arousal while viewing an image. Berlyne (1970) found that there is a bell-shaped relationship between hedonic appreciation and the arousal potential of stimuli: the most preferred stimuli having arousal potential at medium (or optimum) level and stimuli with lower or higher level of arousal potential being less preferred. The term 'arousal potential' covers all the stimulus properties that tend to raise arousal, such as complexity, novelty, surprisingness, or variability (Berlyne, 1970; Mielby et al., 2012).

2.5.3 Visual aesthetics of colors in food

Scientific research about the visual aesthetics of food itself is quite rare. This is despite the fact that aesthetics is commonly believed to affect food attractiveness and appeal, and aesthetic food plating to be an essential part of the multisensory eating experience (Spence et al., 2014). The research done on the aesthetics of food has focused mainly on aesthetics in general, not on the single attributes of foodstuffs, such as colors, affecting aesthetics. For example, Miele and Murdoch (2002) investigated the aestheticization of food in the context of 'eating out' through the case study of a Slow Food restaurant in Tuscany (Slow Food is a movement promoting local food and traditional cooking). Miele and Murdoch (2002) highlighted the practical aesthetics of traditional cuisines and the aesthetic appreciation of typical products and typical restaurants. They identified two main forms of aestheticization, namely an 'aesthetic of entertainment' in which food quality is subordinate to the restaurant experience, and a 'gastronomic aesthetic of food' in which food quality is regarded as a priority. This 'gastronomic aesthetic of food' in their investigation was found to be related especially to freshness, typicality and seasonality of food. Watz (2008) also pointed out the importance of the entirety of the meal. She stated that food is only one 'ingredient' of the meal, the other 'ingredients' being: ideas; art, balance and complexity; line, shape and form; light, color and plates; sound, music, rhythm, movement and atmosphere; and assembling the meal. The pleasantness of the meal depends on the balance between all these 'ingredients'.

Cornil and Chandon (2016) introduced the concepts of "Epicurean eating pleasure" and "visceral eating pleasure." Visceral eating pleasure is defined as "the short-lived hedonic relief created by the satisfaction of eating impulses." According to the "visceral" point of view, eating pleasure is "the enemy of healthy eating" and it must be controlled to avoid overeating. In contrast, the "Epicurean" view points out that eating pleasure is conjoined to moderation and wellbeing. Epicurean eating pleasure derives from the aesthetic appreciation of the sensory and symbolic value of the food, eating pleasure containing both evaluation of the sensory aspects of eating and evaluation of its meaning. According to Cornil and Chandon (2016), Epicurean eating pleasure can be increased by improving the aesthetic value of food, for example by colors and presentations. Batat et al. (2019) extended the concept of Epicurean eating pleasure focusing on the aesthetic appreciation of food to include "experiential pleasure of food", conceptualizing food as a form of art and savoring food as an art experience.

The influence of color and balance in the food presentation on visual attractiveness, willingness to try the food and the hedonic value of the food was investigated by Zellner et al. (2010). They found that although food on a plate was considered aesthetically pleasing, people might not be willing to try that food. In particular, neophobic people were less willing to try unfamiliar foods. In addition, Zellner et al. (2010) found balance and color influenced the enjoyment of the meal by 'delighting the eye' but had no impact on the enjoyment of the flavor of the food itself. The reason for this was supposed to be that when food was actually tasted the sensory components in the mouth (e.g., smell, taste, texture) may override any effects of the initial visual component. In contrast, in other research by Zellner et al. (2011), they found visual cues – the type of presentation – influenced the liking of the taste of the food. A neatly presented meal was liked more than the same food presented in a messy way. Zellner et al. (2011) assumed that the visual cues related to the neatness of the plating expressed the care in preparation, food quality and value of the food that then influenced liking of the taste of the food.

Attractively plated food is found to be preferred over food presented in a less attractive manner. In studies by Zellner et al. (2014a), a creative, 'contemporary', presentation was preferred and rated as more attractive than a 'traditional' presentation of the meal. However, Zellner et al. (2014a) were unsure if it was the attractiveness itself or some other information based on the attractiveness of plating that increased liking for the food. For example, they supposed the presentation of the food expressed the care taken with the food and consequently the quality of the food and the skill of the chef.

Michel et al. (2014) investigated the effect of art-inspired dish design on food expectations and experiences. They used food presentations inspired by one of Kandinsky's abstract paintings (**Figure 11**). The art-inspired presentation was considered more 'complex' and 'artistic', and participants liked it more than the other presentations (neat and regular presentations). Also, the art-inspired presentation was both expected to be and experienced as tastier than the other presentations. Michel et al. (2014) supposed that consuming an aesthetically pleasing product could evoke more enjoyment. According to Deroy et al. (2014), food presentations have all the components of pleasure: the pleasures of expectation, experience and memory.

Figure 11. The food presentations used in the study of Michel et al. (2014) (Creative Commons Attribution License; BioMed Central Ltd.).

The same kind of experiment was conducted in a naturalistic dining context as well, and Michel et al. (2015) found the visual layout of the dish significantly influenced diner's experiences. When a salad was presented in an artistically-inspired manner, the diners were willing to pay more for it, and when the elements of the main course were presented in the center of the plate, the main course was liked more. The importance of balance in aesthetic plating was also investigated by Velasco et al. (2016), and they found balanced presentations to be preferred over unbalanced.

However, it has been noted that food should not be too highly aesthetic. Wu et al. (2017) pointed out that enhanced aesthetics does not always provide a solely positive influence on the product's usage and selection. In their experiment with cupcakes, consumers were more likely to choose the higher aesthetic cupcake, but consumption was inhibited, and lower consumption enjoyment was experienced. According to Wu et al. (2017) this was due to the fact that highly aesthetic products elicited greater perceptions of effort in their creation, and in the consumption process this appreciated effort is destroyed. The product can therefore be considered too pretty to use.

In everyday eating situations, the presentation of food commonly consists of standard plates (typically white) and standard containers (typically white, steel or transparent glass); therefore, the colors in the food itself have a significant role in visual attractiveness. Nevertheless, research about colors in food presentations has been mainly focused on the colors of platings and settings, not on the colors of the food itself. For example, the color of the plate is found to significantly influence the perception of the food both in the laboratory and in a real restaurant setting (Piqueras-Fiszman et al., 2012; 2013). The influence of plate color and shape in taste perception and food quality judgments was found to be complex, with interactions between color and shape of the plate (Stewart & Goss, 2013).

2.6 Color combinations in food

The influence of colors in food presentation on food preference have been confirmed by a large body of research, for example Zellner et al. (2010, 2014a), Michel et al. (2014), Piqueras-Fiszman et al. (2012, 2013), and Stewart & Goss (2013). These investigations have been discussed in section 2.5.3 Visual aesthetics of colors in food. In this section, the focus is on the combinations of colors, and especially on their influence on food preference.

2.6.1 Theory of color combinations

Typically, colors do not appear alone but in combinations, and it is obvious that the appearance of colors is different if they are seen side by side or apart. Albers (2013; *Interaction of Color,* 1963) explored the interaction of color through experience, and revealed that colors can only be understood in relation to the other colors that surround them. Different colors could look alike, and the same colors could look different due to their neighboring colors (**Figure 12**). Practical exercises demonstrated that there is a discrepancy between physical facts and psychological effect. Albers (2013; *Interaction of Color,* 1963) used the term "color deception" to describe the illusion based on the relativity and instability of colors. The same illusion can be also seen in **Figure 10**.

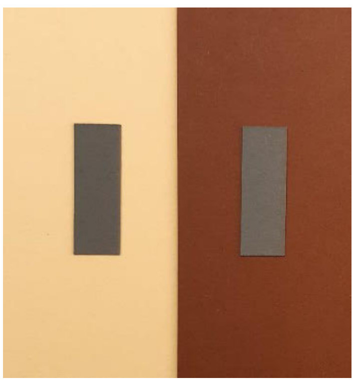

Figure 12. The interaction of neighboring colors. The left small rectangle and the right small rectangle are of the same color.

Hård and Sivik (2001) presented a theoretical model for color combinations. According to their theory, the most relevant attributes of color combinations can be categorized into three main groups: color interval, color chord, and color tuning. Color interval refers to the space between two objects, such as the size of interval of lightness, chromaticness or hue. Color chord describes the complexity and concordance among the colors ("how the colors visually 'sound' together"). Color tuning refers to different ways color combinations can be varied, such as area relations between different colors.

The colors in combination affect each other through simultaneous contrast or after-image (e.g., Arnkil, 2008; Hård & Sivik, 2001; Albers, 2013; *Interaction of Color,* 1963). Simultaneous contrast refers to the phenomenon of sensing the colors differently when they are seen side by side. For example, a neutrally colored area surrounded by a red area can be seen as greenish. According to the rule of simultaneous contrast (Chevreul, 1967; *The Principles of Harmony and Contrast of Colors and their Application to the Arts,* 1839), "in the case where the eye sees at the same time two contiguous colors, they will appear as dissimilar as possible, both in their optical composition [hue] and in the height of their tone [mixture with white or black]." Simultaneous contrast is most intense when the two colors are complementary. Generally, complementary colors (or opposite colors) are defined as colors which, when mixed or combined, produce a grayscale color like white or black. Pridmore (2009) separates complementary colors from opponent colors. Opponent colors are determined by initial appearance (observers estimate opponent colors and their hues), whereas complementary colors are determined as a pair of color stimuli whose admixture matches a selected achromatic color stimulus (usually white). In addition to contrast between complementary colors, there can be contrasts between color hues, color saturations, color lightness (light or dark), color warmness (warm or cool), and proportions of colors (Itten (1972; *Die Kunst der Farbe*, 1961).

In addition to color contrasts, color combinations are commonly described according to their harmony. In particular, the attractiveness of color combinations is found to be based on the balance and harmony (Zellner et al. 2010; Hård & Sivik, 2001). Color harmony (also known as conformity, balance, accord, or match) refers to the property that certain aesthetically pleasing color combinations have. The term color harmony is not a concise, descriptive term; rather, it has a wide range of meanings (Burchett, 2002). When something is said to be not harmonious, it is usually either boring or chaotic. Color harmony refers both to visual interest and to a sense of order. The color harmony properties of color combinations can be categorized based on analogous colors, on complementary colors, or on nature (Arnkil, 2008). Colors in nature are sensed as 'right' and 'correct', and they are perceived to be harmonious and without inconsistency – the colors of the scenery always match with each other. In the visual arts, harmony and disharmony are concepts of great interest. The harmony/disharmony can derive from analogous colors (colors with something in common, such as hue, lightness, or saturation), or contrasts of colors (complementary colors and after-images) (Arnkil, 2008). According to Hård and Sivik (2001), color harmony is based on the assumption that certain similarities between colors make the combination pleasing and harmonious. Obviously, color harmony cannot be defined simply and unambiguously. For example, Burchett (2002) identified the following attributes as describing color harmony: similarity (the colors have something in common, such as hue or chroma), area (dependence of color harmony on amounts or proportions of colors), interaction (simultaneous contrast and other effects attributable to the instability of the visual process), tone (the color itself; visual influences of color dimensions, hue, saturation etc.), association (a social concept of likes and dislikes based on the level of sophistication and innate perceptiveness of the viewer), attitude (a condition of color harmony that appeals to the intuitive, possibly physiological response mechanism), configuration (referring to the general overall design of colors and the manipulation of pictorial factors that modify the interrelationship of colors), and order (referring to color interval or to the combination of colors).

2.6.2 Preference for color combinations in general

The primary factors influencing color pair preferences are preferences for single colors, color harmony, lightness contrast, and figural preference against a colored ground (Schloss & Palmer, 2011). According to the Ecological Valence Theory by Palmer and Schloss (2010), people like colors to the degree that they like correspondingly colored objects. For example, a saturated blue color is generally liked because the clear sky is liked, and brown and dark yellows are disliked because rotting food is disliked. Camgöz et al. (2002) found colors having maximum saturation and brightness to be the most preferred, and in general, the most preferred hue was blue. However, color preferences are linked with a number of factors, such as personality, culture, gender, age, education, biological and social factors, lifestyle, etc. (e.g., Camgöz et al., 2002; Bakker et al., 2015).

In addition to preference for single colors, color harmony is an important factor for color pair preference. Color harmony is found to be a complex phenomenon. Generally, colors of the same hue are agreed to create harmonious color combinations. However, color harmony can be achieved also by complementary colors, especially complementary colors with high lightness contrast (Chuang & Ou, 2001). Szabó et al. (2010) stated the following principles for color harmony: similar hue, different lightness, and small chroma difference.

The similar hue principle was confirmed by Schloss and Palmer (2011), who found color pair preference and color harmony increased as hue similarity increased. In their study, color pairs with highly contrastive hues were not preferred nor judged as harmonious. The influence of lightness contrast was different: harmony was not dependent on lightness contrast, but pair preference did, with more contrastive pairs being preferred. This can be explained by the fluency theory (Reber et al., 2004), which proposes that people prefer things that are easy to process perceptually.

The preference for colors is highly dependent on the background against which the colors are seen. Schloss and Palmer (2011) found both hue contrast and lightness contrast influenced preference for the combination of the figural color and background color. Reynolds-McIlnay et al. (2017) found products with a high brightness contrast between product and environment were preferred because they visually "pop out."

Deng et al. (2010) investigated consumer preferences for aesthetic color combinations using two different perspectives: the visual coherence perspective and the optimal arousal perspective. In the visual coherence perspective, the main principles are similarity and unity, and aesthetic preference is supposed to increase based on color relationships stated to be 'identical matches' (i.e., the same point in the color space) and 'closely related' (i.e., very close in the color space, such as different shades of the same color) (Deng et al., 2010). The optimal arousal perspective is based on Berlyne's theory (Berlyne, 1970) that aesthetic preference is determined by the arousal potential of a stimulus. According to Berlyne (Berlyne et al., 1968; Berlyne, 1970), objects with optimum (moderate) arousal potential are preferred more than objects with less or more arousal potential.

'Color gestalt' is the concept used to describe the holistic way humans see objects with all their elements taken together (e.g., Hård & Sivik, 2001; Hu, 2019). Analyzing and measuring color gestalt is difficult because of the complicated interactions between affective color factors. Recently, Hu (2019) has introduced quantification methods to measure color-affective factors (color harmony, color preferences, and structural composition of colors) and to evaluate the interrelations between the colors and color combinations. In his model, the harmony of color combinations was assessed by familiality and rhythm of colors, with the familiality of colors referring to the identical elements of colors (such as identical hue, saturation, or lightness), and the rhythm of colors referring to the equal contrasts of element values. The color preferences of the model consisted of the tendencies and spans of color parameters (hue, saturation, and lightness). The structural composition of colors consisted of three main factors for each color: the area (small/large), the distribution (concentrated/dispersive) and the patch amount (solid figure/interwoven with other colors); and their interrelation. Although the perception of color gestalt was found to be quite computable using this multifaceted model, Hu (2019) concluded that more research is needed on color-affective factors and their interactions.

2.6.3 The influence of color combinations on food preference

Meals and dishes are usually complex mixes of different foodstuffs creating various color combinations. However, only one scientific research work was found to focus on the effect of color combinations in food itself. Mielby et al. (2012) investigated the relationship between visual preferences and perceived complexity for vegetable and fruit mixes. They found the visual preference increased with increasing perceived complexity of the vegetable and fruit mixes. In particular, the color contrasts in the food was found to affect perceived complexity. Fruit and vegetable mixes with low color contrasts were perceived as less complex than expected and mixes with high color contrasts as more complex than expected compared to the observed linear correlation between designed and perceived complexity found for the mixes (Mielby et al., 2012). In addition to color contrasts, the subject's preferred level of complexity was dependent on age, gender, and the frequency of consuming the products in the mixes.

The color combinations of food and the background against which food is presented are more heavily researched. The color of the background (from packages to cups, plates, and room color) has been found to affect people's perception of food and their consumption behavior (e.g., Spence, 2018a). For example, Lyman (1989) found purple grapes looked less purple on a purple plate, and redder on a blue plate; and red food on a blue plate appeared more orange. These phenomena are based on simultaneous color contrasts. Also, Spence (2018a) concluded in his review that simultaneous contrast (either color or brightness contrast) between background and food can make the food item appear more vivid, and consequently more appealing. This can be explained by enhanced perceptual fluency due to the high contrast between background and foreground (Reber et al., 2004).

Schifferstein et al. (2017) investigated the effect of background color on color perception and the attractiveness of vegetables. The perceived colors of vegetables were not found to be affected by background colors. Instead, differences in the perceived attractiveness of vegetables with differently colored backgrounds were found. Each vegetable seemed to have its own optimal background color. Typically, there was a contrast either in hue, blackness and/or chromaticitybetween the optimal color of the background and the color of the vegetable presented on the background. However, background-object color contrast was found not to be the only reason for attractiveness, vividness and saturation of the colors of vegetables were also influential, as well as the harmoniousness of color combinations.

Color harmony is one of the factors influencing preferences for color combinations. However, the color harmony principles were found to differ according to the context in which the colors are used. Although color harmony is generally associated with combinations of uniform colors, Wei et al. (2014) found that uniformity of colors was not a key factor in the context of juice packages. Similarity between package colors and the colors of the fruits inside the package was noticed to be a more important factor for the liking of the juice.

In addition, the design of presentation of colors in color combinations is important. Woods and Spence (2016) and Woods et al. (2016) investigated the associations between colors and basic taste perceptions. In both studies, it was found that pairs of colors created stronger taste associations compared to single colors, especially when both colors in the color pair were associated with the same taste. However, the influence of color pairs was dependent on the presentation of colors. In the study by Woods and Spence (2016), the equal-sized color squares were placed side by side, and it was found that participants took twice as long to match the color pairs with tastes than the single colors. In the study by Woods et al. (2016), the stimuli were either color squares or color circles with a colored border presented against a grey background, and the response time for color pairs or single colors was equal. Woods et al. (2016) concluded that the color combinations they used were perceived as just one combined element, not as separate conflicting elements.

2.7 Concluding remarks

Color is one of the elements in the multisensory food experience. In normal lighting conditions, food is always seen as possessing color. Commonly, the first perception of food is obtained through vision, and color is certainly part of this first impression, and it creates expectations. Color experience is a synthesis of both bottom-up (product-derived; information processed based on incoming data from the environment) and top-down (viewer-centered; information interpreted using memory, personality and context) processes. In addition, both conscious (e.g. cognition, memory, learning, experiences) and unconscious (e.g., emotions, feelings, desires) factors are involved in color experience, and there are interactions between them: emotions can direct cognitive information processing, and cognition can guide emotional affective processing. **Figure 13** describes the complex context-dependent processing of sensory information (light) in human brains (perception, and both cognitive and emotional processes) during a color experience. In addition, these mental processes can happen both consciously and unconsciously.

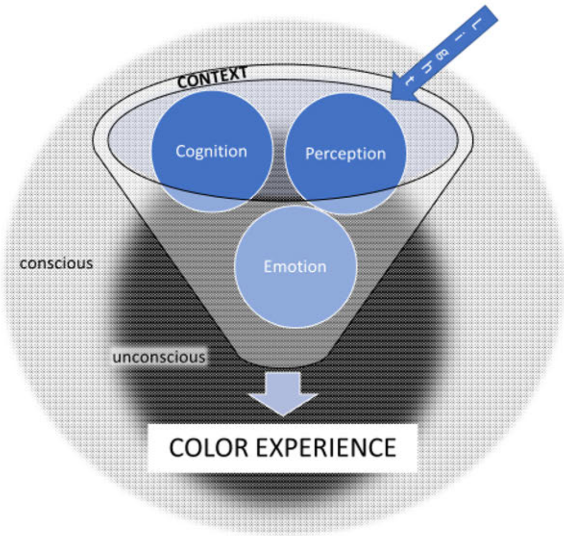

Figure 13. Factors involved in color experience of food.

In food, color has complex and multifaceted roles (**Figure 13**). Firstly, colors perceived in food help to cognitively identify and make quality judgments about foodstuffs. Colors aid in ascertaining the safety of food and make it possible to avoid poisonous or spoiled food (e.g., green on bread is a sign of molds, and brown flecks on salad about an outdated product). In addition, associations between taste perceptions and colors in food have been demonstrated, such as red being associated with sweetness, yellow with sourness, green with bitterness, etc. Associations and expectations induced by perceived colors can be both cognitive and affective – and conscious and unconscious – and consequently they are quite varied owing to the impact of individuals' cultural context, personal attitudes, previous experiences, etc. Different people associate the same color with a number of different tastes, and the same color in different foods can generate different expectations.

In addition to different properties of an object (e.g., different texture or surface properties) and different features of an observer (e.g., different physical or psychological features), the experience of color in food is affected by different contexts, such as physical surroundings, social relationships, circumstances of an event, etc. Consequently, the color experienced is not a constant property to be measured. Although it is possible to measure all color attributes (such as hue, brightness, chroma etc.), it is not possible to quantitatively measure the individual's holistic experience of color by existing measuring methods. Instrumental color measurements are most usable in comparing colors under similar conditions (e.g., quality control), investigating the relationship between color dimensions, and assessing the pure seeing of the object.

The visual attractiveness of food can refer to visual aesthetics and an aesthetically pleasing appearance. The scientific research concerning the visual aesthetics of colors in food has focused mostly on the aesthetics of plating and presentations. The one investigation about the visual attractiveness of color combinations in fruit and vegetable mixes indicated a relationship between color contrasts and perceived complexity and consequently the visual preference for food (Mielby et al., 2012). Generally, the investigations concerning colors in food have been restricted, particularly to single colors and to single color dimensions, such as hue alone or intensity alone, and in artificially colored liquids and solutions as the sample material. More research in different contexts and with colors and color combinations appearing in real food is needed to understand the color-related determinants of the visual attractiveness of food.

3 AIMS OF THE STUDY

The overall aim of the study was to investigate the influence of colors on the visual attractiveness of food (I – III). The focus was on the colors and color combinations in food itself and their roles in everyday eating situations. In the study II, the color values were measured to calculate different color dimensions describing color combinations in food. In addition, the dependence between individual attitudes and evaluation of color-related attractiveness in food was investigated in study I (the trait of food neophobia) and study III (the interest in visual aesthetics).

To achieve the overall aim, three separate investigations were conducted with following sub-aims:

I. To investigate the influence of an atypical color in food on consumers' response and choice (**Study I**).

II. To investigate the impact of different color attributes and dimensions of color combinations on the visual attractiveness of food (**Study II**).

III. To investigate the color-related aesthetic pleasure in food at workday lunches (**Study III**).

4 MATERIALS AND METHODS

Both quantitative and qualitative consumer tests were conducted. All original publications (Studies I-III) include quantitative consumer tests and open-ended answers to explain the choices between samples. Digital image analysis was used to measure color attributes in study II. In study III, a qualitative interview study was carried out, investigating more profoundly the color-related determinants of aesthetic pleasure in food.

The participants in all studies were Finnish consumers (**Table 1**). Participation in the investigations was totally voluntary and all procedures were carried out according to the guidelines in the Declaration of Helsinki (2013).

Three types of sample were used in the consumer studies (**Table 1**). All ingredients in all studies were natural, and no artificial food colorings were used. The food samples represented typical Finnish lunch foodstuffs.

Questionnaires on personal attitudes were used to research the trait of food neophobia (fear of new or unfamiliar foods) in study I, and interest in visual aesthetics of food and plating and general health interest in study III.

The open-ended arguments used to justify the food choices were analyzed using inductive content analysis, where the arguments were coded and categorized into different thematic categories (e.g., Tuomi & Sarajärvi, 2009).

Table 1. Aims, sample types, sample colors and participants in studies I-III.

Study	Aims	Samples in consumer tests	Colors and color combinations	Participants	Questionnaires
I	To study the influence of an atypical color on a consumer's response.	Potato salads	Yellow Blue	N = 235 (F 66%, M 32%, mean age 47 years, range 10-80 y)	FNS*
II	To study the impact of color combinations on visual attractiveness	Pictures of salad portions	Color contrasts, colorful ingredients. No color contrasts, pale ingredients	N = 93 (F 66%, M 34%, mean age 27 years, range 19-62 y)	
III	a) To define people's interest in visual aesthetics.	*(Questionnaire survey)*		N = 188 (F 78%, M 22%, mean age 39 years, range 21-66 y)	CVPA* GHI*
	b) To study the effect of colors on food choices.	Image-processed pictures of food portions.	Vivid colors and color contrasts Pale colors and no color contrasts Bright colors Muted colors	N = 105 (a part of above 188) (F 70%, M 30%, mean age 37 years, range 21-63 y)	
	c) To study the color-related determinants of aesthetic pleasure in food.	*(Interview study)*	Colorful and colorless options of foodstuffs	N = 12 (a part of above 188) (F 83%, M 17%, mean age 45 years, range 27-64 y)	

* FNS = Food Neophobia Scale (Pliner & Hobden, 1992); CVPA = applied Centrality of Visual Product Aesthetics (Bloch et al., 2003); GHI = General Health Interest (Roininen et al., 1999)

4.1 Study I

In study I, consumers evaluated two potato salads (yellow and blue) in trade fair events. The color of the potato salad originated from either naturally yellow-fleshed or blue-fleshed potato varieties. Yellow potatoes represented the typical color in commonly consumed potatoes in Finland, whereas the blue-fleshed potatoes were rare and atypical. Both potato salads had same ingredients and only the color was different. The potato salads were tasted and evaluated for different attributes (pleasantness, tasty, healthiness, lightness, naturalness, appetizing, sweetness and bitterness). In addition, consumers were asked to choose between yellow and blue potatoes and to give their open-ended arguments for their choice.

4.1.1 Food samples

The potato salads (**Figure 14**) were composed of two potato varieties (Melody and Blue Congo; both varieties were cultivated at same farm in Western Finland) having naturally different colors (yellow and blue). The color of yellow potatoes derives from carotenoids, whereas the color of blue potatoes derives from anthocyanins.

Figure 14. Potato salads used as edible samples in Study I.

The taste and texture of both potato salads (yellow and blue) were adjusted to be as similar as possible and the only difference between the salads was assumed to be the color. At first, a base salad was prepared that included a sauce (rapeseed oil, apple wine vinegar, honey, mustard, salt, and ground black pepper) and the other ingredients (apples, red onions, and pickled cucumber) except potatoes. Then, the salad was halved – one half mixed with blue potatoes and the other with yellow potatoes. The taste of the potato salad was intended to come mainly from the spices and other ingredients rather than from the potatoes. Both potato varieties used in this study are described as fairly firm-fleshed. In the study, they were both cooked to be smooth enough to be diced, but not mushy.

4.1.2 Questionnaire

Participants' trait of food neophobia was defined using the ten-item questionnaire (FNS) published by Pliner and Hobden (1992). In the questionnaire, a 7-point Likert scale was used (from 1 = totally disagree to 7 = totally agree), and half of the items were positively and half negatively worded relative to food neophobia. Responses given to negatively worded items were reversed before analysis. The theoretical range of the sum of the responses was 10 – 70, the value 10 representing the most neophilic and the value 70 the most neophobic attitude.

4.1.3 Consumer test

4.1.3.1 Participants

Two-hundred and thirty-five volunteers participated in study I. The participants were recruited at two trade fair events in South Ostrobothnia in Western Finland (in the cities of Kauhajoki: 14 000 inhabitants, and Seinäjoki: 62 000 inhabitants). The age of the participants ranged between 10 and 80 years, and the female/male proportion was 66%/32%. All the participants were Finnish, and they were familiar with potatoes in their diets.

For further statistical analysis, the participants were divided into distinct categories based on their age and food neophobia score: young (< 30 years; N = 43), middle-aged (30 – 60 years; N = 133), and older (> 60 years; N = 59); the most neophilic (Food Neophobia Scale, FNS < 20; N = 49), neither neophilic nor neophobic (FNS 20 – 40; N = 131), and the most neophobic (FNS > 40; N =45). In addition, the volunteers were subdivided into different groups according to their response to the question: "Imagine an occasion where both yellow and blue potatoes are served, which potatoes, yellow or blue, would you choose?"

4.1.3.2 Procedure

At the start of the experiment, each volunteer received a tray with two portions of potato salad and a questionnaire. The samples were presented in a random order. The participants were informed that two different potato varieties, "Melody" and "Blue Congo" were used, and that the color of the potatoes was natural, not artificial.

First, all participants were instructed to taste the potato salads and then express their own opinion about eight attributes (pleasantness, tasty, healthiness, lightness, naturalness, appetizing, sweetness, bitterness). Consumers' hedonic response to potato salads was evaluated using an 8-point scale for the attributes 'pleasantness' and 'tasty'. The scale was anchored with: 0 = attribute does not exist in the salad, 1 = attribute in the salad is very weak, and 7 = attribute in the salad is very intense. In addition to pleasantness and tasty, the attributes appetizing, natural, healthy, light, sweet and bitter, were evaluated. These attributes represented general acceptability (attributes 'appetizing' and 'natural'), impression of healthiness (attributes 'healthy' and 'light'), and description of taste (attributes 'sweet' and 'bitter') of the potato salad.

Finally, the participants were asked to imagine an occasion where both yellow and blue potatoes are served, then to choose between yellow and blue potatoes and justify their choice in their own words.

4.2 Study II

In study II, the participants evaluated the attractiveness of ten pictures of mixed (vegetables and fruits) salad portions. The salads were composed to be either pale colored with no color contrasts or colorful with high color contrasts. To diminish the influence of different ingredients, salad pairs (pale colored/colorful salad portions) were composed with equal number of ingredients with corresponding taste and texture but different color. For example, dark green broccoli was used as an ingredient in colorful salad and white cauliflower in pale colored salad, or red bell pepper was used in colorful salad and green bell pepper in pale green salad with no color contrasts. In addition, different color attributes (instrumentally measured L^*, a^*, and b^* values; calculated color dimensions: chroma, saturation, vividness, depth, and hue angle; and calculated differences between color values and dimensions) were defined to describe colors and color combinations. Finally, these color attributes were used to investigate the relationship between visual attractiveness as evaluated by participants and colors and color combinations in the mixed salads.

4.2.1 Food samples

Ten mixed salads representing typical lunchtime side salads were composed to form five pairs of salads with either pale-colored components with no color contrasts or colorful components with high color contrasts. Each pair of salads had an equal number of equal-quality ingredients, and a taste and structure as identical as possible. The mixed vegetable and fruit salads were prepared in a restaurant kitchen. The portion of each salad was then set on a white ceramic plate (Ø 19 cm). The salad portions were photographed under the normal serving circumstances at the restaurant. The photographs were printed (18.5 cm x 12.5 cm) and pictures were used as samples in the consumer study (**Figure 15**).

Figure 15. Two examples of pictures of mixed salads used as samples in Study II.

4.2.2 Consumer test

4.2.2.1 Participants

Ninety-three volunteers participated in study II. The participants were Finnish students or staff of the University of Tampere (in the city of Tampere: 225 000 inhabitants). The female/male proportion was 66%/34%, and the participants were of working age (between 19 and 66 years).

4.2.2.2 Procedure

The photographs of the ten mixed salads were coded with three-digit random numbers and presented coincidently in a random order. The participants were asked to rank the pictures of the mixed salad portions according to the attractiveness of the salad. The scale was from 1 (the most attractive salad) to 10 (the least attractive salad). Finally, the volunteers were asked to justify their choice of the most and the least attractive salad in their own words.

4.2.3 Color measurements

The colors of the salad components in mixed salads were measured in the $L^*a^*b^*$ color space by digital image analysis. The instrument (Cheos Ltd., Espoo, Finland) consisted of the following: digital camera: Go-5, Qimaging Ltd.; Zoom-lens: Computar M62 1212-35; lamps: Osram Dulux L 36W/865; and image analysis software: Image Pro Plus 7.0, "Color Lab."

In addition to measured color values: L^* (lightness), a^* (green-red component), and b^* (blue-yellow component), the color dimensions chroma (C^*), saturation (S^+), vividness (V^*), depth (D^*) and hue angle (h^*) were calculated to describe the color properties of the salad ingredients. The formulas for the calculation of color dimensions were based on the publications of Pathare et al. (2013), Lübbe (2013), and Berns (2014).

To describe the color variation, and especially the color contrasts, between salad components, the total color differences (ΔE) (Pathare et al., 2013), as well as the differences between color values (L^*, a^*, b^*) and color dimensions (C^*, S^+, V^*, D^*, h^*) were calculated.

4.3 Study III

Firstly, a survey was conducted to define consumers' general interest in the visual aesthetics of food and plating. The items of the questionnaire (applied CVPA) were created based on the CVPA (Centrality of Visual Product Aesthetics) questionnaire developed by Bloch et al. (2003). Secondly, the effect of colors in food on food choice was investigated by using image-processed pictures of food portions in which the only difference between food portions was the color. Finally, a qualitative interview study was conducted to assess the color-related determinants of aesthetic pleasure in food, and the color dimensions involved in these determinants. Four group interviews (three participants in each session) were carried out in the laboratory room used to represent workday lunch environment. Both colorful and colorless salad components were served to stimulate interviewees to discuss colors in food. In addition, differently colored environments (lime green or natural white) were used to promote discussion about colors.

4.3.1 The survey of interest in visual aesthetics

4.3.1.1 Participants

One-hundred and eighty-eight volunteers participated in study III. The questionnaire survey was conducted in two cities in Western Finland: Seinäjoki (N = 105) and Turku (N = 83) (Seinäjoki: 62 000 inhabitants and Turku: 188 000 inhabitants). The female/male proportion was 78%/22%, and the participants were of working age (between 19 and 66 years).The participants in Seinäjoki (N = 105) filled out an additional questionnaire on the choice of image-processed pictures (4.3.2), and twelve volunteers from the 83 participants in Turku participated in the interview study (4.3.3).

4.3.1.2 Questionnaires

Participants' interest in the visual aesthetics of food and plating was defined using an 8-item questionnaire for applied Centrality of Visual Product Aesthetics (applied CVPA). The original questionnaire for Centrality of Visual Product Aesthetics (CVPA) was published by Bloch et al. (2003). In study III, the questionnaire items were modified to measure in particular the level of interest in the visual aesthetics of food and plating. The items used in the survey are listed in Appendix A in publication III. The statements were either positively or negatively worded and the responses given to the negatively worded items were reversed before analysis. The responses were summed, and the sum divided by the number of the items (8), which resulted in a theoretical range of 1 – 7, with the value 1 representing the least interested and value 7 the most interested attitude for visual aesthetics (applied CVPA).

Owing to the overall aim of the project (Health-Supporting Multisensory Food Environment) that study III was part of, participants' general health interest was defined using a questionnaire published by Roininen et al. (1999). The design of the questionnaire was identical to the questionnaire for applied CVPA: an 8-item questionnaire with positively and negatively worded items. A theoretical range of the summed responses was 1 – 7, with the value 1 representing the least interested and value 7 the most interested attitude for health.

4.3.2 The choice of image-processed pictures

Image-processing software (Adobe Photoshop Elements 13.0) was used to edit pictures of lunch dishes. The idea was that the ingredients should not be identifiable and the only variable between the portions should be the color of the food elements. An example of this image processing is shown in **Figure 16**.

Original picture with carrots, cauliflower and broccoli.

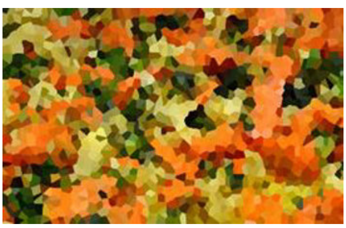

Image-processed picture (Adobe Photoshop Elements 13.0; crystallize 50).

Figure 16. An example of an original and image-processed picture of a dish (modified from Figure 2 in Publication III; pictures reprinted with permission from Elsevier).

The original digital photos were taken of everyday dishes at a Finnish workplace canteen buffet. Every portion was digitally composed of food elements to represent the plate model (**Figure 17**): one half of the plate consisting of vegetables, one quarter of grain or potato products, and one quarter meat or other protein-containing alternative. Altogether, six different image-processed pictures were composed to differ in their degree of colorfulness and brightness: two pictures were colorful (vivid colors and color contrasts), two were colorless (pale colors and no color contrasts), one picture was with brightly colored elements, and one picture with muted elements.

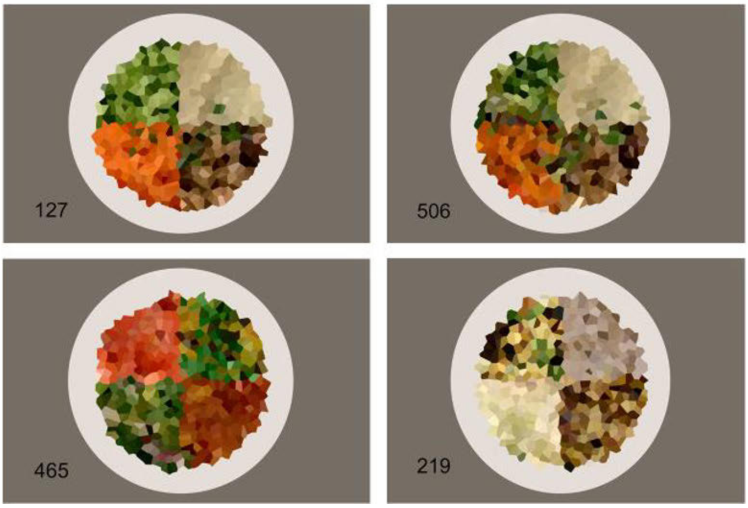

Figure 17. Image-processed pictures (bright colors, muted colors, colorful with contrasts, pale with no contrasts) of lunch portions used as samples in Study III.

The participants (N = 105) were shown image-processed pictures of lunch dishes in a random order. They were asked to choose the most preferable portion and to justify their choices in their own words.

4.3.3 Interview study

A qualitative study of four focus group interviews (three participants in each session, a total of twelve participants) was conducted in a laboratory room representing the eating environment at a workday lunch buffet. The interviews were carried out in the multisensory laboratory of Functional Foods Forum at the University of Turku. Colorful and colorless foodstuffs were served in the salad buffet to stimulate the interviewees to discuss colors in food. All the foodstuffs represented a typical Finnish salad lunch buffet. In addition, the differently colored (either lime green or natural white tablecloths and napkins) eating environments were used to stimulate a discussion about colors in surroundings. The lime green coloring in the surroundings was selected to increase congruence between the surroundings and the salad buffet (Kontukoski et al., 2016).

Four focus group interviews were arranged with three respondents in each session (a total of 12 respondents): two sessions in lime green and two sessions in natural white surroundings. In each interview session, a salad buffet was served, and the interview was conducted both during and after eating.

To facilitate conversation within the group, the focus groups were made as homogenous as possible (e.g., Robinson, 1999). Two different groups of interviewees were composed: A. those less interested in visual aesthetics and the healthiness of food, and B. those more interested in visual aesthetics and the healthiness of food. In addition, the groups were formed to be as close to demographically (gender and age) identical as possible. The interview groups are stated in Table 2 in publication III. Due to practical reasons (e.g., the strict timetables of respondents) the formulation of the groups was not ideal concerning the members' applied CVPA values. The differences between the applied CVPA values of participants in the different interview groups were quite small and all the participants were regarded as rather interested in visual aesthetics of food and plating.

The interviews were conducted by a researcher acquainted with the focus group interview method. In each interview session, a salad buffet was served, and the interview was conducted both during and after eating. The themes in each interview concerned food colors, food choices, healthiness in food, aesthetics in food and food experience. The themes were discussed in a random order in accordance with the spontaneous conversation in the group. The interviews were recorded and transcribed for analysis. The focus group interviews were analyzed using the thematic analysis method (e.g., Braun & Clarke, 2006). For study III, all the comments concerning food choices, colors in food and aesthetics were gathered and analyzed.

4.4 Statistical analyses

All the statistical analyses were performed using IBM SPSS Statistics, versions 19 and 22 in study I, and version 24 in studies II and III (SPSS Inc., an IBM Company©, 1989; 2010; 2016), and Unscrambler 9.8 (Camo Process AS, Oslo, Norway) for PLS (Partial Least Square) Method. All statistical methods and their purposes during the studies are described in **Table 2**.

Table 2. Statistical analyses performed in the studies I-III.

Study	Method	Purpose
I	Mixed-design analysis of variance	To test the impact of color and demographic factors on evaluation of attributes of potato salad, and their interactions.
	Mixed-design analysis of variance	To test interactions between color and choice on evaluation of attributes of potato salad.
	Post hoc Tukey HSD test	To find significantly ($p < 0.05$) different means.
	Levene's test	To test the equality of variances for ANOVA.
	Non-parametric Mann-Whitney test	To confirm the results of ANOVA when the variances were not homogenous.
	Pearson Chi-square test	To find significant dependencies ($p < 0.05$) between factors.
II	Partial Least Square (PLS) method	To test the relationship between attractiveness and color contrasts.
	Non-parametric Wilcoxon signed-ranks test	To test the significance of difference between the attractiveness of pale-colored and colorful salads.
	Non-parametric Kruskal-Wallis test	To test the dependence between the ranking of the salad and demographic factors.
III	Cronbach's alpha	To test the internal consistency of the items of the applied CVPA questionnaire.
	Pearson correlation analysis	To test the correlations between the applied CVPA values and GHI values.
	Pearson Chi-square test	To test the dependence between the applied CVPA values and gender.

5 RESULTS

5.1 The influence of an atypical color in food on consumers' response and choice (Study I)

The color of the potato salad was found to have an effect on the evaluation ratings for potato salads. The potato salad with the typical yellow color was rated higher than the potato salad with an atypical blue color for every attribute except bitterness and lightness (Table 2 in publication I).

Fear of new foods (food neophobia) was found to influence the evaluations of differently colored potato salads (Table 2 in publication I). The food neophobia scale (FNS) measurements of the participants ranged between 10 and 63, mean = 29.6. The attributes pleasantness, healthiness, and lightness were rated highest by neophilics (FNS < 20) and lowest by neophobics (FNS > 40), whereas bitterness was rated lowest by neophilics. Also, some dependence was found between participants' gender or age and the evaluation of potato salads. Males rated potato salads as less tasty, but more bitter than females. The younger (< 30 years) rated potato salads as less appetizing than the older participants (30 - 60 years and over 60 years).

When asked to choose between yellow and blue potatoes, 64.7% (N = 152) of all participants chose yellow potatoes and 28.1% (N = 66) blue potatoes. 3% of the participants chose both yellow and blue potatoes and 4% gave no answer for the question.

The choice between differently colored potatoes was found to be dependent on the participant's food neophobia level ($p < 0.001$) and age ($p = 0.045$) (**Figure 18**). Among neophilics (FNS < 20; n = 49), 55% of participants chose blue potatoes, whereas only 24% chose blue potatoes among neophobics (FNS > 40; n = 41). The influence of age was different: the middle-aged participants (between 30 and 60 years) chose blue potatoes more frequently compared to both younger (< 30 years) and older (> 60 years) participants (**Figure 18**). No interaction between choice and education or between choice and gender were found. The only significant ($p < 0.050$) between-group dependence was found between demographic factors education and age: 42% of the middle-aged group had had higher education and 6% only basic education, whereas the corresponding proportions were for the youngest group: 30% higher education and 17% basic education, and for the oldest group: 22% higher education and 20% basic education.

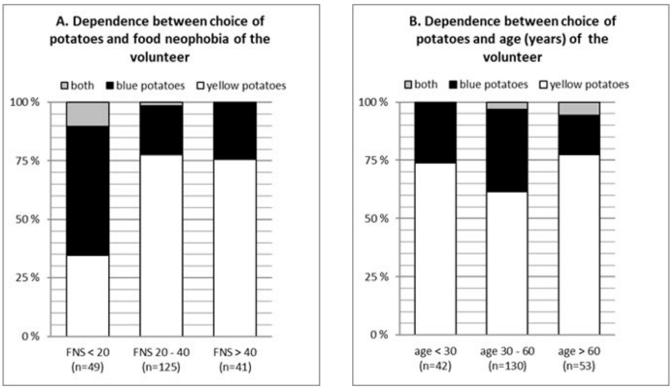

Figure 18. The dependence between the choice of potatoes and the level of food neophobia (A) and between the choice of potatoes and the age of the volunteer (B) (Figure I in Publication I; reprinted with permission from John Wiley & Sons, Inc.).

The color of the potato salad and the choice between differently colored potatoes were found to interact when evaluating different salad attributes (**Table 3**). Yellow potato choosers rated yellow potato salad higher and blue potato salad lower for every attribute except bitterness, whereas blue potato choosers rated blue potato salad higher for pleasantness, tasty, healthiness, lightness, appetizing and sweetness.

To compare individual participants, the scores they had given for blue and yellow potato salads were investigated. Of those who rated positive attributes (all attributes except bitterness) higher for the yellow potato salad, more than 80% chose yellow potatoes. The dependence between attributes of potato salad and choice of potatoes was not equally clear for blue potato choosers. From those who rated blue potato salad more pleasant, tastier or more appetizing, 50-61% chose blue potatoes.

After choosing between yellow and blue potatoes, the participants were asked to justify their choice. 85% of the participants wrote their open-ended arguments for their choice between yellow and blue potatoes. Generally (for both potatoes), the most frequently used arguments were “better taste” (17% of the participants) and “better appearance” (17%). Among yellow potato choosers, the most used arguments for the choice of yellow potatoes were “better taste” (18% of the yellow potato choosers); “traditional, familiar, safe” (18%) and “the other is worse” (17%). Also, arguments: “better appearance” (14%) and “natural” (12%) were used quite often. The arguments for the choice of blue potatoes were quite different. Blue potato choosers justified their choice mostly by “new, exceptional, for a change” (38% of the blue potato choosers). “better appearance” (27%), and “better taste” (17%).

Table 3. Interactions (mixed ANOVA) between the color of the potato salad and choice between yellow and blue potatoes when evaluating different attributes (mean ± standard deviation) (Table 4 in Publication I; reprinted with permission from John Wiley & Sons, Inc.).

	Pleasant	Tasty	Healthy	Light	Natural	Appetizing	Sweet	Bitter
Color * Choice	$p < 0.008$	$p < 0.008$	$p = 0.008$	$p = 0.024$	$p < 0.008$ [1)]	$p < 0.008$	$p = 0.008$	$p = 1.000$
	$F_{(1,215)} = 46.54$	$F_{(1,216)} = 24.15$	$F_{(1,214)} = 10.38$	$F_{(1,215)} = 9.09$	$F_{(1,213)} = 19.16$	$F_{(1,215)} = 43.59$	$F_{(1,213)} = 12.26$	$F_{(1,207)} = 1.95$
Yellow potato choosers								
- Yellow potato salad	5.0 ± 1.49	5.0 ± 1.50	5.0 ± 1.21	4.8 ± 1.39	5.1 ± 1.39	4.8 ± 1.66	4.2 ± 1.67	2.2 ± 1.81
- Blue potato salad	4.1 ± 1.71	4.3 ± 1.71	4.4 ± 1.52	4.6 ± 1.59	3.4 ± 1.79	3.2 ± 1.83	3.5 ± 1.80	2.4 ± 1.85
Blue potato choosers								
- Yellow potato salad	4.6 ± 1.52	4.7 ± 1.57	5.2 ± 1.13	4.8 ± 1.53	5.2 ± 1.37	4.7 ± 1.63	4.2 ± 1.44	2.0 ± 1.91
- Blue potato salad	5.1 ± 1.47	5.1 ± 1.44	5.3 ± 1.17	5.2 ± 1.33	4.8 ± 1.34	4.8 ± 1.49	4.3 ± 1.69	2.0 ± 1.73

Bonferroni corrected *p* values (multiplied by the number of comparisons (8)).

[1)] Variances were not homogenous by the Levene's test of equality of variances ($p<0.005$); results were confirmed by transforming and by non-parametric tests.

5.2 The impact of colors and color combinations on the visual attractiveness of food (Study II)

5.2.1 Consumer study

The results of the ranking of the salad pictures (from 1 = the most attractive to eat, to 10 = the least attractive to eat) are set out in **Figure 19**.

For every individual salad pair (pale colored/colorful) the colorful salad was ranked as significantly more attractive ($p < 0.001$; Wilcoxon Signed-Ranks Test) (Table 2 in publication II).

The dependence between salad ranking and the demographic factors gender and age was tested (Kruskal-Wallis Test), and the only dependence was discovered in salad 4B. The males ranked salad 4B as more attractive (mean ranking 5.2) than the females (mean ranking 6.5). No dependence between the mean salad ranking and the age of the participants was detected.

The open-ended arguments for the most attractive and the least attractive salads provided by the participants were coded and categorized. The thematic categories for the salads are provided in Table 4A (the least attractive salads) and Table 4B (the most attractive salads) in publication II. Of the participants, 83% presented their arguments for the least attractive salad, and 92% for the most attractive salad. The ingredients of the salad or the appearance of the salad were the most frequently used arguments for both the most attractive and the least attractive salad. However, it was found that most of the participants (61%) used different arguments for their choice of the most and the least attractive salad. For example, the same participant argued for the choice of the most attractive salad by appearance and the least attractive salad by ingredients or vice versa. The ingredients of the salad were the most frequently used argument for both choices: 20% of the participants (9 females, 10 males) used ingredients as an argument for the choice of both the most and the least attractive salad, 13% (11 females, 1 male) used both ingredients and appearance, and 5% (3 females, 2 males) only appearance to argue their choices. Of the ingredients, pecans (15 arguments for salad 3B) and dark red grapes (13 arguments for salad 2B) in particular were used as arguments for the most attractive salad. The most frequently used component to argue for the least attractive salad was cauliflower (13 arguments for salad 4A).

The arguments concerning appearance were analyzed in more depth. Of all the arguments describing appearance, approximately two-thirds discussed color, and particularly the colorfulness of the salad. The content of the arguments concerning appearance differed considerably depending on whether they were used for the most attractive or the least attractive salad. The choices of the most

Salad 2B 3.2 ± 2.20 | Salad 1B 3.4 ± 2.53 | Salad 3B 3.7 ± 2.56 | Salad 5B 4.8 ± 2.51 | Salad 1A 5.6 ± 2.33

Salad 2A 5.9 ± 2.28 | Salad 4B 6.1 ± 2.43 | Salad 3A 6.6 ± 2.63 | Salad 5A 7.5 ± 2.01 | Salad 4A 8.2 ± 2.14

Figure 19. The pictures and the means (mean ± standard deviation) of rankings (from 1 = the most attractive to 10 = the least attractive) of the salads in ascending order from the most attractive salad (Salad 2B) to the least attractive salad (Salad 4A). A = pale-colored salad, B = colorful salad. (Modified from Figure 1 in Publication II; pictures reprinted with permission from Elsevier.)

attractive salad were argued with reference to colorfulness, diversity and freshness, whereas the arguments for the least attractive salad involved colorlessness, lack of variety, unfreshness and dullness.

5.2.2 Color measurements

The measured color values (L^*, a^*, b^*) and the calculated color dimensions (C^*, S^+, V^*, D^*, h^*) for every salad component are stated in Appendix A (pale-colored salads) and Appendix B (colorful salads) in publication II. The measured a^* values ranged from -21.7 (green frisée salad) to +36.6 (red bell pepper). Pale-colored salads (A) and colorful salads (B) differed on their a^* values: in pale-colored salads the only positive a^* values (reddish) were detected for pine nuts (+5.6) and for sweet corn (+2.2), whereas in colorful salads most of the ingredients, except the salad base, had positive a^* values. The measured values of b^* ranged from 18.8 (dark red grape) to more yellowish 71.8 (peach) and 72.3 (sweet corn). No negative values of b^*, representing bluish colors, were detected. The smallest L^* value (0 representing black) was noticed for dark red grapes (24.3) and the highest L^* value (100 representing white) for white cauliflower (94.4).

A pale-colored component, cauliflower, was found to have the lowest values for chroma (22.4), saturation (23.0) and depth (23.1) of the color. Of the colorful components, dark red grapes had the highest saturation (77.7) and depth (81.8) values, peach the highest chroma value (73.8), and sweet corn the highest vividness value (110.2).

The maximum total color differences (ΔE) and the maximum differences between the salad components' color values and color dimensions were calculated to describe the color contrasts in the salads (Table 5 in publication II). For every salad pair, the maximum ΔE value was higher for the colorful salads (48.7 – 66.8) than the pale-colored salads (29.9 – 52.2). A total color difference higher than 3 is considered to be a very distinct difference between colors (Pathare et al., 2013). In every mixed salad (both pale colored and colorful), the maximum total color difference was over 29, representing clearly detectable color differences.

5.2.3 Dependence between color measurements and attractiveness

The relationships between the factors describing color contrasts (X-variable; maximum differences between color values and dimensions, and maximum total color difference) and attractiveness in the salads (Y-variable) are set out in **Figure 20**. According to Partial Least Square (PLS) analysis, a 73% variation in

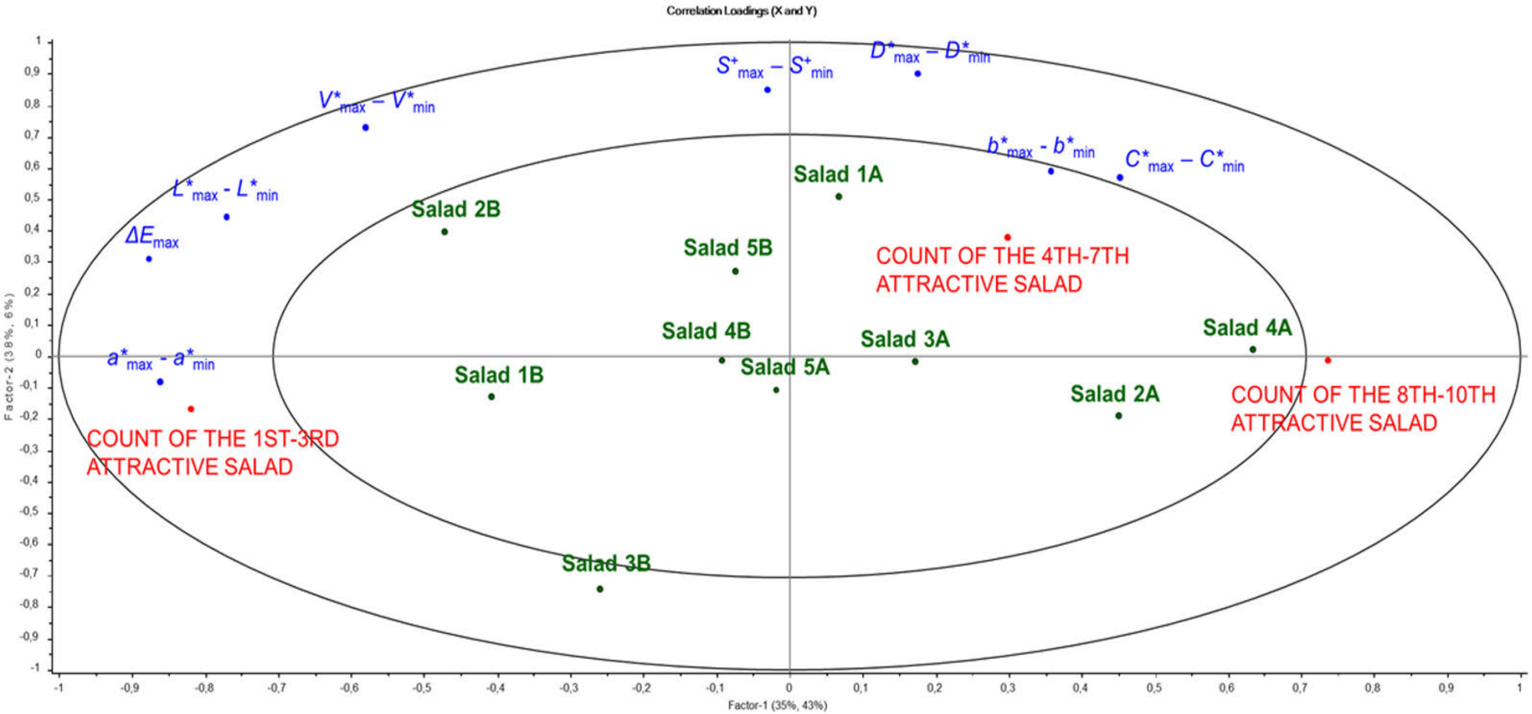

Figure 20. Multivariate Partial Least Square (PLS) regression correlation loadings plot expressing how the factors describing color contrasts in the salads (maximum differences between color values (L^*, a^*, b^*), maximum differences between color dimensions (C^*, S^+, V^*, D^*), and the maximum total color difference (ΔE_{max}) predict attractiveness in the salads. (Figure 2 in Publication II; reprinted with permission from Elsevier.)

the factors describing color contrasts explained 49% variation in the attractiveness in the salads.

In particular, the colorful salads (3B, 1B and 2B) were evaluated as more attractive compared to the pale-colored salads (4A and 2A). The maximum total color difference (ΔE_{max}), the maximum difference between a^* values (a^*_{max} - a^*_{min}) and the maximum difference between L^* values (L^*_{max} - L^*_{min}) were found to be the strongest predictors for attractiveness in the salads. Consequently, those salads having great variation in colors, especially those with both green and red ingredients along with dark and light colors, were considered to be attractive.

Generally, the saturation values and the depth values were higher with the more attractive salads compared to the less attractive salads. The opposite trend was observed with the vividness values, the less attractive salads having higher vividness values. For the most attractive salad (2B), the saturation values of the salad ingredients, with the exception of the salad base, ranged from 68.5 to 77.7 and the vividness values from 39.2 to 77.6. The corresponding color values for the least attractive salad (4A) were 31.2 – 59.2 for saturation and 92.7 – 107.0 for vividness.

5.3 Visual aesthetics of colors in food (Study III)

5.3.1 The survey of interest in visual aesthetics of food and plating

The applied CVPA values of the participants (N = 188) ranged from 1.5 to 7.0 (value 1 representing the least interested and value 7 the most interested attitude for visual aesthetics). The mean value of all participants was 4.79 (Md = 5.0) indicating the participants to be generally interested in the visual aesthetics of food and plating.

The applied CVPA values were found to depend on gender (Pearson Chi-Square test, $p < 0.010$). Females were commonly more interested in visual aesthetics (mean value 4.95) than males (mean value 4.19).

In addition to interest in visual aesthetics, participants' interest in general health was defined. These interests were found to correlate positively (Pearson Correlation, r = 0.236, $p < 0.001$) with each other when all data was analyzed. However, the correlation was found to depend on gender: the correlation was significant only for the female participants (r = 0.270, $p < 0.001$), not for the males (r = - 0.011, $p = 0.946$).

5.3.2 The effect of colors in food on food choice

When choosing between pictures of differently colored food portions, the participants (N = 105) preferred either colorful portions (chosen by 45% of the participants) or portions with bright colors (chosen by 45% of the participants). Only 8% of the participants chose portions with muted colors and 2% portions with colorless components. **Figure 21** presents the most and the least preferred food portions. There was no difference between females (N = 73) and males (N = 32) in their choice between food portions.

Figure 21. The most and the least preferred pictures of image-processed pictures of food portions.

In the group of participants who chose colorful portions or portions with bright colors (n =94), the mean value of applied CVPA was 5.00 (sd = 1.098) compared to the mean value of 4.11 (sd = 1.335) in the group that chose colorless portions or portions with muted colors (n = 10). Unfortunately, there were so few choices of colorless and muted colors that it was not possible to statistically analyze the dependences between the choice and applied CVPA values.

The most frequently used argument for the choice of portion was the colors in the food (54% of the participants), and 30% of the participants justified their choice by the foodstuffs they imagined to be in the portions. Plating was used as an argument by 15% of the participants. Arguments directly associated with the visual aesthetics of food were stated quite rarely: visually appealing (10% of the participants), and balance/harmony (9%). Terms such as ‘beautiful’ or ‘aesthetics’ were not mentioned in the open-ended answers as an argument for the food choice, although, according to the applied CVPA values, the participants were quite interested in visual aesthetics.

5.3.3 The interview study to assess color-related determinants of aesthetic pleasure in food

In general, interviewees considered both aesthetics and colors in food to exert influence on an unconscious level and their influences were difficult to verbalize in the context of lunch food. However, both colors and aesthetics were considered to be important. They were not regarded as a primary argument for food choices at lunch but were mentioned as having a great impact on food choice. In the interviews, the main arguments for food choices were given as healthiness, diversity and taste. However, almost every respondent said that colors in food have an impact on their food choices, and visual factors were found to affect food choices particularly at buffets.

The discussion on everyday aesthetics concerned fluency and pleasantness, and the sense of purpose, functionality and tranquility. A 40-year-old woman described aesthetics as follows: "*In my life, I link aesthetics with functionality and some kind of ease of use and pleasantness and peace of mind….*" and "*…. it is just like some kind of holistic impression that everything is all right.*" The basic requirements for aesthetics in food were discussed to be cleanliness and tidiness: food cannot be aesthetic if it is not safe and prepared carefully. Food with a neat appearance is assumed to have been prepared carefully and with great effort.

The attractiveness and pleasantness of lunch food were both associated with "clearness," "simplicity" and "recognizability." It was considered to be especially important that the food should look like itself and be typically colored. For instance, a 44-year-old woman stated: "*If food looks like some kind of mash, it is not attractive. It should be clear and simple….*" Typical colors were considered essential for identifying the foodstuffs.

In general, everyday lunch food was regarded as pleasant when it was ordinary, unsurprising, typically colored and easy to identify. However, "unsurprisingness" did not mean the same as "dullness." In lunch food, variety and diversity were also preferred. It was discussed that colors and colorfulness in food would add to the variety and diversity of people's diet. The unexpected beauty during everyday life was appreciated by some of the respondents, and they found, for example, beautiful color combinations in lunch food to be a valuable feature in itself. However, most of the respondents preferred typical, practical and fluent aspects of lunch food without verbally describing the aesthetic dimensions.

Food choices were considered to be based on the informative role of the colors. Colors in food were said to provide information and evoke expectations about taste, quality, safety, familiarity, and freshness in food. Particulary in vegetables, colors were associated with freshness. The expectations concerning the pleasantness of taste were considered to be caused by the colors. For example, a 43-year-old woman stated, "*I believe that if this portion suddenly turned black and white, some dimensions of the taste would disappear as well.*"

Most of the respondents preferred colorful lunch food: colorful food was considered attractive and pleasant, and colorless food was not considered equally appetizing. This is conveyed by the following example statements of middle-aged women: "*... some pale fish in some very pale cheese sauce, it seems quite flat to me…,*" and "*When you look at those side by side, and that one with more coloring… you take the one with more colors.*" In the interviews, the attractive colorfulness of food was understood as 1) being multi-colored, 2) having saturated colors, and 3) having contrasts between colors. The complementary color contrasts, such as red tomatoes and green salad, were considered to be pleasant in food. Colorless food was discussed to give the impression of tastelessness. Natural colors and colors typical for the foodstuff were preferred. Consequently, the color blue, which is naturally rare in food, was considered odd, unnatural and not attractive in lunch food.

The response to lime green colored surroundings varied: some of the respondents did not notice the green color of tablecloths and napkins at all, and some of the respondents found the coloring too dominant. In general, the interviewees liked the lime green color and associated it with peacefulness and discussed the importance of congruence between a green coloring in the surroundings and the salad buffet. The lime green surroundings seemed to have some kind of impact on behavior as the interviews arranged in the lime green environment took longer than the interviews in the natural white environment. The interview times in the white surroundings were 53 minutes and 54 minutes, and the interview times in the green surroundings were 79 minutes and 85 minutes.

6 DISCUSSION

The results of the experiments showed that the influence of colors in food on the visual attractiveness of food was important but unconscious and difficult to verbalize. Colors in food were found to generate expectations of quality, such as bright colors evoking an impression of freshness in vegetables or colorfulness an impression of variety in food. In contrast, pale colors and colorlessness created an impression of tastelessness and lack of variety. In mixed salads, the color dimensions saturated colors, brightness, complementary color contrasts, and variation of lightness, were found to predict the visual attractiveness. In the lunch context, the informative role of colors in food was highlighted. For example, colors were said to help the evaluation of quality or ripeness of vegetables and appropriately (typically) colored foodstuffs were found easier to identify. In particular, fluency (that is easy and quick identification of food) was considered an important determinant of aesthetic pleasure in everyday eating situations. According to the fluency theory (Reber et al., 2004), "the more fluently perceivers can process an object, the more positive their aesthetic response." Moreover, the results confirmed that the influence of colors in food was highly individual dependent. On the other hand, there may be some key attributes, such as a willingness to try new things (e.g., atypical colors in food), for food choice for variety-seeking or neophilic consumers, although most consumers preferred typical colors in food.

6.1 Color attributes related to visual attractiveness of food

Colorful and bright colors were found to be liked in lunch food. In study II, colorful salads were evaluated as more attractive than pale salads in every salad pair (colorful/colorless). In study III (survey with image-processed pictures of portions), 90% of the participants preferred either colorful portions or portions with bright colors. Similarly, Lee et al. (2013) have discovered that people prefer food with higher chroma and more vivid colors. In the interviews conducted in study III, the attractive colorfulness of food was described as multi-colored and to have saturated colors and color contrasts. In particular, the complementary color contrasts, such as green salad and red tomatoes, were considered to be pleasant in food. The preference for colorfulness in food could be partly based on the fact that colorful foodstuffs are more eye-catching. Milosavljevic et al. (2012) have found the product more detectable if there is a large color contrast between the product and background. This is in accordance with the results of study II, indicating that complementary color contrasts are preferred in lunch food.

In the experiments, colors typical for the foodstuff in question were generally preferred. In the interview study conducted in study III, participants stated that they like typical colors in food. The color blue, which is a naturally rare color in food, was considered odd, unnatural and not attractive in lunch food. This is in accordance with the statement by Spence (2018b) that blue is generally not liked in gastronomy, but natural colors are more preferred. Schifferstein et al. (2019) investigated consumer expectations using typically (orange) and atypically (purple, red, white, yellow, white/green) colored carrot varieties as sample material (actually pictures of carrots). They found that most positive expectations were for the typical and most familiar orange carrots. Atypically colored carrots were rated as less familiar, less attractive and less healthy than orange ones. The results of study I, which revealed that typically colored yellow potato salad was ranked higher for the 'positive' attributes (appetizing, naturalness, healthiness, pleasantness, tasty, and sweetness), confirmed the argument put forward by Clydesdale (1993) that correctly colored foods generally receive the highest hedonic response. Generally, appropriately and typically colored foodstuffs are found more accurate to identify and they are usually considered more pleasant (e.g., Zellner et al., 1991; Stevenson & Oaten, 2008; Cardello 1996; Schifferstein et al., 2019). However, opposite results have been stated as well. Although Kaspar et al. (2013) found unfamiliar purple potatoes to be the least accepted based on aroma and appearance, they found no significant differences in overall acceptance between potatoes with different colors (white, yellow, purple). Also, in study I with yellow and blue potatoes, even if most participants preferred typically colored yellow potatoes, there was a considerable number of participants (28%) who chose blue potatoes instead of yellow ones.

Artificial coloring was not accepted in lunch food. In the interviews (study III), it came out clearly that although bright and vivid colors are liked, they should be natural, and artificial coloring is not liked. Commonly, naturalness has been regarded as one of the most important factors behind the food choices of the majority of consumers (Martinsdóttir, 2013; Román et al., 2017). However, naturalness was not a key attribute for food choice for a group that chose blue potatoes found in study I. Instead of naturalness, blue potato choosers appreciated variety and argued for their choices with the following attributes: new, exceptional, for a change.

In study II, different color attributes were measured to investigate the dependence between color and the visual attractiveness of food. The attractiveness was found to be predicted by high total color difference (ΔE), the complementary colors green-red (high difference between a^* values) and variation in lightness (high difference between L^* values). This contradicts the statement by Schloss and Palmer (2011) that generally color pairs with highly contrastive hues are not preferred. However, general color preference ratings were found to increase as hue contrast with the background increases (Schloss & Palmer, 2011). Unfortunately, corresponding investigations concerning attractiveness and preference for color combinations in naturally colored food mixes could not be found. For different sample materials, Deng et al. (2010) have investigated aesthetic color combinations in athletic shoes. They found people liked combinations of colors that are closely related (visual coherence), whereas colors that differ greatly in hue or saturation (arousal potential) were seldom preferred. In contrast, in our study using mixed salads as the sample material, visual attractiveness seemed to be associated with the arousal potential rather than the visual coherence. Deng et al. (2010) have also noted the importance of arousal potential, because in their investigations some people liked to use contrastive colors to highlight some components. It is obvious, that the product is more detectable if there is a large color contrast between the product and background. Milosavljevic et al. (2012) have found that visual salience could influence food choices even more than preferences do. According to Creusen and Schoormans (2005), attention drawing and categorizations (i.e., visual typicality) in particular were supposed to be influential for food products.

In addition to complementary colors, the attractiveness of the mixed salads was found to correlate with the saturation and depth values of the salad components (Appendices and Table 2 in publication II). Both saturation and depth are terms used to describe the perceived intensity of the color. According to Berns (2014), increasing depth value corresponds to a ‘stronger’ color, and according to Lübbe (2008) increasing saturation value corresponds to a higher degree of saturation of the color. Similarly, Lee et al. (2013) found colors described as intensive, vivid or ‘strong’ to be the most attractive, and foods with high chroma values to be the most preferable. In our study, attractiveness depended more on the saturation of colors than the chroma of colors. Lee et al. (2013) used only chroma in their investigation, and the influence of saturation was not investigated. Chroma value has been criticized as confusing and having a relatively poor consistency in visual perceptions (Cho et al., 2017). In particular, the color depth value by Berns (2014) is found to agree well with the visual result of saturation (Cho et al., 2017). In our study, both saturation and depth values were found to be related to visual attractiveness. In addition, Schifferstein et al. (2019) have found a relationship between the saturation of the color orange and liking of carrots. They found a greater saturation of orange resulted in higher liking ratings, but the liking was dependent on the saturation level: for low and medium saturation levels, the saturation of orange was associated with the attractiveness of carrots, but for the highest saturation level, carrots were evaluated as more artificial.

In addition to colors, arrangement and orientation of the food on the plate can also influence food preferences (e.g., Michel et al., 2015; Rowley & Spence, 2018). To diminish the influence of arrangement in study III, every food portion was composed to form a circle of four equal-sized sectors. In addition, there were two different circles (differently arranged sectors) for both colorful and colorless portions.

6.2 Color-induced associations related to visual attractiveness of food

The attractiveness of the salads was found to be associated with the variety of the salad (study II). The most attractive colorful salads were described as possessing “variety” and “diversity,” whereas the least attractive pale salads were assumed “to have no complexity,” “to be boring,” and “to be too simple.” Mielby et al. (2012) found color contrasts to influence the perceived complexity. They investigated the relationship between visual preference and perceived complexity using fruit and vegetable mixes as visual stimuli and found that mixes with low color contrasts were perceived as less complex than expected, and mixes with high color contrasts were perceived as more complex than expected. In addition, they stated that complexity was an important parameter for the appreciation of foods (Mielby et al., 2012). This is in accordance with our results, where both colorful and pale-colored salads had the same number of ingredients, but the preferred colorful salads with color contrasts were associated with diversity and attractiveness, whereas the less preferred pale-colored salads without color contrasts were described as boring and without variation. Also, Carins et al. (2020) have found a strong relationship between food variety and satisfaction, increased perception of variety having a positive impact on satisfaction. In addition, offering more alternatives, such as food varying in appearance, has been found to increase their consumption (Wadhera & Capaldi-Phillips, 2014). König and Renner (2018) have found a positive correlation between increased perceived meal color variety and an increased proportion of vegetables consumed. This was confirmed in our real-life experiments conducted in a teaching restaurant at the Seinäjoki University of Applied Sciences. The results of the study indicated that multicolored salads were chosen more than monocolor salads (Kontukoski et al., 2015).

In addition to variety, the attractiveness of the salads was found to be associated with freshness, and colors were used to estimate the degree of freshness. The most attractive salads (colorful salads with high color contrasts) were described as being fresh, whereas the least attractive salads (pale salads with no color contrasts) were described as being leathery and old, although all the salad ingredients were equally fresh and high-quality. According to research by Lee et al. (2013), bright and vivid colors are generally associated with freshness and pleasantness in vegetables. In addition to freshness, in the interviews (study III) colors were considered to create expectations about taste, pleasantness of taste, quality, safety, and familiarity in food. According to Köster (2009), the expectations are based on learned relationships between the product and the post-ingestive satisfaction, and the expected satisfaction can be even more important than the sensory stimulation itself when evaluating the attractiveness of food.

6.3 The relationship between aesthetic pleasure and colors in food

In study III, food at workday lunches was considered pleasant when it was ordinary, unsurprising, typically colored, and easy to identify. The attributes used were almost identical to the elements listed in the fluency theory as being generally appreciated in visual aesthetics (Reber, 2012). Further, Naukkarinen (2011) has stated that the attributes unsurprising, ordinary, reliable, and familiar, are considered pleasant in everyday life. In everyday aesthetics, unsurprisingness is an important factor for the functional fluency of the ordinary day, and normal fluent functions are associated with satisfaction. However, "unsurprisingness" does not mean the same thing as "dullness." In the interviews, variety and diversity were preferred in lunch food, and colors in particular were said to increase the attractiveness and variety of food through the use of foodstuffs with different colors. This is in correspondence with Berlyne's theory of arousal dynamics (Berlyne, 1970), according to which pleasure is related to the observer's degree of arousal, and an optimum level of arousal potential of stimuli is preferred. In lunch food, color variety and diversity seem to be capable of raising arousal potential to the preferred level.

In **Figure 22** (Study III), the factors found to be important in aesthetic pleasure in the context of a workday lunch (pleasantness, fluency, functionality and tidiness) and the color dimensions related to them (brightness, colorfulness, variability, typicality, and naturalness) are summarized. In addition, congruences between the food, physical surroundings and context were found to be factors of aesthetic pleasure. The determinants of aesthetic pleasure (pleasantness, fluency, functionality, tidiness) were fairly similar to the properties considered central to everyday aesthetics, such as neatness, cleanliness, rightness, and pleasantness (Vihalem, 2016), routine and easiness (Naukkarinen, 2013), and functionality and utilitarian purpose (Saito, 2001).

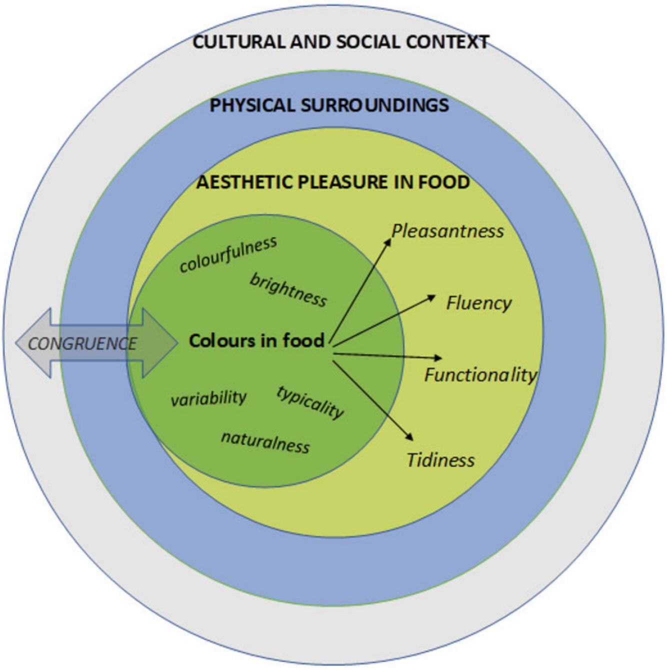

Figure 22. Color-related determinants of aesthetic pleasure in food in the context of a Finnish workday lunch (Figure 4 in Publication III; reprinted with permission from Elsevier).

Associations between colors in food and the visual aesthetics of food were stated quite rarely as an argument for food choice. In study III (survey with image-processed pictures), being visually appealing was used as an argument by 10% of the participants, balance or harmony by 9% of the participants, and plating by 15% of the participants. Terms such as ‘beautiful’ or ‘aesthetic’ were not mentioned at all. This was a relatively unexpected result because the participants were quite interested in visual aesthetics according to the results of the applied CVPA questionnaire. Naukkarinen (2013) has stated that although everyday aesthetics is important for people, it is rare to strictly analyze and argue for opinions on aesthetic issues. Similarly, a large proportion of decision making occurs at a non-conscious level, and food choices have been found to be based on intuitive reasoning and hedonic appreciation (Köster, 2009).

6.4 The product-dependent character of colors in food

Color is an intrinsic part of a product. A product cannot be visually perceived without colors (except in the dark or gloom), and colors are always perceived on a product. Elliot and Maier (2012) have stated that the object on which the color is perceived influences the associations and preferences for the color. In this study, the aim was to investigate the influence of colors on visual attractiveness, not the preference for certain foodstuffs. In order to diminish the influence of the ingredients on the evaluated attractiveness, sample materials were selected to be either 1) foodstuffs as similar as possible with naturally different colors (potato salads composed of yellow and blue potato varieties in study I), 2) several different sample pairs with an equal number of equal-quality familiar and typical ingredients that were not expected to be strongly liked or disliked (five pairs of pale-colored/colorful salad mixes in study II), or 3) pictures where ingredients were image-processed in order to make them unidentifiable (image-processed pictures of food portions in study III). Nevertheless, the association between colors in food and foodstuffs proved to be strong. With image-processed pictures where the color was the only variable between samples and the ingredients were not identifiable, 30% of the participants based their open-ended arguments entirely on the foodstuffs they imagined to be in the food portions.

According to Jimenez et al. (2015), the liking of some foods affects liking of the entire meal. Similarly, in study II with mixed salads, it was noticed that the participant's liking/disliking of certain ingredients certainly influenced the rating of the visual attractiveness of some salads. Although only an opinion on the visual attractiveness of the salads was requested in the questionnaire, and not, for example, "willingness to eat", ingredients were fairly frequently used as an argument to justify salad choices. It was noticed that there were some liked ingredients (e.g., pecans, watermelon or grapes) used as reasons for the choice of the most attractive salad. In contrast, if one of the salad components was not liked (e.g., cauliflower), the entire salad could be evaluated as unattractive. However, it was observed that for every five salad pairs (pale-colored/colorful), the colorful salad was ranked as more attractive than the pale-colored salad even though the liked/disliked ingredients were addressed only for some salads. Therefore, it was concluded that liking/disliking of certain ingredients alone did not explain the ratings of visual attractiveness, but there was also a dependence between visual attractiveness and color dimensions.

In addition, in study II, having to argue for one's preferences in one's own words possibly favored 'easy' arguments, such as ingredients, over descriptions about abstract matters such as colors and visual aesthetics which are more difficult to verbalize. Men in particular used ingredients as an argument for their choice. Women seemed to argue more holistically, using both ingredients and appearance as an argument. Gender differences in food perceptions and eating behaviors have been observed in several previous studies, for example Beardsworth et al. (2002); Wardle et al. (2004); Chao et al. (2017); Spence, (2019). Chao et al. (2017) have discovered women to be more sensitive or reactive to visual food cues than men.

6.5 Individual attitudes influencing color preferences in food

Generally, in addition to the food properties, the features of individual consumers (former experiences, knowledge, attitudes, economic factors, social factors, etc.) affect food preferences and choices. For example, food neophobia has been found to affect the hedonic ratings of food (e.g., Pliner & Hobden, 1992; Costell et al., 2010). In this study, the attitudes researched were food neophobia (study I) and interest in visual aesthetics (study III). Unfortunately, people uninterested in the visual aesthetics of food and plating could not be recruited during the study. Consequently, given that all the participants were quite interested in visual aesthetics, the dependence between interest in visual aesthetics and the color-related visual attractiveness of food could not be investigated.

In study I, it was found that the level of food neophobia influenced both the evaluation of potato salads and the choice between ‘familiarly’ colored yellow potatoes and ‘oddly’ colored blue potatoes. Of the participants, 21% ranked blue potato salad higher than yellow potato salad for pleasantness and 24% for tastiness, and especially food neophilics (FNS < 20) rated the unfamiliar, blue potato salad higher than neophobics (FNS > 40). This kind of result was to be expected (e.g., Siegrist et al., 2013). Nevertheless, 24% of the food neophobics (FNS > 40) chose blue potatoes. Consequently, it could be concluded that food neophobia was not the only factor behind the choice between yellow and blue potatoes. For example, according to Januszewska and Viaene (2012), there are consumers called variety-seekers who have an internal need for variety, and these variety-seekers can be observed both among neophobics and neophilics. Potentially an attribute such as “new” or “exceptional” describing variety-seeking would have been more essential for predicting the choice of blue potatoes in this study.

The choice between yellow and blue potatoes was found to be related to the participant’s food neophobia and age. “Blue potato choosers” tended to be more neophilic compared to “yellow potato choosers” and mostly middle-aged (30 – 60 years). In several studies, food neophobia has been found to depend both on education and age: neophobia decreases with increasing levels of education and increases with age (e.g., Tuorila et al., 2001; Meiselman et al., 2010; Siegrist et al., 2013). In study I, a significant dependence was found between the age and education of the participants: the middle-aged group had a higher level of education compared to other age groups. However, the choice of potatoes was found to be dependent only on the participant's age not on the participant's education. The relationship between individuals' food neophobia, education, age and choice between familiar and unfamiliar foods needs to be investigated more profoundly in further research.

The liking of food is greatly affected by expectations and their fulfillment. In addition to color of food product, a variety of factors, such as the product's label, package, advertising, price etc., can generate expectations and consequently affect preference judgment (e.g., Deliza & MacFie, 1996; Zellner et al., 2014b; Yeomans et al., 2008). In study I, the names of the potato varieties, 'Melody' and 'Blue Congo', were provided to the participants in order to assure them that the color of both potato salad samples was natural and derived merely from different potato varieties, and that no artificial coloring was used. However, these different potato variety labels might have generated different expectations among individuals. For example, food neophobics could have found the unfamiliar name of 'Blue Congo' more unappealing than food neophilics.

In study I, "Yellow potato choosers" could be described as traditional consumers appreciating good taste and arguing for their potato choice through traditionality, familiarity, and safety. They assumed blue, unfamiliarly colored potatoes to be worse than yellow potatoes, perhaps even spoiled, and consequently valued blue potato salad significantly lower than yellow potato salad for every 'positive' attribute. These results are in accordance with statements by Januszewska and Viaene (2012) that neophobics have a stronger negative attitude toward novel foods than neophilics, and familiarity is one of the key food choice motives among traditional consumers. "Blue potato choosers" in study I justified their choice of atypically colored blue potatoes mostly via terms such as "new, exceptional, for a change," "better appearance" and "better taste." They appreciated the appearance of blue potatoes and were interested in trying potatoes with the new, exceptional color. "Blue potato choosers" could be characterized as variety-seeking (Januszewska & Viaene, 2012) and hedonistic as pleasantness, tastiness and good appearance were the most important attributes for them.

In study III, the applied CVPA (Centrality of Visual Product Aesthetics) questionnaire was used to discover how interested people are in visual aesthetics. The original questionnaire was developed by Bloch et al. (2003) to measure "the level of significance that visual aesthetics hold for a particular consumer in his/her relationship with products," and they stated that consumers with a high CVPA level regard visual aesthetics as important for a wide range of product categories. In study III, the questionnaire was modified to measure the level of interest in visual aesthetics concerning food and plating in particular, for example there were questions about food decoration and table setting. The results of the survey with Finnish working-age adults indicated that consumers are interested in visual aesthetics of food. Similarly, the dependence of food choices on the appearance of food, the appearance-induced expectations, and the visual quality of food has been confirmed by many research results, for example Imram, 1999; Brunsø et al., 2002; Shankar et al., 2010.

The interest in visual aesthetics (applied CVPA) was found to be gender dependent, females being more interested in visual aesthetics (mean value = 4.95) than males (mean value = 4.19). Because the proportion of males and females was not balanced (78% females/22% males), the result is only indicative. However, the same type of gender differences has been found in other fields of visual aesthetics as well, for example in website preference aesthetics (Moss & Gunn, 2009) and in clothing shopping satisfaction (Chang et al., 2004). Chang et al. (2004) found that for clothing shopping satisfaction, the motives of males were more utilitarian than hedonic. Tivadar and Luthar (2005) investigated food practices and defined different food cultures. One of the food cultures was "Health-conscious hedonists," and females constituted 70% of the group. Males formed the majority in the groups "Male traditionalists" (62% men) and "Male modernists" (64% men), and it was found that members of these groups were not interested in aesthetics.

In the survey with image-processed pictures (study III), it was found that the applied CVPA levels were lower among those participants who chose either colorless portions or portions with muted colors (mean value of applied CVPA 4.11) compared to those participants who chose either colorful portions or portions with bright colors (mean value of applied CVPA 5.00). Due to the low number of the choices of colorless or muted colors in this study (N = 10) it was not possible to statistically analyze more profoundly the dependence between the choice and the applied CVPA value.

6.6 The relationship between colors in food and eating situations

Color meanings and color effects have been stated to be context specific, and the meaning of color is determined by its contextual surroundings (Elliot & Maier, 2012). In the context of workday lunch in study III, the attractiveness and aesthetics of food was associated with recognizability, clearness, simplicity, and with fluent identification of food. When interviewees were asked to describe aesthetics at lunch, no associations between lunch food and art or artworks were mentioned, although aesthetics is commonly associated with the fine arts. On the contrary, it was considered to be especially important that the lunch food should look like itself and be typically colored. According to Reber's fluency theory (Reber et al., 2004), easy and fluent processing itself is experienced as aesthetically pleasing. Commonly, ordinariness was preferred in lunch food, which is in accordance with the point of view that ordinariness itself is aesthetically desirable in everyday life (e.g., Melchionne, 2013; Naukkarinen, 2011; Naukkarinen, 2013). However, ordinariness and unsurprisingness did not mean the same as "dullness," and it was desired that lunch food should have variety and diversity.

From the present experiments in everyday lunch context, it became apparent that at an ordinary workday lunch people usually justify their food choices by rational reasons such as nutritional values or healthiness etc. The informative role of colors was highlighted, and colors in food were supposed to provide information about the expected flavor and quality, for example, the intensity of taste and the freshness of the ingredients. In the interviews (study III), visuality was discussed to affect food choices, but the effect of colors and aesthetics was often considered to be unconscious and, consequently, difficult to verbalize. The difficulty of specification of the precise influence of colors at lunch might derive from the fact that lunch is certainly one of the routine practices in everyday life, and everyday routines are inconspicuous, unremarkable and unrecognized, and therefore usually not verbalized (Jokinen, 2005; Wahlen, 2011). However, unconscious and intuitional factors have been found to be very important in making food choices (Brunsø et al., 2002; Köster, 2009). It has been shown that it is not possible to explain user judgments such as perception of quality and attractiveness solely through cognitive processes; rather, emotions and aesthetics are supposed to be at least equally important factors (e.g., Bhandari et al., 2019).

According to Stroebele and De Castro (2004), environmental colors seem to influence food attractiveness, food choices, mood, sensation etc. In the interview study (III), congruence between a green coloring in the surroundings and the salad buffet was discussed to be important. This is in accordance with investigations by Mattila and Wirz (2001) and with our previous research (Kontukoski et al., 2016) about the importance of congruence between food and the colors of the eating environment. A lime green coloring (used in study III) has been found to be suitable for salad restaurants and to be associated with words such as refreshing, cheerful and joyful (Kontukoski et al., 2016). The interviews in study III were found to take longer in green surroundings (lime green tablecloths and napkins) compared to white surrounding. Commonly, it is known that colors may have an unconscious and intuitive impact on behaviour (Elliot & Maier, 2007).

Moreover, in real eating situations, in addition to different colors in the surroundings, there are plenty of other factors, from plating and social surroundings to the entire context, that affect the overall attractiveness and liking of food. Furthermore, response and behavior are always highly individual-dependent. According to Onwezen (2018) "individuals have different motives and preferences across contexts. For example, a true convenience seeker might particularly focus on convenience when buying groceries and snacking but focus on health and coziness when preparing a dinner for friends."

6.7 Limitations and further research

This study has limitations and challenges that future research should consider. The sample material in this study was limited to typical vegetables at lunch (salads and potatoes), and the results cannot be directly generalized to every kind of food. The advantage of vegetables was that they have a large number of different and vivid colors. However, it was possible that the use of colorful vegetables as sample material over-emphasized the importance of the colorfulness and brightness of colors in the experiments. The potential importance and meaning of the colorlessness and dim colors like brown or gray might not have become apparent. In addition, the participants in the interviews verbally associated colors in food with "strong" colors and colorfulness, although pale hues are considered colors as well. To evaluate the meaning of colors in food more comprehensively, more research with different sample materials and different color hues is needed.

In study I involving the yellow and blue potato salads, the aim was to investigate consumers' reactions to products with same ingredients but different colors. The taste of the potatoes was assumed to be mild compared to the ingredients of the salad and the taste of the salad to come mainly from the spices and other ingredients rather than from the potatoes. However, this presumption should have been confirmed by testing the salads by blindfolded subjects prior to the consumer study. Also, it was possible that the names of the potato varieties created different expectations among different participants and consequently affected the judgments of the potato salads. The name 'Melody' is quite familiar and does not connote anything unusual, but 'Blue Congo' suggests an unfamiliar, exotic place which might appeal to neophilics but be unappealing to neophobics. In further research, this kind of label effect should be avoided by using neutral codes for samples.

In study II with mixed salads, the predictions between the color attributes and visual attractiveness were based on the consideration that every perceived color was equally important in spite of the different size of the color area. The significance of the areas of the colors and their proportions should be investigated in greater detail in further research. In addition to color contrasts, there are many other factors in color combinations, such as color harmony, that should be researched. In the future, more precise and exact methods for color measurements (e.g., the applications of photonics to specify spectrums) should be developed.

Of all the individual attitudes affecting color experience, only the influence of food neophobia was investigated in study I. The influence of the interest in visual aesthetics could not be evaluated in study III because too few volunteers with no interest in visual aesthetics were able to participate in the interviews. Consequently, further research is needed about the impact of consumers' interest in visual aesthetics. In addition, there are a large number of other personal features, values, attitudes, emotions etc. whose influence on the experience and preference for colors should be investigated in further research.

In study III, it was observed that a green color in the surroundings extended the session times in the interviews. However, there were only two sessions (three interviewees per session) arranged in either lime green or neutral white surroundings in this study and more research with more participants is needed to confirm this type of influence. Moreover, the impact of the environment (e.g., visual and auditory environments, etc.), and the entire context (e.g., workday lunch, fine-dining, social interaction) should be investigated further. For example, Spence (2015b) has highlighted the fact that in most laboratory studies investigating the effects of colors in food, the color of the foodstuff was the only cue, whereas in the real world there are many other cues to utilize when evaluating the sensory and hedonic qualities of food, and this might have biased the impression of the importance of colors.

In this study, both quantitative and qualitative methods were used, both methods having their own limitations. For example, the ideal for the quantitative statistical analysis is to use samples differing by only one variable but this ideal could not be followed in this study. It was not possible to find identical foodstuffs (e.g., same taste and texture) with a naturally different color. In the qualitative focus group interviews, there was probably some social desirability bias due to the participants' willingness to answer in a way that would be viewed favorably by others. Attempts were made to diminish this type of bias by ensuring that the interviewer was fully familiar with interviewing technique and by making the interview session as a whole as comfortable and relaxed as possible in order to allow free discussion. On the whole, it came out during the study that applying both quantitative and qualitative methods broaden the understanding of the meaning of colors in food, but more triangular research using a combination of several research methods to collect data is needed to understand both the conscious and unconscious nature of colors more profoundly.

7 CONCLUSIONS

The results of the experiments indicate that colors in food influence the visual attractiveness of lunch food. Colors in food were found to contribute to the identification of food components, to generate expectations about taste, freshness and quality of food, and to influence the overall attractiveness of appearance.

Color attributes indicating the visual attractiveness of lunch food were found to be colorfulness, typicality, vividness and brightness. Color contrasts and color variation were found to increase the impression of variety and diversity, and consequently the preferred complexity of food. In addition, high color contrasts with vivid and bright colors drew more attention. Colors in food generate expectations of quality, such as bright colors evoking an impression about freshness in vegetables or colorfulness associated with variety. In contrast, pale colors and colorlessness create an impression of tastelessness and lack of variety. Because visual signals are especially important at the stage of choosing and buying foodstuffs, visually attractive colors and color combinations in food can be used to nudge people, for example, to have a healthier diet with more vegetables. At a lunch buffet, visually attractive food is easily perceived, without excessive surprises but with sufficient complexity and variety, and colors and color combinations in food are one tool to enhance these attributes.

The informative role of colors in lunch food was highlighted in the interviews, and food choices were mostly justified through rational reasons. Nevertheless, colors and visual aesthetics were considered to be important and have a great impact on food choices. In general, people were interested in the visual aesthetics of food, but they found difficult to verbalize the unconscious effects of colors and aesthetics in food. It is common in everyday life that aesthetics is merely experienced and not carefully analyzed and verbalized. In the context of a Finnish workday lunch, the color-related determinants for aesthetic pleasure were found to be pleasantness, fluency, functionality and tidiness; the determinants corresponding to the properties considered central to everyday aesthetics in general. Fluency in particular was considered an important factor of aesthetic pleasure in a lunch context. Clear and typical colors in food can enhance fluency by improving the easy and quick observation and identification of food components.

In everyday eating situations, colors in food are commonly not perceived as colors themselves but as colors in foodstuffs. Consequently, the pleasantness of colors and color combinations in food differs from the pleasantness of colors in general. The common rule that harmonious colors with similar color hues are preferred cannot be applied with food. On the contrary, in lunch food, vivid colors and high color contrasts with complementary colors such as red and green or light and dark are considered attractive.

The personal features and attitudes of individuals were found to affect color preferences in food. Generally, typical and appropriate colors in food were appreciated, but consumers preferring atypical colors were also discovered. Food neophobia and a willingness to try new things as well as an appreciation of pleasantness and appearance were found to be important factors lying behind the choice of atypically colored foodstuffs.

Color in food is one part of the holistic multisensory experience of food. The role of colors in food varies depending on the product, the consumer, and the context in which the observations are made. In general, consumers like every part of the experience – from the colors of the food to the entire context – to be in congruence. In this study, the color-related determinants of visual attractiveness and aesthetic pleasure in food were investigated in a Finnish everyday lunch context. Further research is needed to explore and specify the color-related factors influencing visual attractiveness in food in different contexts.

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APPENDIX: ORIGINAL PUBLICATIONS

I. Reprinted from the Journal of Sensory Studies 2016, 31, 78–89, with permission from John Wiley & Sons Inc.

II. Reprinted from Food Quality and Preference 2019, 76, 81–90, with permission from Elsevier.

III. Reprinted from the International Journal of Gastronomy and Food Science 2019, 16, 100131, with permission from Elsevier.

DOCTORAL THESES IN FOOD SCIENCES AT THE UNIVERSITY OF TURKU

1. **REINO R. LINKO (1967)** Fatty acids and other components of Baltic herring flesh lipids. (Organic chemistry).
2. **HEIKKI KALLIO (1975)** Identification of volatile aroma compounds in arctic bramble, *Rubus arcticus* L. and their development during ripening of the berry, with special reference to *Rubus stellatus* SM.
3. **JUKKA KAITARANTA (1981)** Fish roe lipids and lipid hydrolysis in processed roe of certain *Salmonidae* fish as studied by novel chromatographic techniques.
4. **TIMO HIRVI (1983)** Aromas of some strawberry and blueberry species and varieties studied by gas liquid chromatographic and selected ion monitoring techniques.
5. **RAINER HUOPALAHTI (1985)** Composition and content of aroma compounds in the dill herb, *Anethum graveolens* L., affected by different factors.
6. **MARKKU HONKAVAARA (1989)** Effect of porcine stress on the development of PSE meat, its characteristics and influence on the economics of meat products manufacture.
7. **PÄIVI LAAKSO (1992)** Triacylglycerols – approaching the molecular composition of natural mixtures.
8. **MERJA LEINO (1993)** Application of the headspace gas chromatography complemented with sensory evaluation to analysis of various foods.
9. **KAISLI KERROLA (1994)** Essential oils from herbs and spices: isolation by carbon dioxide extraction and characterization by gas chromatography and sensory evaluation.
10. **ANJA LAPVETELÄINEN (1994)** Barley and oat protein products from wet processes: food use potential.
11. **RAIJA TAHVONEN (1995)** Contents of lead and cadmium in foods in Finland.
12. **MAIJA SAXELIN (1995)** Development of dietary probiotics: estimation of optimal *Lactobacillus* GG concentrations.
13. **PIRJO-LIISA PENTTILÄ (1995)** Estimation of food additive and pesticide intakes by means of a stepwise method.
14. **SIRKKA PLAAMI (1996)** Contents of dietary fiber and inositol phosphates in some foods consumed in Finland.
15. **SUSANNA EEROLA (1997)** Biologically active amines: analytics, occurrence and formation in dry sausages.
16. **PEKKA MANNINEN (1997)** Utilization of supercritical carbon dioxide in the analysis of triacylglycerols and isolation of berry oils.
17. **TUULA VESA (1997)** Symptoms of lactose intolerance: influence of milk composition, gastric emptying, and irritable bowel syndrome.
18. **EILA JÄRVENPÄÄ (1998)** Strategies for supercritical fluid extraction of analytes in trace amounts from food matrices.
19. **ELINA TUOMOLA (1999)** *In vitro* adhesion of probiotic lactic acid bacteria.
20. **ANU JOHANSSON (1999)** Availability of seed oils from Finnish berries with special reference to compositional, geographical and nutritional aspects.
21. **ANNE PIHLANTO-LEPPÄLÄ (1999)** Isolation and characteristics of milk-derived bioactive peptides.
22. **MIKA TUOMOLA (2000)** New methods for the measurement of androstenone and skatole – compounds associated with boar taint problem. (Biotechnology).
23. **LEEA PELTO (2000)** Milk hypersensitivity in adults: studies on diagnosis, prevalence and nutritional management.
24. **ANNE NYKÄNEN (2001)** Use of nisin and lactic acid/lactate to improve the microbial and sensory quality of rainbow trout products.
25. **BAORU YANG (2001)** Lipophilic components of sea buckthorn (*Hippophaë rhamnoides*) seeds and berries and physiological effects of sea buckthorn oils.
26. **MINNA KAHALA (2001)** Lactobacillar S-layers: Use of *Lactobacillus brevis* S-layer signals for heterologous protein production.
27. **OLLI SJÖVALL (2002)** Chromatographic and mass spectrometric analysis of non-volatile oxidation products of triacylglycerols with emphasis on core aldehydes.
28. **JUHA-PEKKA KURVINEN (2002)** Automatic data processing as an aid to mass spectrometry of dietary triacylglycerols and tissue glycerophospholipids.
29. **MARI HAKALA (2002)** Factors affecting the internal quality of strawberry (*Fragaria x ananassa* Duch.) fruit.
30. **PIRKKA KIRJAVAINEN (2003)** The intestinal microbiota – a target for treatment in infant atopic eczema?
31. **TARJA ARO (2003)** Chemical composition of Baltic herring: effects of processing and storage on fatty acids, mineral elements and volatile compounds.
32. **SAMI NIKOSKELAINEN (2003)** Innate immunity of rainbow trout: effects of opsonins, temperature and probiotics on phagocytic and complement activity as well as on disease resistance.
33. **KAISA YLI-JOKIPII (2004)** Effect of triacylglycerol fatty acid positional distribution on postprandial lipid metabolism.
34. **MARIKA JESTOI (2005)** Emerging *Fusarium*-mycotoxins in Finland.
35. **KATJA TIITINEN (2006)** Factors contributing to sea buckthorn (*Hippophaë rhamnoides* L.) flavour.
36. **SATU VESTERLUND (2006)** Methods to determine the safety and influence of probiotics on the adherence and viability of pathogens.
37. **FANDI FAWAZ ALI IBRAHIM (2006)** Lactic acid bacteria: an approach for heavy metal detoxification.
38. **JUKKA-PEKKA SUOMELA (2006)** Effects of dietary fat oxidation products and flavonols on lipoprotein oxidation.
39. **SAMPO LAHTINEN (2007)** New insights into the viability of probiotic bacteria.
40. **SASKA TUOMASJUKKA (2007)** Strategies for reducing postprandial triacylglycerolemia.

41. **HARRI MÄKIVUOKKO (2007)** Simulating the human colon microbiota: studies on polydextrose, lactose and cocoa mass.
42. **RENATA ADAMI (2007)** Micronization of pharmaceuticals and food ingredients using supercritical fluid techniques.
43. **TEEMU HALTTUNEN (2008)** Removal of cadmium, lead and arsenic from water by lactic acid bacteria.
44. **SUSANNA ROKKA (2008)** Bovine colostral antibodies and selected lactobacilli as means to control gastrointestinal infections.
45. **ANU LÄHTEENMÄKI-UUTELA (2009)** Foodstuffs and medicines as legal categories in the EU and China. Functional foods as a borderline case. (Law).
46. **TARJA SUOMALAINEN (2009)** Characterizing *Propionibacterium freudenreichii* ssp. *shermanii* JS and *Lactobacillus rhamnosus* LC705 as a new probiotic combination: basic properties of JS and pilot *in vivo* assessment of the combination.
47. **HEIDI LESKINEN (2010)** Positional distribution of fatty acids in plant triacylglycerols: contributing factors and chromatographic/mass spectrometric analysis.
48. **TERHI POHJANHEIMO (2010)** Sensory and non-sensory factors behind the liking and choice of healthy food products.
49. **RIIKKA JÄRVINEN (2010)** Cuticular and suberin polymers of edible plants – analysis by gas chromatographic-mass spectrometric and solid state spectroscopic methods.
50. **HENNA-MARIA LEHTONEN (2010)** Berry polyphenol absorption and the effect of northern berries on metabolism, ectopic fat accumulation, and associated diseases.
51. **PASI KANKAANPÄÄ (2010)** Interactions between polyunsaturated fatty acids and probiotics.
52. **PETRA LARMO (2011)** The health effects of sea buckthorn berries and oil.
53. **HENNA RÖYTIÖ (2011)** Identifying and characterizing new ingredients *in vitro* for prebiotic and synbiotic use.
54. **RITVA REPO-CARRASCO-VALENCIA (2011)** Andean indigenous food crops: nutritional value and bioactive compounds.
55. **OSKAR LAAKSONEN (2011)** Astringent food compounds and their interactions with taste properties.
56. **ŁUKASZ MARCIN GRZEŚKOWIAK (2012)** Gut microbiota in early infancy: effect of environment, diet and probiotics.
57. **PENGZHAN LIU (2012)** Composition of hawthorn (*Crataegus* spp.) fruits and leaves and emblic leafflower (*Phyllanthus emblica*) fruits.
58. **HEIKKI ARO (2012)** Fractionation of hen egg and oat lipids with supercritical fluids. Chemical and functional properties of fractions.
59. **SOILI ALANNE (2012)** An infant with food allergy and eczema in the family – the mental and economic burden of caring.
60. **MARKO TARVAINEN (2013)** Analysis of lipid oxidation during digestion by liquid chromatography-mass spectrometric and nuclear magnetic resonance spectroscopic techniques.
61. **JIE ZHENG (2013)** Sugars, acids and phenolic compounds in currants and sea buckthorn in relation to the effects of environmental factors.
62. **SARI MÄKINEN (2014)** Production, isolation and characterization of bioactive peptides with antihypertensive properties from potato and rapeseed proteins.
63. **MIKA KAIMAINEN (2014)** Stability of natural colorants of plant origin.
64. **LOTTA NYLUND (2015)** Early life intestinal microbiota in health and in atopic eczema.
65. **JAAKKO HIIDENHOVI (2015)** Isolation and characterization of ovomucin – a bioactive agent of egg white.
66. **HANNA-LEENA HIETARANTA-LUOMA (2016)** Promoting healthy lifestyles with personalized, *APOE* genotype based health information: The effects on psychological-, health behavioral and clinical factors.
67. **VELI HIETANIEMI (2016)** The *Fusarium* mycotoxins in Finnish cereal grains: How to control and manage the risk.
68. **MAARIA KORTESNIEMI (2016)** NMR metabolomics of foods – Investigating the influence of origin on sea buckthorn berries, *Brassica* oilseeds and honey.
69. **JUHANI AAKKO (2016)** New insights into human gut microbiota development in early infancy: influence of diet, environment and mother's microbiota.
70. **WEI YANG (2017)** Effects of genetic and environmental factors on proanthocyanidins in sea buckthorn (*Hippophaë rhamnoides*) and flavonol glycosides in leaves of currants (*Ribes* spp.).
71. **LEENAMAIJA MÄKILÄ (2017)** Effect of processing technologies on phenolic compounds in berry products.
72. **JUHA-MATTI PIHLAVA (2017)** Selected bioactive compounds in cereals and cereal products – their role and analysis by chromatographic methods.
73. **TOMMI KUMPULAINEN (2018)** The complexity of freshness and locality in a food consumption context
74. **XUEYING MA (2018)** Non-volatile bioactive and sensory compounds in berries and leaves of sea buckthorn (*Hippophaë rhamnoides*)
75. **ANU NUORA (2018)** Postprandial lipid metabolism resulting from heated beef, homogenized milk and interesterified palm oil.
76. **HEIKKI AISALA (2019)** Sensory properties and underlying chemistry of Finnish edible wild mushrooms.
77. **YE TIAN (2019)** Phenolic compounds from Finnish berry species to enhance food safety.
78. **MAIJA PAAKKI (2020)** The importance of natural colors in food for the visual attractiveness of everyday lunch.

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