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REVIEW ARTICLE

Advances in Sensory Science: From Perceptions to Consumer Acceptance

On the manipulation, and meaning(s), of color in food: A historical perspective

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Abstract

While there has long been public concern over the use of artificial/synthetic food colors, it should be remembered that food and drink products (e.g., red wine) have been purposefully colored for millennia. This narrative historical review highlights a number of reasons that food and drink have been colored, including to capture the shopper's visual attention through to signaling the likely taste/flavor. Over the course of the last century, there has, on occasion, also been interest in the playful, or sometimes even deliberately discombobulating, use of food coloring by modernist chefs and others. The coloring (or absence of color) of food and drink can, though, sometimes also take on more of a symbolic meaning, and, in a few cases, specific food colors may acquire a signature, or branded (i.e., semantic) association. That said, with food color being associated with so many different potential "meanings," it is an open question as to which meaning the consumer will associate with any given instance of color in food, and what role context may play in their decision. Laboratory-based sensory science research may not necessarily successfully capture the full range of meanings that may be associated with food color in the mind of the consumer. Nevertheless, it seems likely that food color will continue to play an important role in dictating consumer behavior in the years to come, even though the visual appearance of food is increasingly being mediated via technological means, including virtual and augmented reality.

KEYWORDS

color meaning, color-in-context, crossmodal correspondence, food color, history of food coloring

1 | INTRODUCTION

Color has long been relevant to the perception of food and drink (e.g., Downham & Collins, 2000). In fact, trichromatic color vision may originally have developed in primates in order to facilitate our ancestors' ability to detect red leaves or fruit (folivory or frugivory, respectively; see Sumner & Mollon, 2000, 2003) among the green foliage (see Fernandez & Morris [2007] for the rejection of the alternative sexual selection account of the development

of trichromacy).[1] That said, it should be noted that the evolutionary origins of trichromatic color vision are still being debated (Carvalho et al., 2017). Somewhat surprisingly, however, Foroni et al. (2016) failed to demonstrate any association between redness and caloric density in food images, as might have been expected, despite finding an inverse correlation between increased greenness and a lack of calories. Over the course of human history, the visual appearance of food has sometimes been appreciated in its own right (see also Lee et al., 2013). For instance, the color-changing Surmullet fish that was displayed before diners in Ancient Rome was prized specifically because of the rainbow array of colors its skin would present to guests (Andrews, 1949; see also Lampridius, 2002; Weiss, 2002).

That being said, the ways in which the color of food has been controlled and optimized have changed dramatically over the millennia. The focus of this narrative historical review is on the various different ways in which the visual appearance of food and drink products have been deliberately manipulated. In particular, the multiple "meanings" that are potentially associated with the presence of color are highlighted, while also questioning whether sensory science research, typically conducted in a laboratory setting (i.e., in a very particular context), has successfully captured the multiple meanings of color that the consumer may have internalized. I will also take a closer look at current concerns/opportunities as far as the coloring of food is concerned, before briefly highlighting some of the ways in which the appearance of color in food looks set to change in the years ahead.

2 | ON THE HISTORY OF FOOD COLORING

While it is sometimes assumed that a fascination with the visual appearance of food is nothing more than a contemporary fad, a closer look at the literature soon reveals that this is very definitely not the case. For example, in Medieval Britain, a variety of herbs and spices were added to dishes to give the latter a distinctive color (Woolgar, 2018). Consider here only the case of saffron, which adds a golden color to pale foods (such as white rice and milk-based dishes), and has long been one of the world's most expensive spices (Crossley, 2014). Meanwhile, according to Colquhoun (2007, p. 57): "The love of bright color evident in medieval illuminated manuscripts, clothing and heraldry inevitably found its way to the table." She continues "Glowing medieval jellies were set in brightly colored layers… Boiled blood was used to color foods black, and a sandalwood-like bark known as *sanders* or mulberries or red alkanet were employed to turn them red or purple. Wheat starch, egg whites or crushed almonds were used for white; mint, spinach and parsley for green, and for blue the turnsole, or heliotrope, was mashed" (Colquhoun, 2007, p. 58; see also Cole, 2007; Stewart, 2011). According to Wilson (1991, p. 25): "Color often seems to have been valued more for its own sake in English mediaeval cookery than as a signal of the ingredients of the dish. This was certainly true of jellies set from meat or fish stock: they were saffron-colored at first, but later also tinted purple with turnsole or indigo, and red with alkanet or sanders (red sandalwood). The only variation in flavor was that supplied by the various coloring agents."

2.1 | On the selective breeding of plants for color

Color cues have long helped consumers to determine the freshness and ripeness of produce (e.g., Aono et al., 2021; Péneau et al., 2007; cf. Arce-Lopera et al., 2015; Imura et al., 2016; Jia et al., 2013). Over the centuries, several specific fruits and vegetables (including carrots and tomatoes) have been selectively bred in order to modify their visual appearance (e.g., Anonymous, 2005; Macrae, 2011). That said, different explanations have been put forward to explain why the predominant color of carrots switched from purple to orange. According to one suggestion, this was simply to stop the vegetable from turning the foods to which it was added (e.g., stews) purple (see Cone [2009] for recent interest in the food coloring potential of ancient strains of purple carrot). However, according to an alternative suggestion, the change was more symbolic, with the orange color being linked to an attempt to honor the Dutch royal family back in the 17th century (Dalby, 2003; Greene, 2012, p. 81; Macrae, 2011; see also Banga, 1963; Bry, 2015).

Nowadays, the appeal of unusually colored produce, such as, for example, white strawberries (otherwise known as pine berries), is primarily related to the fact that their visual appearance is unusual, rather than necessarily having anything to do with the produce's taste/flavor profile (Macrae, 2011). Produce that strikes the consumer as looking unusual is unlikely to have been grown locally (otherwise it presumably would not appear unusual; buying local produce is a growing concern for many consumers concerned with minimizing their food miles [Le Page, 2022]). The expectations that consumers currently have for those vegetables that are sold in both typical and atypical colors have been studied in the case of carrots by Schifferstein et al. (2019). The latter's research revealed that consumers hold very different expectations concerning the sensory and functional properties, including expected freshness and nutritional value, depending on the vegetable's hue (orange, red, purple, yellow, white, and white-green) and saturation (see also Gracia et al., 2020). A few years

earlier, Paakki et al. (2016) investigated the contemporary consumer's response to blue potatoes (see also Carter, 2011; Tysoe, 1985). Interest in unusually colored fresh produce therefore extends across a range of products and has fascinated researchers for decades.

Hisano (2019, Chapter 5: Making oranges orange) describes how, in the opening years of the 20th century, both green- and orange-skinned oranges were equally popular in the United States. However, within a few years, the orange-colored peel variety took over. Similarly, the red-skinned bananas (Red Dacca) that were a common sight in North America around 1900 were soon replaced by yellow-skinned varieties (e.g., the Cavendish; see Hisano, 2019). In both cases, the selective pressures were based on standardizing what was presumed (by the food marketers of the time) to be the most appealing visual appearance for the fruits concerned (though note that, in this case, it was the color of the skin, rather than the flesh, that was at stake). While degreening is typically achieved in North America by exposure to ethylene (or by the addition of artificial orange coloring), it should be noted that different orange varietals naturally express different skin colors (Hisano, 2019; McPhee, 1966).

2.2 | On the use of animal feed to control product color

There have also been attempts to modify both the visual appearance of the shells (i.e., brown or white) and yolks of eggs. Note that these can be modified simply by changing the animal's diet (Hammeishøj, 2011). For example, adding carotenoid-rich ingredients to bird feed has proved to be an effective means of controlling the yellowness of the yolks. Once again, the food marketers were apparently responsible for the contemporary reintroduction of brown-shelled eggs to the marketplace and wanted to open up a space for more natural-looking specialty eggs (though the preference for brown or white eggs is very much culture dependent), despite the nutritional qualities of brown and white eggs being essentially identical (Anderson, 2013; Johnston et al., 2011; Jones et al., 2010; White, 1971). In recent decades, the diet of farmed salmon has also been carefully modified (once again, by means of the addition of carotenoids). The aim in the latter case is to give the farmed fish, which would otherwise be gray, a suitably rich pink hue, which wild salmon get naturally from the crustaceans and other food in their environment (see Gajanan, 2017).[2] The commercial importance of the fish's pink, red, or orange hue to consumers is hinted at by the fact that the coloring agent has been estimated to account for around 20% of the total cost of fish feed (Dissing et al., 2011; see also Anderson, 2000; Gormley, 1992; Miyake et al., 2009).

2.3 | Controlling the color of food and beverage products

In terms of those foods that are, in some sense, processed, it is worth highlighting how grape skins have been used to add color to red wine for millennia (Downham & Collins, 2000; see also Spence, 2010). Meanwhile, burnt sugar (e.g., caramel) has been used to color alcohol for several hundred years too (Anonymous, 1848). Butter has been artificially colored in the winter months for centuries by farmers to give it the same consistent rich golden color throughout the year (Hisano, 2019). Typically, annatto, a food-coloring agent derived from the seeds of the achiote tree, has been used.[3] The butter lobby campaigned vigorously in the early decades of the 20th century to try and prevent the makers of margarine, which has a naturally white appearance, from adding yellow food coloring to their product so as to imitate the carefully controlled color of butter (see Ball & Lilly, 1982; Masurovsky, 1939). This historical anecdote helps to highlight the longstanding importance that has been placed on food coloring.

2.4 | On the rise of artificial/synthetic food coloring

However, the real explosion in food coloring (i.e., of the deliberate manipulation of color in food) was undoubtedly facilitated by the emergence of artificial/synthetic colorings and flavorings during the latter part of the 19th Century (see Hisano, 2016; Wilson, 2009). Oftentimes, unhealthy ingredients were used to give foods a bright and appealing visual appearance. So, for example, during the Industrial Age, the coloring of sweets with poisonous chemicals, so that they would look more visually appealing to children, was particularly common (Hisano, 2016). Accum (1820) documented sweets colored with a variety of unpleasant coloring agents, including red vermillion (mercury sulfide), yellow lead chromate, white lead, red lead (see also Tannahill, 1973), verdigris (a mixture of copper salts of acetate, carbonate, chloride, formate, hydroxide, and sulphate), blue vitriol (copper sulphate also known as bluestone), and Scheele's green (copper arsenite).

Concerns over the use of artificial/synthetic food colorings peaked in developed countries in the 1970s (Anonymous, 1979a, 1979b, 1980; see Spence [2015b] for a review; though see also Hansen et al., 1966; Hicks, 1979). However, the public's concern with the use of artificial colorants, such as titanium dioxide, continues even to this day (e.g., see Kobylewski & Jacobson, 2010; Reuters & Bashinsky,

2022). At the same time, however, people's beliefs about the natural versus artificial/synthetic origin of color in food continue to be an important consideration (Bearth et al., 2014). Many consumers associate bright colors in processed foods with artificiality, even though that is not necessarily always the case (e.g., see Harris, 2011; Licata, 2015; Wollan, 2016).[4] And while consumers have long associated the presence of blue color in food and drink with the presence of artificial/synthetic coloring (see Spence [2018b] for a review), there are now a number of food-grade natural blue coloring agents on the market (e.g., see Brauch et al., 2016). That said, blue spirulina (going under the brand name Blue Majik; Music, 2017), one of the blue dyes that is currently most popular, can taint the food to which it is added with an unpleasant fishy taste (Elgart, 2018). At the same time, the shelf stability of many natural food coloring agents has also proved to be a problem for the food companies (see Jespersen et al., 2004; Newsome et al., 2014; Nohynek, 2017; Thakur & Modi, 2022).[5] Taken together, therefore, the conflation between brightly colored foods and notions of artificiality in the mind of the consumer continues to influence the general public's response to the appearance of color in food.

3 | CONTEMPORARY USES OF FOOD COLOR

Nowadays, there are a number of different reasons as to why food and drink products and/or their packaging might be colored in a particular way (Wadhera & Capaldi-Phillips, 2014). Oftentimes, color is used in processed foods to signal the variant and/or reinforce the flavor visually (e.g., Calvo et al., 2001; Tuorila-Ollikainen, 1982, 1984). However, there are a number of other meanings that may be attached to (or purposes behind the presence of) color in food and drink. It may also sometimes take on a signature color (think only of the distinctive pink color of Pepto-Bismol; e.g., Urken, 2008), with the meaning of color in such cases presumably being mediated by specific brand associations rather than by any direct associations between color and flavor (see also Baxter et al., 2018; Elliott, 2012). Sometimes color (e.g., black and white) can take on more of a symbolic meaning in the context of foods/meals (see Spence [2020a] for a review): Consider here only the funereal black meal that was served to guests in Huysmans' (1884/1926) novel "Against Nature" (see also Weiss, 2002). In the last few years, charcoal also has been introduced into various foods to deliver a distinctive black color that many consumers, rightly or wrongly, associate with various health benefits (Nicholson & Ferrier, 2017). White foods/meals, by contrast, tend to be associated symbolically with purity (e.g., Sherman & Clore, 2009; Strand, 2021). That said, while the clear/white–purity association tends to be obvious in the home and personal care product category, it is perhaps less apparent in the context of processed foods.[6]

FIGURE 1 "The four tastes," an amuse-bouche, as served by chef Jozef Youssef of Kitchen Theory (see Spence et al., 2015). In the restaurant, the spoons were randomly placed down in front of diners, who were asked to arrange them in order, salty on the left, then bitter, sour, and sweet on the right. The chef, in other words, is here explicitly playing with his guests' color-based taste expectations.

3.1 | On the playful use, or absence, of color in food

There has been something of an explosion of interest in, and playfulness around, unusual (or atypical) food color in recent years (for reviews, see Piqueras-Fiszman & Spence, 2012; Velasco et al., 2016). Famous examples here include the Beetroot and Orange jelly served a couple of decades ago at Heston Blumenthal's The Fat Duck restaurant in Bray (e.g., see Blumenthal, 2007, 2008; Spence, 2013).[7] More recently, Michelin-starred North American chef Grant Achatz served a dish going by the name of *Halibut. Black pepper, coffee, lemon* in a white monochromatic presentation. The most surprising aspect of the dish is that the majority of the elements are naturally black (coffee, black pepper, black licorice, vanilla) but are served in a white form (see Spence, 2020a). Another example of the playful use of color in a modernist dish came from "the four tastes" amuse bouche served by London-based chef Jozef Youssef of Kitchen Theory. Four espherified balls of colored liquid were presented to diners who were invited to associate each sphere with one of the four basic tastes (i.e., sweet, salty, sour, and bitter; see Figure 1). In this case, the results of several peer-reviewed empirical studies revealed that roughly 70% of those asked would associate white with salty, browny-black with bitter, pinkish-red with sweet, and green with sour.[8] The same results were obtained both with diners who were served the dish in the restaurant

and with several groups of participants tested online (see Spence et al., 2015; Velasco et al., 2016).

In the context of a modernist meal, the incongruent use of color may well be appealing; it may sometimes even be expected by diners (see Spence & Youssef, 2018; though see Yeomans et al., 2008; Zellner et al., 2004). However, it is important to note that the consumer's response to the incongruent use of color is context dependent (see Huang & Wan, 2019; Peng et al., 2022). That is, the influence of the crossmodal congruency between color and flavor on product evaluations is different in the context of modernist restaurants than in the case of supermarket products consumed in the home environment, say (see Desmet & Schifferstein, 2008; Myhrvold & Young, 2011; Schifferstein & Spence, 2008; Spence & Piqueras-Fiszman, 2014).

In fact, go back to the 1930s and one finds the Italian Futurists, provocateurs such as F. T. Marinetti, deliberately miscoloring everyday drinks (such as white wine, orange juice, and milk) in order to discombobulate those whom they served (Marinetti, 1932/2014). Alfred Hitchcock would also disconcert his dinner guests by coloring all of the food that was served blue (see Hitchcock & Gottlieb, 2003; see also Spence, 2021b). It is, though, not always clear in hindsight quite what the goal of other unusual uses of food coloring may have been, as with Fanny Cradock's green-dyed duchess potatoes. Cradock was the first TV chef in the United Kingdom in the middle decades of the 20th century (Ellis, 2007).

3.2 | On the attention-capturing use of food coloring

Sometimes, food products are given distinctive colors in order to help capture the consumer's visual attention (Garber et al., 2001; cf. Del Gatto et al. [2021] for the importance of color to attentional capture by energy-dense food stimuli). This was presumably the case with the striking blue drink "Bolt from the blue" introduced by Innocent Smoothies (Jewell, 2019a; see Spence [2021b] for a review). The growing popularity of blue wines and spirits also plays in this space of attention-capturing use of food color, as does recent launch of a bright blue mint chocolate dipping sauce for chicken by KFC in South Korea (Lindsay, 2022). A similar approach was successfully used almost two decades earlier when Heinz briefly launched green, purple, and blue variants of their tomato ketchup in the marketplace (e.g., see Farrell, 2000). Heinz reintroduced a green ketchup in a Shrek-themed marketing intervention (see Wood, 2021). Burger King Japan used color to capture the attention of consumers by coloring its burgers and buns red and, on another occasion, black (Anonymous, 2015; Cook, 2012). Coco Pops switched temporarily from chocolate brown to white with the launch of their White Choc Coco Pops (Jewell, 2019b). Such strikingly unusual uses of food coloring have often proved successful in the marketplace. So, for instance, Heinz temporarily captured an additional 10% market share in what has traditionally been a very slow-moving market simply by radically altering the colour of their ketchup. Notice how, in such cases, the attention-capturing use of color has no real "meaning" in terms of signaling the likely flavor of the product (which, to all intents and purposes, has not changed). While it has perhaps always been true that plants and animals have used color cues to attract or repel, in the contemporary era, it becomes difficult to know quite what particular role color cues may be playing in any given situation, especially when food colors are chosen primarily to capture attention.

3.3 | Interim summary

The research that has been reviewed in this section highlights how multiple "meanings" may potentially be associated with color in food by the consumer. The presence of a particular color in food may be intended to capture the shopper's attention, to discombobulate, or to surprise (pleasantly, one hopes). Color is often used to differentiate between different flavors, and to signal specific variants. Occasionally, particular colors may take on a signature role if they become uniquely associated in the mind of the consumer with a given brand (e.g., as in the case of the distinctive pinkish-white appearance of PeptoBismo). A given signature color may sometimes be associated with different brands in different markets. It is important to note that changing the color of a food product can lead to a significant change in the product's taste, flavor, and even the perceived efficacy of energy drinks (see Brown et al. [2021] on the latter theme; cf. Clydesdale, 1993; Clydesdale et al., 1992; Remington et al., 1997; Suzuki et al., 2017; Zellner & Durlach, 2003).

The specific meaning that the consumer is likely to associate with the color present in food is also likely to be determined by prior experience. Here, it is worth noting that the effects of prior experience on perception may be fruitfully explained using Bayesian models (e.g., Kersten et al., 2004). Such models have, for example, been used to explain memory color effects (i.e., effects of object memory on color perception [Hansen et al., 2006]). It has been suggested that modulatory feedback may be the neural mechanism responsible for integrating the bottom-up sensory data with top-down expectations (Grossberg, 1980). Bayesian models have also been used to explain crossmodal integration (see Ernst & Banks, 2002). Consider here only how the appreciation of food requires crossmodal integration, at least across vision, smell, and taste (cf. Maier & Elliott, 2020). Bayesian models therefore offer

a potential for a more quantitative, scientific approach to the role of color in food.

4 | THE INFLUENCE OF FOOD COLORING ON TASTE/FLAVOR PERCEPTION

One point that many food companies fail to recognize is that when they (for whatever reason) change the color of their products, it can actually affect the taste/flavor of the food itself, at least as experienced by the consumer (Spence, 2012a, 2016; Vanderbilt, 2015; Zellner, 2015). So, for example, the research shows that the addition of the appropriate food coloring can lead to a significant change in gustatory thresholds (Maga, 1974), suprathreshold intensity ratings (e.g., DuBose et al., 1980; Hyman, 1983; Johnson & Clydesdale, 1982; Johnson et al., 1983, 1982), as well as flavor identification responses (e.g., Garber et al., 2000; Stillman, 1993; Wang & Spence, 2019; Zampini et al., 2007, 2008; see also Zellner et al., 1991).

Spence et al. (2010) reviewed the several hundred sensory science studies that had been published in this area of food color over the years since the chemist Moir first reported on the impact of adding coloring to foods (Moir, 1936; see also Duncker [1939] for other early research conducted soon after white chocolate was first brought to market). Duncker was particularly interested in the role of prior experience on perception. Memory colors, not to be confused with color memory, defined as the color that a person considers to be characteristic for an object based on their prior experience (Witzel & Gegenfurtner, 2018, 2020), likely also influences the taste. Duncker was interested in people's color memory of chocolate as brown in the context of the white chocolate that had just been released into the market. Importantly, while color has often been found to influence taste/flavor perception, it by no means always does so (Frank et al., 1989; Lavin & Lawless, 1998; see also Arao et al., 2012; Kappes et al., 2006). One reason for this difference in outcomes may relate to the fact that different consumers may associate different flavors with particular colors (see Shankar et al., 2010a, 2010b; Shankar, Simons, et al., 2010). Shankar and her colleagues conducted a series of studies highlighting the importance of the degree of discrepancy between the flavor that an individual associates with a given color and the actual flavor that they experience in a fruit-flavored beverage. What is clear is that color cues set product-specific expectations (Blackmore et al., 2021; Christensen, 1983; Francis, 1995; Levitan et al., 2008; Parpinello et al., 2009; Piqueras-Fiszman & Spence, 2015; Reinoso-Carvalho et al., 2019; Reinoso Carvalho et al., 2017; Shermer & Levitan, 2014; Spence, 2010; Sugrue & Dando, 2018; Van Doorn et al., 2019; Wadhwani & McMahon, 2012; Wongthahan et al., 2020).

Although the research suggests that telling people to ignore the visual appearance of drinks has little impact on the visual dominance (or influence) of food coloring over taste/flavor (see Parr et al., 2003; Zampini et al., 2007, 2008), it should nevertheless be considered whether the crossmodal influence of a given food color on taste/flavor perception might also be dependent on the context in which that food color is seen and hence on the particular meaning, or association that it is given.

5 | MEANING OF COLOR IN CONTEXT

Blue tends to be a deeply unappealing food color in meat and fish (Sakai, 2011; Spence, 2021a, 2021b; though see also Tannenbaum, 2020), while potentially signaling an appealing raspberry-flavored confection in cotton candy and, subsequently, Slushie-type iced drinks (e.g., Park, 2016, 2019; Spence, 2021b; Swarns, 2014). Hence, the substrate in which a given food color is presented can affect its meaning for the consumer. Moving one stage further out, one might also consider the context or environment in which a given food color is seen. According to Elliot and Maier's (2012) "color-in-context" theory, the meaning of color depends on the context in which it is seen. So, for example, red might be expected to prime notions of failure in an educational context, while the same color may be associated with (or prime thoughts of) a warm/hot temperature when seen in the context of bathroom taps, say. While I am not aware of color-in-context theory having been applied in the case of food coloring, it would not seem to be much of a stretch to suggest that the meaning attributed to color by the consumer is at least sometimes likely to depend on the context in which it is seen.

One way of thinking about context in the case of food coloring relates to the receptacle in which a drink is presented (e.g., Wan et al., 2014, 2016). Consider here only how a transparent blue drink might be associated with mouthwash, blue curacao, a raspberry-flavored drink, or one of the increasingly popular blue gins (see Kiely, 2015; Lockhart, 2022; Shankar, Levitan, et al., 2010) or blue wines (e.g., Edkins, 2018; Hohenadel, 2016; Marchetti, 2017). A blue drink seen in a wine bar might well be assumed to be a wine, whereas the same drink color when seen in a bathroom is likely to be associated with a minty mouthwash (e.g., something like Listerine) instead. The turbidity of a drink can also influence the meaning, or interpretation, that the consumer gives to a particular drink color (Barnett et al., 2017). Consider here only how clear green liquids are likely to be associated with lime (and hence

an acidic taste), whereas turbid green solutions are more likely to remind people of vegetables instead (and hence possibly a bitter taste).

It is often unclear whether the results of laboratory studies of food color—typically assessing the abstract or, on occasion, semantic meaning of color—necessarily pick up the full range of meanings that may potentially be associated with such visual appearance cues in a range of different more ecologically valid contexts. One might wonder whether the majority of the meaning is, in some sense, semantic, or at least acquired. After all, what counts as congruent in terms of color–taste/flavor mappings is presumably acquired as a result of prior experience. Infants of only a few months of age have been shown to pick up color–taste associations (Reardon & Bushnell, 1988; see also Higgins & Hayes, 2019). While nowadays a fizzy black liquid would remind most people of a cola beverage, Sprite, the clear fizzy liquid, was once also colored black (see Spence, 2018a). Hence, there can also be a historic element to what counts as congruent in terms of color–taste correspondences.

It is important to recognize that the meaning of food color in the context of the sensory science lab may be importantly different from what one finds in the context of real-world consumer behavior (cf. Garber et al., 2001, 2003a, 2003b). When researchers have used abstract patches of color rather than necessarily specific food colors, the range of possible meanings, or associations, with color expands even wider. Further research is also needed on the differing influence of food color as a function of the age of the consumer (Christensen, 1985; Spence, 2012b). Notice here also how children's responses to unusually (e.g., blue) colored foods can be influenced by peer behavior (Greenhalgh et al., 2009).

Palmer et al. (2013) have thoroughly summarized the literature on the visual aesthetics of color. It is, however, interesting to consider the relationship between the aesthetics of color in the abstract (e.g., with color patches) versus in the context of food and drink. One observation hinting at the possibility that somewhat different rules may apply comes from the observation that while blue and green typically top people's lists of most preferred hues, these tend to be the least liked colors in the context of food and drink. In related work, Schloss et al. (2013) have demonstrated that color preferences vary depending on the objects shown (or which come to mind) having that color.

5.1 | The emotional mediation of color–taste correspondences

As one starts to move further away from recognizable food color, emotional mediation increasingly comes to provide the link between color and flavor (e.g., Gilbert et al., 2016; Hanada, 2018; see also Fateminia et al., 2020; Gilbert et al., 1996; Raevskiy et al., 2022; Saluja, & Stevenson, 2018; van Beilen et al., 2011). In such cases, it is more likely that the meaning of color is linked to a particular emotion rather than to a specific taste or flavor. Consistent with such a view, Foroni et al. (2016) demonstrated that the arousal of food images was positively correlated with the amount of red brightness in food images while being negatively correlated with the green brightness. There is perhaps a certain degree of uncertainty in many of the studies as to whether the crossmodal correspondences that have been reported to date between color and taste should be considered as being based on a recognizable source object, what one might call the semantically mediated account, or else emotionally mediated (see Palmer et al., 2013; Spence, 2020c). In fact, Gilbert et al. (2016, p. 203) go further, and open their article by suggesting that "Color cues impact the chemosensory perception of foods and beverages. Evidence suggests that color exerts these effects through a link with emotion." Of course, as the appearance of color becomes more abstract (i.e., further removed from a plausible food substrate), then emotional mediation becomes the more likely route to associate meaning to color (see also Guinard et al., 1996; Koch & Koch, 2003; O'Mahony, 1983; Spence et al., 2015).

6 | CURRENT FOOD COLORING TRENDS

There is undoubtedly a trend-related element to the particular food colors that tend to be in and out of fashion. Here, one might consider only the phenomenal recent growth in popularity of rosé wines (Peres et al., 2020). Many commentators have been tempted to put this down to the drink's instagrammability (Jonze, 2017; Mileham, 2018; see also Ough & Amerine, 1970; Wang & Spence, 2019). Similarly, as has been mentioned already, coloring foods blue has also become very popular among the images that one finds displayed on Instagram. In part, this trend has been facilitated by the emergence of a number of natural blue food colorings (see Spence, 2021b). That said, few chefs have chosen to color any of their dishes blue, presumably because there is no justification for doing so from a flavor perspective.

Separately, there is a growing recognition of the health benefits that may be associated with consuming a variety of colors of fresh produce (see König & Renner, 2018, 2019; Paakki et al., 2019, 2019; Spence, 2020b; though see also Piqueras-Fiszman & Spence, 2014). Health benefits have been associated with produce of a particular color, such as, for example, the putatively possibly blood pressure

lowering effect of purple potatoes (Poulter, 2011; see also Francis, 2018). Consumers would also appear to associate health benefits with those foods having a charcoal black appearance. At the same time, there is also growing interest in unusually colored, not to mention color-changing, foods (e.g., see Spence [2019, 2021b] for reviews). So, for example, the incorporation of pea-flower means that a food or drink will change from blue to purple with the addition of acid (e.g., a slice of lemon), and has been incorporated in everything from gin to tea in recent years (see Spence, 2018b).

7 | EFFECTS OF BACKGROUND/AMBIENT COLOR

While the focus in this review has been on the color of food and drink itself, an emerging literature has highlighted the significant impact of background color, be it of plateware, glassware, or food packaging (e.g., Baptista et al., 2021; Fateminia et al., 2018; Huang & Lu, 2015; Kovač et al., 2019; Lyman, 1989; Merlo et al., 2018; Piqueras-Fiszman et al., 2012; Sugimori & Kawasaki, 2022; van Esch et al., 2019; Velasco et al., 2014), on the tasting experience (see Spence & Velasco [2018, 2019] for reviews). So, for example, serving desserts on white plates has been shown to enhance perceived sweetness when compared to serving the same dessert from a black plate (Piqueras-Fiszman et al., 2012; Stewart & Goss, 2013). Meanwhile, Taiwanese researchers have demonstrated that serving spicy tofu off a red plate results in people reporting it as tasting spicier than when served on a white, yellow, or green plate instead (Tu et al., 2016). Elsewhere, cup color has been shown to prime expectations of a sweeter (pink cup) or more acidic coffee (yellow or green cup). These expectations can sometimes carry over to influence the taste of the coffee (Carvalho & Spence, 2019).

There has also been something of a growing interest in the use of ambient color to change the perceived taste/flavor of drinks such as wine (e.g., Denkewicz, 2008; Oberfeld et al., 2009; Spence et al., 2014; see also Wang & Spence, 2015; Yang et al., 2016). In one representative study, for example, almost 3000 participants who tasted a red wine from a black tasting glass (to obscure the visual appearance of the liquid itself) rated it as almost 15% sweeter under red ambient lighting than under green lighting (Velasco et al., 2014).[9] Meanwhile, Motoki et al. (2021) recently demonstrated that the color properties of coffee shop interiors can also help to set people's taste expectations (see also Wu et al., 2022).

8 | CONCLUSIONS

There can be little doubting that the visual appearance of food and drink has long been important for humans (e.g., Anonymous, 1848; Colquhoun, 2007; Downham & Collins, 2000; Lee et al., 2013; Walford, 1980; Woolgar, 2018). Sometimes, food is deliberately miscolored in order to surprise or discombobulate (Piqueras-Fiszman & Spence, 2012; Velasco et al., 2016). More often, however, the color of food and drink is meant to signal the flavor (see Spence [2015a] for a review), or else to capture the consumer's attention (see Wood, 2021). However, with so many different meanings potentially attached to food color, it becomes a little hard to know which one will be primed in the mind of the consumer. Context likely plays an important role here. At the same time, however, acknowledging the potential relevance of context to establishing the meaning of color in any given situation raises questions about the extent to which much of the laboratory-based sensory science research that has been published to date effectively captures the full range of potential meanings that consumers evaluating color in ecologically valid conditions of everyday life may choose to associate with the color of food and drink.

8.1 | On the future manipulation of food color

Technical developments mean that it is now possible to alter the visual appearance of food and drink using digital technologies, such as virtual reality (VR) and augmented reality (AR). In recent years, a number of sensory science researchers have investigated the consumers' response to food and drink whose visual appearance has been rendered in VR or AR (e.g., Ammann et al., 2020; Chen et al., 2020; Huang et al., 2019; Stäger et al., 2021; Ueda et al., 2020; see also Burkert, Schaufler, & Voigt-Antons, 2022). As such, it may not be too long before such color-changing technologies make their way onto the menu at some top modernist restaurant or other (Spence, 2017). From there, it may only be a short jump to branded sensory apps that allow the consumer to modify the visual appearance of food at home. After all, there is already a growing interest among consumers in modifying the visual appearance of the foods they choose to post online (e.g., see Spence et al. [2022] for a review). Color, be it the actual color of a food product, or virtual, will, then, likely continue to play a key role in the consumer's experience of food in the years ahead (cf. Cascone, 2022).

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ENDNOTE

[1] Young leaves, which tend to be redder, are preferred by primates because they are higher in protein and are not as tough as older leaves (Dominy & Lucas, 2001).

[2] Salmon are unique in being able to bind carotenoid to their muscle fiber.

[3] Annatto is sometimes also used to color cheese (Harper, 1952). It is certainly better than the red lead that was once apparently used to color the rind of orange Gloucester cheese (Hisano, 2016; Tannahill, 1973).

[4] Here, of course, one might also consider the carmine red food coloring that looks artificial to many because it is so bright, and yet its natural credentials extracted from the carapace of beetles might be expected to be equally unpleasant to many consumers were they to be aware of the insect-based source of their food coloring (see Deroy et al. [2015] on the barriers to entomophagy).

[5] The resurgence of interest in the ancient purple carrot's coloring potential has also been linked to the move away from artificial/synthetic food colorings (Cone, 2009).

[6] Though see http://www.marijevogelzang.nl; Marije Vogelzang, TEDxMunich—Marije Vogelzang—Food Love (2010), http://www.youtube.com/watch?v=1WZv459bOCQ.

[7] In such cases, it would seem important that the desired color is natural (hence the use of golden beetroots and blood red orange in the Blumenthal dish).

[8] Here, it is important to be aware that the strongest, or dominant, association (e.g., between color and taste) might not always determine the inferred meaning of color for the consumer. According to the theory of semantic discriminability for perceptual encoding systems (see Mukherjee et al., 2022; Schloss et al., 2018), the meaning/association that consumers attribute to a given color may sometimes be determined by the set of comparison stimuli. Consequently, results such as those reported by Spence et al. (2015) should not necessarily be taken as identifying the color having the strongest link to a given taste, but rather the correspondence that makes the most sense given the range of options that need to be paired up.

[9] The recently discovered "neon fruit" illusion provides another intriguing technological means of modifying the appearance of fruits by alternating between two different metameric lighting distributions (see Harvey et al., 2019).

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