RUNNING HEAD: COLOUR-CHANGING FOOD & DRINK

On the changing colour of food & drink

Prof. Charles Spence

Crossmodal Research Laboratory, Oxford University

WORD COUNT: 10,500 WORDS

RESUBMITTED TO: *INTERNATIONAL JOURNAL OF GASTRONOMY & FOOD SCIENCE*

DATE: MAY, 2019

CORRESPONDENCE TO: Prof. Charles Spence, Crossmodal Research Laboratory, Department of Experimental Psychology, Anna Watts Building, University of Oxford, Oxford, OX2 6GG, UK.

ABSTRACT

There is something of a tension between consistency and natural variation as far as the visual appearance properties of food and drink are concerned. While the majority of natural products tend to change their appearance as they age/ripen, many processed foods, by contrast, are specifically designed, or formulated, so as to maintain a consistent (optimal) visual appearance during the lifetime (or shelf-life) of the product. That said, food and beverage companies sometimes do suddenly change the colour of their products (e.g., to address legislation around the use of artificial food colours, as a result of changing consumer preferences/interests, or else simply to capture the consumers' attention on the shelf). A number of modernist chefs, especially those fond of molecular gastronomy/cuisine, and mixologists, have also become increasingly interested in (changing) the colour of the foods and drinks that they serve (either to surprise or entertain their guests, or else to play to the Instagram crowd). Intriguingly, several new chemical/technical means of changing the appearance properties of food and drink in real-time have been developed recently, thus raising the question of how people will respond. The context in which the colour change occurs, and the cause to which it is attributed, may well both play a key role in determining consumer acceptance of such novel rapid transformation of the appearance of food and drink, especially given the a widespread aversion amongst consumers to those food colours that are (perceived to be) artificial.

KEYWORDS: COLOUR; FOOD TRANSFORMATION; COLOUR-CHANGING FOOD AND DRINK. FOOD COLOURING; ARTIFICIAL; NATURAL.

Introduction

Many fruits and vegetables change their colour (and other visual appearance properties) as they ripen and subsequently age/decay/rot. In fact, a number of commentators have suggested that the very emergence of tri-chromatic colour vision in primates can be attributed to the facility it once provided for picking out the ripe, and hence energy-dense, red fruits from amongst the dark green leafy jungle canopy (e.g., see Bompas, Kendall, & Sumner, 2013; Foroni, Pergola, & Rumiati, 2016; Schaefer & Schmidt, 2013; though note that this suggestion has attracted some controversy). According to Allman (2012, p. 145), the emergence of colouration in plants, and the ability to detect such signals, may have co-evolved a long time ago in evolutionary history (Polyak, 1957). Some natural products have changed their colour. For example, carrots were once white, black, yellow, and purple (Cone, 2009; Dalby, 2003). The bright orange colour that so many of us are all familiar with today is the result of selective breeding. Specifically, in the 17th Century, farmers in The Netherlands worked to develop a carrot that had a bright orange colour as a tribute to The House of Orange (e.g., Carter, 2011; Greene, 2012, p. 81; Macrae, 2011).

A bright appearance has long been recognized as an important part of what makes (e.g., vegetables) attractive to consumers (e.g., Birren, 1963; Bonnell, 1966; Francis, 1977; Sant'Anna, Gurak, Marczak, & Cristina, 2013; Shewfelt, 1990; Urbányi, 1982; see also Watson, 2013). This, a key issue, given that many foods (e.g., vegetables) change their appearance properties when cooked (This, 2009). Both the colour of food and drink, as well as any variation in the range of different food colours, are considered attractive to consumers (e.g., Paakki, Aaltojärvi, Sandell, & Hopia, 2019). Indeed, we would seem to have internalized a crossmodal correspondence between the saturation, or intensity, of food/drink colour and taste/flavour intensity (see Piqueras-Fiszman & Spence, 2015a, for a review). According to an oft-made suggestion, consumers tend to like those food colours (hues) that are associated with sweet-tasting foods, while disliking those that are associated with bitter-tasting foods (e.g., green vegetables; Lee, Lee, Lee, & Song, 2013), and/or rotting foods (Piqueras-Fiszman, Kraus, & Spence, 2014; though see Mugaritz's blue bread dish; see https://www.mugaritz.com/en/-039blue-039-bread-photo-jose-luis-lopez-de-zubiria-mugaritz/fo-1460645511/).[1]

[1] Another suggestion that one occasionally finds in the literature is that our general aversion to brown and olive is attributable to these colours' association with faeces and rotting foods (e.g., Fugate & Franco, 2019, p. 2). This curious suggestion, though, seemingly ignores the fact that brown is also the colour of cooked meats, something

While natural produce tends to change its visual appearance (i.e., colour) gradually over its lifetime (so gradually, in fact, that we are not aware of the change as it happens), most processed/branded foods are instead specifically formulated in order to maintain the same appearance over the lifetime of the product on the shelf (see Hutchings, 1999; Masurovsky, 1939; Walford, 1980).[2] That said, food and beverage companies sometimes do suddenly change the colours of their products. There are several reasons for this: Sometimes it is done in order to address new legislation around the use of artificial food colours, or as a result of changing consumer preferences/interests, or else simply as a means of trying to capture the consumers' attention on the shelf. That said, the decision to change the colour of an already commercially-successful product is not (and probably should not be) one that is undertaken lightly (see Wollan, 2016). At the same time, however, the general public's interest in colour-changing foods is hinted at by the runaway success of Yumchaa Blue Voodoo Magic colour-changing tea (see **Figure 1A**; Blake, 2017), not to mention the short-term success of Heinz blue ketchup several years earlier (e.g., Farrell, 2001; Srakocic, 2003). Indeed, over the years, a number of food and beverage companies have managed to achieve (at least short-lasting) marketing success by temporarily launching their best-selling products in various new and unfamiliar colours (e.g., see WSJ Staff, 2015). That said, simply changing the colour of one's product by no means guarantees success in the marketplace. For instance, Kraft's blue macaroni and cheese, and Kellogg's cereal that turned the milk in the bowl a baby-blue colour didn't last too long when they were launched at around the same time as the miscoloured ketchup (see Wollan, 2016, on these failed product launches).

INSERT FIGURE 1 ABOUT HERE

Modernist chefs (especially those fond of molecular gastronomy/cuisine; This, 2009) and mixologists have also become increasingly interested in (changing) the colour of the foods and drinks they serve (either to surprise of entertain their guests, or else to play to the Instagram crowd; Anon., 2018; Blumenthal, 2008; Elgart, 2018; see Piqueras-Fiszman & Spence, 2014; Spence, Okajima, Cheok, Petit, & Michel, 2016, for reviews). In a way, the deconstruction of foods/ingredients that lies at the heart of so much of molecular gastronomy/cuisine (see

that both we humans, and our primate cousins seem to have an innate (or perhaps better said 'natural' predisposition toward liking; e.g., Pollan, 2013). That said, Lee et al. (2013) reported that people tend to prefer foods with higher chroma, which indicates more vivid colour than the original food colour, whereas during the process of decomposition the chroma of most foods decreases.

[2] Note that according to Schlosser (2001, p. 121): *"About 90 per cent of the money that Americans spend on food is used to buy processed food"*.

Gopnik, 2011; Spence & Youssef, 2018) allows the creative chef to separate the elements (e.g., the flavour from the substrate or colour that normally accompanies it), and then to recombine them in a variety of new and potentially playful/theatrical ways. There is undoubtedly a danger of this leading to a negatively-valenced 'disconfirmation of expectation' response (e.g., Verastegui-Tena, van Trijp, & Piqueras-Fiszman, 2019; Yeomans, Chambers, Blumenthal, & Blake, 2008; see Piqueras-Fiszman & Spence, 2015b, for a review of the literature on disconfirmed expectations). However, if handled appropriately by a top chef or mixologist (i.e., as part of a designed experience), playing with the colour of a dish or drink can instead undoubtedly bring a pleasurable element of surprise to a dish (see Ludden, Schifferstein, & Hekkert, 2007, 2008; Piqueras-Fiszman & Spence, 2012; Velasco, Michel, Youssef, Gamez, Cheok, & Spence, 2016, for reviews). That said, given that public sentiment continues to be suspicious of (when not actively hostile toward) the notion of artificial food colouring (e.g., Anon., 1980; Chapman, 2011; Stevens, Kuczek, Burgess, Stochelski, Arnold, & Galland, 2013; Weiss, Williams, Margen, Abrams, Caan, Citron, Cox, McKibben, Ogar, & Schutz, 1980; Whitehill, 1980; and for a historical perspective, see Accum, 1820; Tannahill, 1973; Wilson, 2009)[3], the chefs/mixologists have mostly tended to work with natural colours, or, as we will see later, with the removal of colour altogether from the foods they serve (see Spence & Piqueras-Fiszman, 2014; Velasco et al., 2016).

Intriguingly, a number of new chemical/technical means of changing the appearance properties of food and drink in real-time have appeared in recent years. These include the emergence of bioluminescent food grade materials (e.g., Anon., 2012; Moon, 2014; Pérez-Lloréns, 2019), the use of augmented reality (AR) and virtual reality (VR) food applications (e.g., Spence et al., 2016; Ueda, Masuda, & Okajima, 2014). Intriguing new means of changing the appearance properties of foods have also emerged from the field of vision/colour science that enable (e.g., fruits) to glow in the absence of any obvious change in the ambient light source (Harvey, Morimoto, & Spitschan, 2019). Such new approaches/technological solutions raise an important theoretical question about how people will respond to such sudden transformation is the appearance properties of that which they consume. The suggestion is that the context in which the colour change emerges, and the cause to which it is attributed, may well ultimately

[3] The latter references highlighting various dubious practices, such as adding copper to transform pallid pickles into an eye-catching bright green. Who knows whether one day in the future this may be seen as akin to today's practice of adding nitrates to processed meats (e.g., bacon) to give them a bright pink appearance (see Wilson, 2018, on the negative health consequences of the latter).

both play a key role in determining the eventual consumer acceptance (or otherwise) of such novel rapid transformation of the appearance of food and drink.

In this review, I summarize the various ways, both natural and artificial, that foods change their appearance properties, and assess the factors that may make this desirable/undesirable to consumers/diners/drinkers. While slow changes in the appearance properties of foods may not themselves be noticed (i.e., in the moment), rapid/sudden colour change constitute but one example of a dynamic, and hence likely attention-capturing, element being brought to the world of food and drink. Given that we mostly expect our food to be static/unchanging, the interest in colour-changing food and drink can perhaps be linked to the recent fascination with animate, or animate-seeming, foods (see Spence, 2018d, for a review). At the same time, however, it is important to note that dynamic foods may also potentially be off-putting to consumers – in the one case, because notions of animate foods may trigger concerns about a choking hazard, and, in the other, because colour-changing foods may well prime thoughts of artificiality and unnaturalness (see Rosenbaum, 1979; Shell, 1986).[4]

On the changing colour of food and beverages

Everyday food experiences

Many fruits and vegetables change their visual appearance as they mature/ripen (Hutchings, 1999, pp. 453-491). However, this transformation tends to occur too slowly for one to observe it happening. That said, a number of everyday food and beverage products do change their visual appearance properties much more rapidly when they are prepared/mixed. There is, for example, the oxidization that leads to browning e.g., of slices of apples (Hutchings, 1999, pp. 517-531; McLandsborough, n.d.).[5] There is also the chemical reaction, a staple of children's science experiments, whereby something acidic is added to red cabbage juice, and the colour suddenly turns from blue to red. In this case, the colourful cabbage-juice acts as an indicator of the pH of whatever is added to it (e.g., https://www.rigb.org/families/experimental/cabbage-indicator). Elsewhere, there are translucent anise-flavoured spirits (such as Pernod, Ricard,

[4] Though note that views regarding technology and science/processed foods have undoubtedly changes over the years (e.g., see Cardello, 2003; Lauden, 2001; Toops, 1998).

[5] One thing to note here is that the kind of colour changes that are observed with the ripening of food and drink, are largely unidirectional. As such, it might be expected that consumers would be sensitive to any aberration from this norm, likely internalized as some kind of unidirectional slow-changing prior in terms of the currently-popular Bayesian decision theory.

Sambuca, and ouzo) that turn predictably opaque white on the addition of water. This phenomenon, known as 'the ouzo effect', is attributable to the insoluble mixing of water with droplets of oil (though see also Scholten, van der Linden, & This, 2008; and Gill, 2008).[6]

Many fruits and vegetables also come in multiple colours (e.g., pink grapefruits, blood red oranges, purple broccoli, white strawberries, blue/purple potatoes, black garlic, etc., etc.; Carter, 2011). Nowadays, these unusual colour variants in natural produce are more or less familiar to consumers in different parts of the world (e.g., see Carter, 2011; Poulter, 2011), though the consumer response is something that certainly cannot necessarily be taken for granted (Paakki, Sandell, & Hopia, 2016). There does, however, seem to have been a growing interest amongst consumers in/for such unusually-coloured fruits and vegetables (see Piqueras-Fiszman & Spence, 2012).

On the changing colour of processed foods

The majority of processed food brands tend to strive for a consistent visual appearance, ideally one that is strongly identified with the brand itself (so perhaps making it a signature colour; the electric blue of Gatorade, launched 1995 has achieved this; Wollan, 2016), and which should not change appreciably (or noticeably) over the lifetime of the product.[7,8] We have been colouring our foods for millennia (see Downham & Collins, 2000; Tannahill, 1973). According to Classen et al. (2005), it is only really from the 1930s onward, that many of our foods started to be artificially coloured – including such staples such as butter, cheese ice cream, gelatine desserts, candy crackers, jams and jellies. In the 1950s, one find early celebrity chefs, such as Fanny Cradock introducing dramatic artificial colouring into the foods she presented on TV in the UK (see Ellis, 2007).

[6] That said, this latter sudden appearance of turbidity (or cloudiness) does not, strictly-speaking, count as a change of colour, since neither white, nor black, are recognized as colours by the vision scientists.

[7] One of the few 'processed' foods that does sometimes change its appearance properties is wine as it ages. As they do (and here we are talking years), wines slowly change their appearance properties. In this case, the change in colour is seen as a natural part of the aging process, and one that is, in some sense, desirable, or at the very least informative about e.g., the age of the wine (see Spence, 2010a, b, for reviews). It is, however, worth stressing how few other processed foods/drinks there are where such natural variation is deemed acceptable. But, then again, it can be argued that there are precious few other foods/beverages that we are minded to age for anything like as long as a quality wine.

[8] Note that commercial product packaging is often designed specifically to protect/maintain the visual appearance of the product within. Think here only of all those cream-based drinks sold in dark brown glass (e.g., Baileys; Kahlua) in order to prevent the browning of the contents due to exposure to sunlight (see Spence, 2016, for a review).

In the early part of the 20th Century, commercial food products did, on rare occasion, change their colour. However, in the early days, the aim was either to help differentiate a product from its competitors, or else to help make one product look more similar to another. That is, change for change's sake, does not seem to have been considered. An example of the former occurring when the colour of Sprite changed from brown, like other cola drinks, to clear (see Spence, 2018b). An example of the latter comes from the 1930s when margarine was first sold commercially. Margarine itself is naturally white (like lard). However, early on, the marketers realized that the product would be more appealing to consumers if it were simply to be artificially coloured to give the processed food the golden yellow hue of butter. Perhaps understandably, the butter lobby fought vociferously against this 'deceit', though ultimately they lost (see Masurovsky, 1939).

It feels as though the colour of many commercial food and beverage products has changed more frequently in recent years than was the case formerly. In fact, closer analysis reveals that there are a number of reasons behind such contemporary colour changes: One important driver for change is linked to legislative issues (and consumer sentiment) increasingly turning against the use of artificial colorants in food and drink (see Anon., 1980; Wollan, 2016). Over the years, many consumers have become increasingly concerned about the overly vivid colours of their foods. Indeed, there have been periodic bouts of hysteria around the influence of certain colorants on mental well-being (see, for instance, the mass hysteria surrounding the claim that hyperactivity in children was linked, albeit in this case without any good evidence, to artificial colouring agents back in the 1970s; see Wollan, 2016). Meanwhile, in the 1950s, various artificial dyes (such as Orange No. 1 and Red No. 32) were banned (Wollan, 2016), with a number of others food dyes having been banned in the years since (see Scotter, 2015).[9] As a consequence of such changing legislation/consumer sentiment, the colour of various well-known, formerly brightly-coloured, foods (e.g., Cheerios, Trix, Cheetos, & M&Ms) have changed in recent years, typically moving toward a more natural (less-vivid or saturated) palette (e.g., Carter, 2011; Cone, 2001; Wollan, 2016).[10] The search for natural colouring agents that are capable of delivering a consistent enough hue, that are also shelf-stable, and that can be produced in sufficient volumes for the global food producers continuing to prove

[9] And, if Marion Nestle Professor of nutrition, food studies, and public health at New York University (as well as a best-selling author) had her way, they would all be banned. Harris (2011, p. 3) quotes her as saying: *"These dyes have no purpose whatsoever other than to sell junk food."*

[10] There is sometimes a debate about whether such colour changes should occur suddenly, or else be introduced more gradually, such that the consumers' attention may perhaps not be drawn to the visual appearance change.

something of a challenge (e.g., see Jespersen, Strømdahl, Olsen, & Skibsted, 2004; Tolliday, 2012; Wissgott & Bortlik, 1996; Wollan, 2016).

Relevant here, a number of formerly colourful food and beverage products have, in recent years, also been marketed in a clear format (for clear coffee, see Best, 2017; for a clear beer-like drink, see French, 2018; and for yet another attempt at a clear cola, see Ratkin, 2018), presumably because this is taken by the consumer as signalling a product that is somehow more natural (see Spence, 2018b; though note that turning popular coloured drinks clear has not always proved popular with consumers, see Tourila-Ollikainen, 1982; Triplett, 1994).

A second reason for food and beverage companies to change the colour of their products is in order to try and capture the attention of the consumer by trying to stand out on the shelf (e.g., Farrell, 2000; Spence, 2018c; Wollan, 2016). Following on from the very successful blue drink launched by Gatorade in 1995 (Wollan, 2016), a number of other successful changes to blue coloration have been introduced into the marketplace Perhaps one of the more successful examples being the deliberate change in colour of Heinz tomato ketchup, including, for a short while at least, a teal version (Farrell, 2000; Wollan, 2016). While eventually discontinued, the simple addition of 0.1% food colouring enabled Heinz to capture an additional 7% market share, in what has traditionally been a very slow moving market. Hence, it can be argued that changing the colour of this particular product was a huge success (in the short-term at least).

More recently, we have seen a number of wines, alcoholic drinks, and spirits being launched in a blue hue. These include Edgerton gin,[11] WKD, still and sparkling 'white' wines, such as *Blumond* and *GiK* (Spence, 2018c). What is interesting in these cases is how the producers are often so keen to stress the natural origins of the blue colouring, from pea flower to spirulina, and a number of other natural sources that have become available to producers in recent years (e.g., Edkins, 2018; Marchetti, 2017; Spence, 2018c). Indeed, the recent emergence on a number of alcoholic blue drinks in the marketplace can only really be understood as a means of trying to capture the consumers' attention (e.g., when the product is seen on the shelf). There are, after all, few flavourful blue ingredients that impart a desirable flavour to a food or beverage product. That said, given the rarity of genuinely blue products in the marketplace, and given the conviction of various cultural commentators in the decades gone by that blue foods would never sell (see Spence, 2018c, for a review), there was always going to be a gap in the colour palette in many product categories. That said, one often unexpected challenge that

[11] Though note that only clear and colourless gins can be labelled as London gins.

many food producers have run into when introducing such colour changes is that the perceived flavour of the product in the mind of the consumer also changes. This can be surprising, given that the actual physical flavour of the product has typically not changed (see Hidaka & Shimoda, 2014; Spence, 2015b; Spence, Levitan, Shankar, & Zampini, 2010, for reviews). From a gastrophysics perspective (Spence, 2017), though, this should not come as any surprise, given the many hundreds of published studies demonstrating the impact of colour, and of colour change, on taste/flavour perception (see Spence, 2015b).

A third reason for suddenly changing the colour of a popular food product also seems to more-or-less guarantee some media interest. It is for this reason that colour changes are often introduced as a short-term marketing-led intervention. This, for example, presumably the rational behind Burger King Japan selling their all-red and all-black burgers (see **Figure 2**). The red burger coming in a red bun with red cheese (see WSJ Staff, 2015). Finally, a number of confectionary brands have deliberately messed with the colour-flavour correspondence in their variety packs, and introduced this to the market as a fun and playful food encounter (e.g., for kids to try and correctly guess the flavour of the differently-coloured candies). Confused Skittles and miscoloured Smarties were both launched at around the same time and are representative of this approach (see Piqueras-Fiszman & Spence, 2012, 2014; Velasco et al., 2016).[12] Once again, the deliberately confusing mixing of colour-taste/flavour is one that is only ever introduced as a short-term marketing intervention. That is, I am not aware of any examples of long-term success stories involving products that have a confusing colour scheme in the marketplace.

INSERT FIGURE 2 ABOUT HERE

The consumer response to any change in the colour of their food and drink

When the colour of popular processed foods are changed, it doesn't always result in a successful/positive outcome amongst consumers (e.g., Harris, 2011; Triplett, 1994). Rather, it can sometimes lead to a negatively-valenced response. There are a number of reasons for this: First off, confounding the colour-taste/flavour correspondences that the consumer has internalized (e.g., Bry, 2015; see Piqueras-Fiszman & Spence, 2015a), may inadvertently lead

[12] Relevant here, Kellogg's came out with a colour-changing spoon recently (https://www.kelloggsvantage.com/en-gb/marketing/on-pack-promotions/magic-spoons/; see also Ferrara & Bengisu, 2014).

a loss of 'processing fluency' (Reber, 2012). Processing fluency note an oft-discussed notion in the marketing/sensory congruency literature. Second, as we have just seen, changing the colour of the product may change the perceived taste/flavour (Spence, 2015b). Third, suddenly changing the colour of a product can all too easily be negatively-valenced because it may prime notions of, or hint at an, artificiality (Anon. 1980; Classen, Howes, & Synnott, 2005; see Wollan, 2016). That is, it can serve to bring into focus the fact that colouring of the product is itself in some sense arbitrary – that is, it suggests that the colour is not essential to the delivery of flavour, narrowly defined (see Spence, Auvray, & Smith, 2015).

Indeed, the unease that many people feel toward unnaturally coloured foods (or foods with changed colours) has, over the years, often been played on by artists, activists, and provocateurs. The Italian Futurists, for instance, were deliberately miscolouring the drinks they served back in the 1930s, serving blue wine, orange milk, and red mineral water (e.g., Marinetti, 1932/2014). However, in this case, the aim was to discombobulate their guests. Similarly, contemporary artists have sometimes given the foods they portray a surreal colour in order to raise issues around genetically-modified foods (e.g., Ivanova, 2015; Poon, 2014). Meanwhile, in the 1950s, Man Ray famously coloured a baguette bright blue (e.g., see de Gramont, 1970). Note that in these cases, the change to the visual appearance of the food and drink is not itself introduced in order to make the food any more appealing, but rather to challenge, and provoke. This would also seem to have been very much the aim when the film director Alfred Hitchcock used to serve his dinner guests in the Trocadero in London meals consisting entirely of foods that had been coloured blue (Hitchcock & Gottleib, 2003; see also Wheatley, 1973).[13]

Modernist chefs (molecular gastronomy) playing with the appearance (colour) of food

A number of modernist chefs (especially those engaging in molecular gastronomy/cuisine; This, 2009) have also been fascinated with changing the appearance properties of the foods they serve. The idea being to play with their guest's expectations and possibly also to introduce an element of playful surprise.[14] Indeed, modernist cuisine/molecular gastronomy techniques

[13] As Hitchcock himself put it: *"And all the food I had made up was blue! Even when you broke your roll. It looked like a brown roll but when you broke it open it was blue. Blue soup, thick blue soup. Blue trout. Blue chicken. Blue ice cream."* (quoted in Hitchcock & Gottlieb, 2003, p. 76).

[14] The fourth of the *10 Principles of Modernist Cuisine* (http://modernistcuisine.com/about-modernist-cuisine/principles/) makes a similar point: *"Diners have expectations—some explicit, some implicit – of what sort of food is possible. Surprising them with food that defies their expectations is another way to engage them intellectually. This includes putting familiar flavors in unfamiliar forms of the converse."*

have increasingly enabled chefs to alter the colours of the dishes they serve (see Piqueras-Fiszman & Spence, 2012; Velasco et al., 2016). One example of this comes from playing with people's expectations by switching the colour of the foods that we already have strong associations with. This was precisely the approach famously taken by Heston Blumenthal with his Beetroot and Orange jelly dish some 15 years ago (Blumenthal, 2008, pp. 138-143; Spence & Piqueras-Fiszman, 2014) as served at *The Fat Duck* (https://www.thefatduck.co.uk/). These *pâtes de fruits* used blood orange and golden or yellow beetroot in order to naturally reverse the normal flavour-colour correspondence (see **Figure 3A**). When the dish was laid down in front of the guests, the waiter would deliberately say: *"Monsieur, madame. These are the Orange and Beetroot Jellies. May I suggest that you begin with the orange…"* (Blumenthal, 2008, p. 140). Blumenthal continues: *"…they bit in and doubt turned to surprise, though not always straight away. Sometimes the first jelly was eaten distractedly, and it was only as their teeth sank into the second that people realised something was up. The second jelly had a deep beet-red colour, but the flavour was unmistakenly, unquestionably orange."* The aim, in other words, was a playful sabotaging of the diner's expectations through the misleading use of colour (Blumenthal, 2008, p. 140).

INSERT FIGURE 3 ABOUT HERE

Others, like the Roca Brothers in Girona, Spain have been deliberately stripping all colour from certain of their flavourful creations, as in their white chocolate cake (see Anon., 2015; Velasco et al., 2016),[15] created with distilled coco bean essence. Although completely white, the dish has an intense dark chocolate taste (see Anon., 2012a). The Roca brothers have done something very similar in a more recent dish (see **Figure 3B**). In this case, the use of the rotary evaporator has enabled the chefs (with the money for the requisite equipment) to distil pure flavours (without colour/material substrate). Intriguingly, while the dish itself has no colour, it is nevertheless still packed with rich/intense flavours (flavours that we normally associate with strongly coloured foods; see Piqueras-Fiszman & Spence, 2015; Spence et al., 2015). This dish seemingly on the same as the White flavoured textures (originally developed by elBulli; see Spence & Piqueras-Fiszman, 2012, Figure 8.2). Note that shapes/food textures, even in the absence of colour, can nevertheless still be strongly associated with different tastes, at least if suitably iconic (see Spence, Corujo, & Youssef, 2019). The dissociation of flavour from

[15] Blumenthal (2008, p. 141) apparently once pursued a similar idea when researching an entirely white squid and almond dish. There is a resonance here also with the classic white tomato (soup, sauce, foam) dish.

substance/colour is exciting/playful. It is interesting to note how many of the chefs seem to feel a strong need to resist the use of artificial colorants. Indeed, it is also striking is how blue, a food colour that has seen something of a resurgence in recent years (e.g., on Instagram sites such as The Art of Plating) never appears to be used by modernist chefs (see Spence, 2018c).[16]

Meanwhile, chef Jozef Youssef from Kitchen Theory in London (see https://www.kitchen-theory.com/home/) has also been working to question the meaning of colour in his dish, *'The four tastes'* (see Spence, Wan, Woods, Velasco, Deng, Youssef, & Deroy, 2015). This dish, first trialled in a London-based multisensory dining experience, has subsequently been presented to diners in a number of other countries, with largely similar results (Velasco et al., 2016), namely, that people exhibit robust associations between colour and basic tastes. Most of those tested so far have been shown to associate a pinkish-red colour with sweet, yellow and green with sour, browny-black with bitter, and white (and blue) with salty. In fact, according to research by Saluja and Stevenson (2018), when asked, the majority of people report associating tastes with colours on the basis of familiar foods/beverages. That said, a few also report making associations on the basis of the emotional connotation (or valence) of the component stimuli, while others are simply unable (or unwilling) to offer any rational for their choices.

Futuristic dynamic colour-changing food and drink experiences

Thus far, the majority of the changes in the appearance properties of foods have occurred outside the moment when the food or drink is actually being consumed. Some such transformations may be perceptible to the diner/drinker during their consumption of the food/beverage stimulus. We have already come across the Yumchaa Blue Voodoo tea example (Blake, 2017). It is interesting to note that while one might expect it to be the modernist/molecular chefs/mixologists who would be at the forefront championing colour-change in the dishes/drinks that they serve, thus far it would seem to be the commercial food producers who have taken the lead (e.g., see **Figure 1**, for a couple of recent examples of colour-changing drinks launched commercially). The one example of a chef introducing a colour-changing dish that I have come across comes from The Magic Noodle Salad as sold at Thaimee, a restaurant located at the McCarron Hotel, New York (see Matthews, 2017). The

[16] These can be thought of as examples of hidden, rather than visible, novelty (see Schifferstein & Spence, 2008).

chef has incorporated pea flower into the vermicelli noodles. Then the diner adds a squeeze of lime to these noodles thus changing the colour. Interesting here, the addition of a dash of acidity is already an accepted step for diners before they consume the Thai noodle dish anyway. The only problem being that diners apparently add too much lime as they enjoy the colour-change so much.[17]

Others have developed an ice-cream that changes color when it is licked (see **Figure 4A**). According to Moon (2014), Linares (a physicist by training) also planned to develop an ice cream that turns from white to pink, and another one that glows under ultraviolet light. Then, there is the AR and VR routes, as for instance, highlighted by some of the very impressive AR work coming out of Katsuo Okajima's laboratory in Japan (e.g., Okajima & Spence, 2011; Ueda et al., 2014; see also Mangiaricini, 2017; Spence et al., 2016). In one such demonstration, milk can be added virtually to a cup of black coffee (see **Figure 4B**). Okajima's team also have a version of the AR that allows them to strip the colour from a pint of beer rendering it seemingly colourless.[18] See also Huang, Huang, and Wan (2019) for some of the other impressive developments in this fast-developing area. The colour change of the foods in these cases can either be achieved by the development of innovative food-grade ingredients, or else by the use of digital technology.

INSERT FIGURE 4 ABOUT HERE

Meanwhile, elsewhere, the food scientists/food technologists have sourced edible bioluminescent phytoplankton (an ostracod, a tiny crustacean – though the exact details are secret) that fluoresces (see Anon., 2012b; Pérez-Lloréns, 2019) (see **Figure 5A**). As the chef describes it (talking about the powdered and freeze-dried end result): *"This culinary creation was offered in Aponiente as part of the 'Sea Light Grand Menu' in the 2017 season. During each serving, the dining room lights are turned off, music fills the room, and waiters enter bearing glass bowls filled with the finely ground powder. Once the water or broth is poured*

[17] There might be an opportunity to think of the colour-change not as a scientific indicator, as in the cabbage-juice example, as mentioned earlier, but as a visual indicator when seasoning a dish to taste. In much the same way as one might use the colour to indicate the preferred taste of brewing tea (cf. Wan, Zhou, Mu, Du, Velasco, Michel, & Spence, 2014), or the right amount of milk to add to one's coffee. Here, one is also reminded of colour-change being used as an indicator in the colour-changing paint (https://www.valsparpaint.com/en/find-the-right-product/interior/paint/color-change-ceiling.html).

[18] It is, though, worth noting that there can also be a problem with some of the AR solutions in that the augmenting of the visual image isn't always perfect. Hence, one often sees some interference at the edges of the visual food image (especially if there are any sudden movements, and this may potentially break the illusion, due to current computing power not being yet quite up to scratch).

into the bowl and stirred, it starts to glow in the dark in ethereal blue swirls, lasting for 20 min. The taste and flavour of dishes are not affected; it is more a culinary technique than an ingredient. Its use in cocktails also seems promising." (Pérez-Lloréns, 2019, p. 6).

Another intriguing new way in which to make the colour of food appear to fluoresce is by changing the spectra of the ambient lighting, building on the prior that we internalize that the colour of lighting doesn't change.[19] This was the approach popularized by Harvey et al. (2019) in their recently-exhibited glowing (or neon) fruit illusion (see **Figure 5B**).[20] There is, though, an interesting theoretical question here as to how observers will interpret the meaning, or expected taste/flavour, of foods that fluoresce, or whose colour appears to change as a result of AR? As yet, it is unclear quite how the introduction of these new/unusual food experiences in which the rapid changing of the colour, or the fluorescence will be received/interpreted. Indeed, as highlighted recently by Zellner, Greene, Jimenez, Calderon, Diaz, and Sheraton (2018), in their study of variously-coloured candy wrappers, there may be situations in which the consumer takes (product- or packaging-related) colour to be informative about the likely taste/flavour of a food or beverage product, while at other times, colour, or colour-variation may not be taken to signal, or necessarily to relate to, the taste/flavour. One such situation in which the appearance of food is not taken (literally) to be representative of the actual colour of the product itself is when e.g., looking at black and white images (cf. Greenlee, 2010; Lee, Deng, Unnava, & Fujita, 2014; though see also Miyake, Yoshimatsu, & Sakai, 2009). Further research is therefore needed in order to understand better when visual appearance and colour are taken by viewers as a meaningful indication of the taste/flavour of a product, and when they are treated as uninformative/unrelated.

INSERT FIGURE 5 ABOUT HERE

Conclusions

In conclusion, the present review has highlighted the existence of something of a tension between the world of natural foods, where a gradual change in appearance properties is often

[19] The appearance properties of food and drink are influenced by the backdrop against which they are presented. Hence, changing the colour of the background or plate/glass has been shown to influence appearance properties of food, drink, and fruit and veg. (e.g., Lyman, 1989; Schifferstein, Howell, & Pont, 2016; Spence, 2018a).

[20] Here, one might think of this as similar to the blue fluorescence that quinine undergoes when exposed to ultraviolet light (e.g., see Science Buddies, 2014).

seen as desirable (or, at the very least, informative, e.g., regarding the quality), and the world of processed (and branded) foods where the goal has very much been to achieve a consistent colour over the lifetime of the product and/or brand. Natural products typically change their appearance properties (i.e., colour as they ripen and age, cf. Bannert & Bartels, 2013; Hansen, Olkkonen, Walter, & Gegenfurtner, 2006; the latter, sometimes desirable, at other times not). Very often, of course, the act of cooking itself leads to predictable transformations too. As we have seen, there are situations in which food companies periodically change the colour of their products. They do so for a variety of reasons including responding to legislation, changing consumer sentiment, trying to capture the consumer's attention, and/or simply to generate media interest. Meanwhile, a number of the modernist chefs, practicing what can, least controversially, be called 'experimental cooking' (see Spence & Youssef, 2018), have also been fascinated by the various ways in which colour and flavour are connected in the minds of those they serve, and how they can be pulled apart (i.e., deconstructed; see also vegetables with charcoal oil: http://www.elbulli.com/catalogo/catalogo/anyo.php?lang=en&anyo=2001&id=778).

However, at the same time, this review has also highlighted the fact that in both the worlds of processed food and modernist/molecular cuisine, there is still a general concern around/aversion toward the use of artificial colorants that one needs to be aware of. Hence, the understandable insistence on the natural source of the colorants in much of the discourse/solutions in the world of food/drink in recent decades. This stress being very apparent in the introduction of e.g., the many blue drinks that have been launched in recent years (see Spence, 2018c, for a review). Another solution to playing with the visual appearance that we have seen is just simply to remove colour from food or drink altogether, thus rendering it white/colourless (Spence & Piqueras-Fiszman, 2014; though again this only likely works in certain designed food experiences; Harris, 2011).

INSERT FIGURE 6 ABOUT HERE

However, none of these changes in food or drink have been perceptible over the course of a dish/drink when served at the table. More dramatic (i.e., sudden) changes in appearance that have been familiar for a very long time include the opacity that appears when water added to certain anise-flavoured drinks. What is more, given the consumer interest, together with the emergence of new techniques to change the apparent-colour of foods in real time, or else the emergence of foods that fluoresce (either because they are bioluminescent, or else because of a trick of the light), the would seem to be little reason that more of the food and drink

experiences we have in the future may involve some sort of visual (and visually-intriguing) transformation. Finally here, though, it is perhaps worth closing by noting that while the popular interest in colour-changing foods might seem like a particularly novel phenomenon, Ancient Romans were also fascinated. Indeed, there was once a fashion for the surmullet, a kind of fish, to be served (see **Figure 6**). Apparently, it would have been paraded in front of the guests as its skin fluttered through a rainbow of iridescent colours before eventually being consumed (Andrews, 1949).

Coda: A suggested future experiment

Looking to the future, it may be possible to develop a dining experience in which the diners are offered a range of coloured drinks and asked to pick the colour that they want to taste. Thereafter, the colour of the drinks is changed slowly (e.g., over the course of 30 seconds to a minute, say). In this case, even though the colour changes in front of the guests' eyes, they should not notice (given that there is no transient visual stimulus signalling the change). This, at least the suggestion from the psychological literature on the phenomenon of change blindness to slow changes (see Auvray & O'Regan, 2001, 2003; David, Laloyaux, Devue, & Cleeremans, 2006). In this way, the host/waiter may have the opportunity to play with the diners, by returning to the table, and asking whether they are sure they have the right drink (i.e., drawing the guests' attention to categorizing the colour which has changed without their realizing it). Under such conditions, the guests will be put in a state where they are simply not able to say whether the change is physico-chemical in origin, a lighting/technology-induced change, and/or some sleight (or misdirection – magic, or illusion, if you will; see Swanson, 2015). Should this approach work as planned, then the hope is that it should make for an intriguing/playful drink/dish. And, as a follow-on, one might then look to see whether any slow changes are noted more quickly if they introduce an unnatural food colour (such as blue) to the table.

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FIGURE LEGENDS

Figure 1. A) Yumchaa's Blue Voodoo Magic tea. This popular tea drink changes colour from blue (from pea-flower) to purple with the addition of something acidic (e.g., a slice of lemon). [Picture from Blake (2017).]; From the description for those who have been, it sounds like a the guests at The Cauldron, a Harry Potter-themed bar get to play a similar trick (see Ritschel, 2018). B) Butterfly Pea Lemonade Cold Brew from Starbucks, assold in Asia. According to the Starbucks press release: *"the drink's color-changing properties come courtesy of the butterfly tea powder for which the beverages gets its name. As the popular Southeast Asian ingredient mixes in with the citrus in the lemonade, it changes colors from its natural blue hue to a luscious shade of violet."* [Figure from Anon. (2018).]

Figure 2. The Aka Samurai Chicken burger from Burger King Japan featuring red buns and red cheese, and below the successful all-black burger [Burger King Japan]

Figure 3. A) The beetroot and orange jelly. A classic example of the natural, but surprising, use of colour to mislead the guests. This a dish once served at *The Fat Duck* restaurant in Bray; B) Cromatisme blanc – Restaurant *El Celler de Can Roca*. Sorbet de destil·lat de cafè, escuma de destil·lat de safrà, gelatin de destil·lat de cardamom I salsa de destil·latde pebre. This example of the distillation of cocoa, cinnamon, citrus and coffee was originally developed by the research team at elBulli, in Spain. [Copyright elBulli.com]

Figure 4. A) One of Manuel Linares colour-changing ice creams, called Xamaleón (a play on the Spanish word for chameleon). The tutti-frutti-flavoured ice cream apparently starts out as a periwinkle blue but is coated with a special compound that reacts to changes in temperature and saliva, causing the surface to turn purple and then pink as it is licked. [Figure from Moon, 2014.]; B) Changing the appearance of a cup of black coffee using AR. [Image courtesy of

Katsuo Okajima.] Notice how the changing appearance of the food/drink can be achieved either through the ingredients used in the food itself or via the use of technology.

Figure 5. A) One of the bioluminescent dishes served by José Lucas Pérez-Lloréns [Image from Pérez-Lloréns (2019).]; B) A sequence of frames taken from a video of the neon fruit illusion. [Image reprinted from Harvey et al. (2019).] Notice, once again, how the fluorescing/neon glow can be achieved either through the ingredients used in the food or via technology.

Figure 6. The surmullet, a fish that was prized in Roman banquets because it would flicker through a rainbow of colours. The interest in foods that change their colour goes back a very long way. [Royalty free picture from Surmulet (Mullus Surmuletus) illustration from The Natural History of British Fishes (1802) by Edward Donovan (1768-1837). Original from The New York Public Library.]

Figure 1.

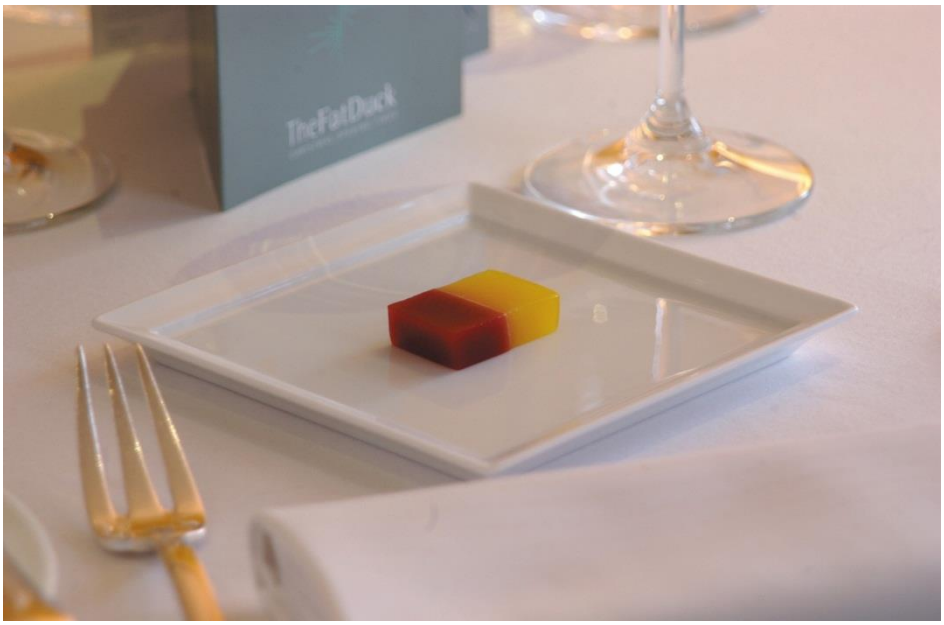
A)

B)

Figure 2.

Figure 3.

A)



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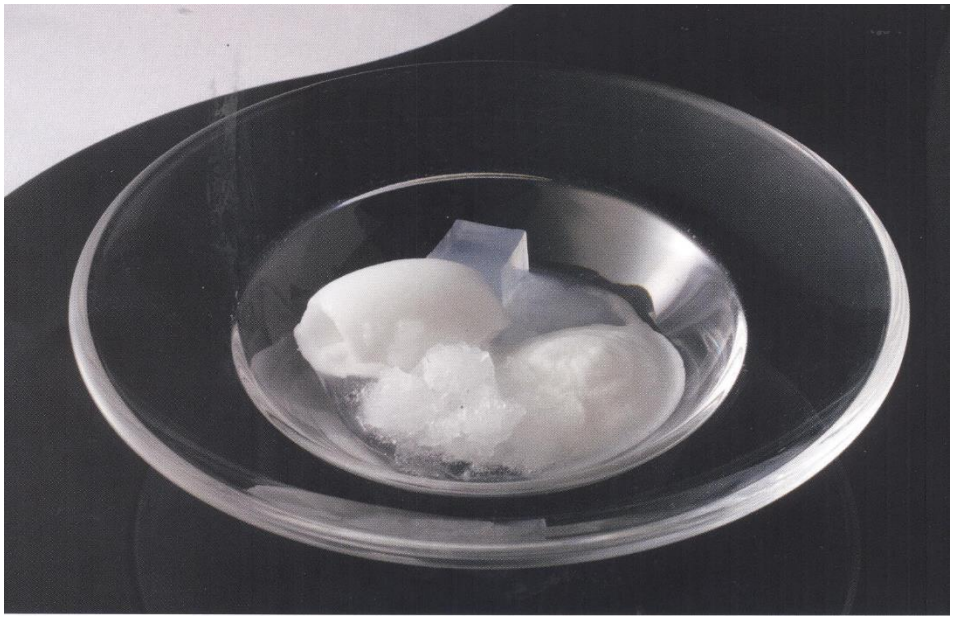

Figure 4.

A)

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Figure 5.

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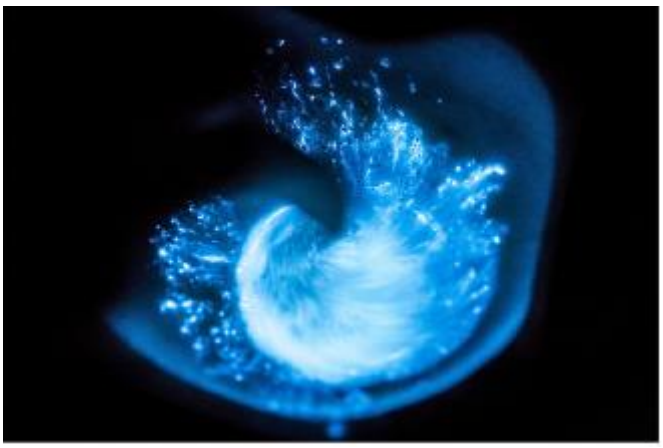

B)

Figure 6.