

EFFECT OF COLOR ON THE ODOR, FLAVOR, AND ACCEPTANCE PROPERTIES OF
FOODS AND BEVERAGES

by

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Abstract

A significant increase in the number of products carried in supermarkets has lead manufacturers to use food color as a way to differentiate their products from competitor's products or as a form of communication. This report's overall objective was to review the impact of color on sensory properties of foods and beverages and help product developers understand the multiple sensory properties within a food or beverage that may potentially change by manipulating color. The effect of color on flavor or odor identification, basic taste perception, flavor or odor intensity, quality and refreshment, and consumer acceptance has been extensively researched. Research to date has shown inconsistent findings, although key themes are consistent. Some colors are more appropriate for certain foods and beverages, and product color can be directly linked to palatability. Color cues can be used for flavor identification within a food or beverage, and the presence of certain colors evoke flavor associations within a product. Perceived intensities of basic taste or flavor attributes have increased or decreased merely with color addition. Consumers use color cues to determine quality, therefore color can ultimately affect product acceptance.

Keywords: color, flavor, odor, consumer acceptance, quality, foods, beverages

Table of Contents

List of Figures	v
List of Tables	vii
Acknowledgements.....	ix
Chapter 1 - Significance.....	1
Definitions, Regulations, and Other Concerns	1
Color and Food Palatability	2
Appropriateness of Color in Foods.....	3
Introducing Novel Colors into the Marketplace	4
Chapter 2 - Effect of Color on the Sensory Properties of Foods and Beverages.....	6
Effect of Color on Flavor or Odor Identification.....	6
Matching Color to Flavor or Odor	14
Effect of Color on Basic Taste Perception.....	18
Effect of Color on Flavor and Odor Intensity.....	27
Effect of Color on Quality, Freshness, Thirst Quenching, and Refreshment	39
Effect of Color on Consumer Acceptance	45
Chapter 3 - Conclusion	54
References.....	56

List of Figures

- FIG. 1. RESULTS (LEVITAN *ET AL.* 2008) OF A SAME-DIFFERENCE TEST SHOWING PROPORTION OF CORRECT RESPONSES FOR DIFFERENT COLOR PAIRINGS OF SMARTIES CANDIES. IN THE TOP CHART (A), BLACK BARS REPRESENT THOSE WHO BELIEVE ORANGE COLORED SMARTIES HAVE A DISTINCTIVE FLAVOR AND WHITE BARS ARE THOSE WHO DO NOT. IN THE BOTTOM CHART (B), BLACK BARS REPRESENT THOSE WHO BELIEVE NON-ORANGE SMARTIES HAVE A DISTINCTIVE FLAVOR AND WHITE BARS ARE THOSE WHO DO NOT..... 12
- FIG. 2. RESULTS (JOHNSON *ET AL.* 1982) SHOWING THE SWEETNESS FOR CHERRY FLAVORED AND RED COLORED SOLUTIONS AT 3.96%, 4.0% AND 4.4% SUCROSE; COLORS 1-5 INCREASE IN RED INTENSITY FROM LIGHTEST TO DARKEST 22
- FIG. 3. RANK SUM FOR FRUIT FLAVOR INTENSITY IN PEACH, KIWI, ORANGE, AND BERRY BEVERAGES THAT DIFFER IN COLOR INTENSITY (BAYARRI *ET AL.* 2001) 28
- FIG. 4. MEAN SCORES ASSIGNED TO COLORED (C), UNCOLORED OR ABNORMALLY COLORED (U) FOOD BASED ON AROMA INTENSITY (CHRISTENSEN 1983)..... 30
- FIG. 5. MEAN CHOCOLATE INTENSITY RATINGS FOR CHOCOLATYNESS OF M&M'S UNDER TESTING CONDITIONS OF COLOR, LABEL, AND BOTH COLOR AND LABEL (SHANKAR *ET AL.* 2009); CONDITION A-COLOR ONLY (GREEN VS. BROWN), CONDITION B-LABEL ONLY (MILK VS. DARK CHOCOLATE), CONDITION C-BOTH COLOR AND LABEL (GREEN, BROWN, MILK CHOCOLATE, AND DARK CHOCOLATE)..... 32
- FIG. 6. RESULTS SHOWING MEAN ODOR INTENSITY RATINGS OF OC (ODOR PLUS COLOR), O (ODOR, NO COLOR), C (ODORLESS WITH COLOR), AND N (NO ODOR OR COLOR) SOLUTIONS SCENTED MINT, STRAWBERRY, ORANGE, AND LEMON (ZELLNER AND KAUTZ 1990)..... 33

FIG. 7. MEAN ODOR INTENSITY RATINGS AND MEAN APPROPRIATENESS RANKING FOR RED STRAWBERRY ODOR SOLUTIONS AND GREEN MINT ODOR SOLUTIONS (ZELLNER AND WHITTEN 1999).....	35
FIG. 8. MEAN ORTHONASAL (PART A) AND MEAN RETRONASAL (PART B) FRUITINESS INTENSITY SCORES BASED ON FRUIT FLAVORED SOLUTIONS (KOZA <i>ET AL.</i> 2005)	38
FIG 9. MEAN FRESHNESS RATINGS FOR SOFT DRINKS CONTAINING DIFFERENT COMBINATIONS OF ODORANT AND COLOR (FENKO <i>ET AL.</i> 2008).....	42
FIG. 10. OVERALL ACCEPTABILITY RATINGS FOR ORANGE AND CHERRY BEVERAGES CONTAINING DIFFERENT LEVELS OF COLOR AND FLAVOR (DUBOSE <i>ET AL.</i> 1980).....	49
FIG. 11. OVERALL ACCEPTABILITY AND COLOR ACCEPTABILITY RATINGS FOR CAKE CONTAINING DIFFERENT LEVELS OF YELLOW COLOR AND LEMON FLAVOR (DUBOSE <i>ET AL.</i> 1980).....	50
FIG. 12. RESULTS ILLUSTRATING THE DIFFERENCES BETWEEN THE CONTROL ORANGE JUICE AND THE ADULTERATED ORANGE JUICE (GREEN COLOR) ON THE ATTRIBUTES OF COLOR, SWEETNESS, FLAVOR, AND OVERALL LIKING (TEPPER 1993)	51
FIG. 13. RESULTS SHOWING THE PERCENTAGE OF PANELISTS PREFERRING DARKER CHIPS TO LIGHTER CHIPS OVER TIME BASED, ON FLAVOR AND ODOR (MAGA 1974)	53

List of Tables

TABLE 2.1. EXPERIMENTAL DESIGN WITH FOOD COLOR AND LABELING AS FACTORS TO DETERMINE FLAVOR EXPECTATIONS OF ORANGE FLAVORED BEVERAGES (GARBER <i>ET AL.</i> 2000).....	9
TABLE 2.2. RESULTS OF ASSOCIATIONS BETWEEN COLOR AND TASTE ATTRIBUTES CHARACTERISTICALLY ASSOCIATED WITH SODA (KOCH AND KOCH 2003).....	14
TABLE 2.3. RESULTS OF ASSOCIATIONS BETWEEN COLOR AND FLAVOR ATTRIBUTES BASED ON COLORED SOLUTIONS (ZAMPINI <i>ET AL.</i> 2007)	15
TABLE 2.4. RESULTS OF COLOR/FLAVOR ASSOCIATIONS FROM RESPONDENTS IN UK AND TAIWAN AFTER LOOKING AT COLORED SOLUTIONS (SHANKAR <i>ET AL.</i> 2010).....	16
TABLE 2.5. FREQUENCY COUNTS FOR THE SWEETER SAMPLE BETWEEN DARK AND LIGHT RED (STRAWBERRY) OR GREEN (KEY LIME) BEVERAGES (LAVIN AND LAWLESS 1998)	25
TABLE 2.6. AVERAGE PERCEIVED SWEETNESS RATINGS AND THE MEAN DIFFERENCE BETWEEN LIQUID AND SOLID SAMPLES, BY COLOR (ALLEY AND ALLEY 1998).....	26
TABLE 2.7. RESULTS (SCHUTZ 1954) HIGHLIGHTING THE EFFECT OF COLOR ON LIKING AND QUALITY OF ORANGE JUICE.....	41
TABLE 2.8. QUESTIONNAIRE USED TO UNDERSTAND RESPONDENTS' OPINIONS ABOUT REFRESHING FOODS AND BEVERAGES (ZELLNER & DURLACH 2002)	43
TABLE 2.9. MEAN REFRESHMENT RATINGS FOR FLAVOR/COLOR COMBINATIONS AMONG SUBJECTS WHO ONLY LOOKED AT THE BEVERAGES (EXPECTATIONS GROUP) (ZELLNER AND DURLACH 2003)	44
TABLE 2.10 MEAN REFRESHMENT RATINGS FOR FLAVOR/COLOR COMBINATIONS AMONG SUBJECTS WHO TASTED THE BEVERAGES (TASTE GROUP) (ZELLNER AND DURLACH 2003).....	44

TABLE 2.11. RESULTS SHOWING CHILDREN'S PREFERENCE FOR COLOR BROKEN
DOWN BY CANDY TYPE AND DEMOGRAPHICS (WALSH *ET AL.* 1989)..... 46

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Chapter 1 - Significance

The average number of products carried in a supermarket more than tripled (15,000 to 50,000) from 1980 to 2002 (Nestle 2002). The need for differentiation between products at the point of purchase has led manufacturers to use food color as a form of communication (Garber and Hyatt 2000) and for distinguishing products from the competition (Parikh and Zhang 2011). Using color is a way to identify or unify products within a product line, and set apart products within a product line (Parikh and Zhang 2011). It is understood that product color conveys meaning to a consumer and sets up flavor and performance expectations (Garber and Hyatt 2000). Therefore, the risk of changing a food's color will alter the expectations a consumer has about a product.

Definitions, Regulations, and Other Concerns

Color is defined as the visual effect produced on the eye by waves of light that differ in wavelength or frequency (The Columbia Encyclopedia 2008). A prism may be used to visualize the spectrum of color found within visible or white light. When light is shown through a prism, the longest wavelengths travel more rapidly through the glass than the shortest wavelengths, which appears in a separated band of colors. The visible spectrum consists of the colors red, orange, yellow, green blue, indigo and violet. Red and orange colors have the longest wavelengths; medium wavelengths appear as colors of yellow and green, while blues and violets have the shortest wavelengths (The Columbia Encyclopedia 2008; The American Heritage Dictionary of the English Language 2007).

Color can also be defined as “A substance, such as a dye, pigment, or paint that imparts a hue (The American Heritage Dictionary of the English Language 2007). Therefore, food coloring can be defined as any substance that is added to a food or beverage to change its color (Wikipedia, the free encyclopedia 2011). Specifically, a color additive, as defined by the regulations is “Any dye, pigment or other substance that can impart color to a food, drug, or to the human body” (Barrows 2003).

The Food and Drugs Act was passed by Congress in 1906 in order to protect the public from adulterated, misbranded, and even toxic products. This act prohibited the use of harmful colors in foods and also the use of color to hide inferior or damaged food products (Barrows

2003). The Food and Drug Administration (FDA) is responsible for determining which colorants are safe for use in food, drug and cosmetics, and lists approved synthetic food dyes with FD&C numbers. As of May 9, 2011 the FDA there were 9 approved or certified color additives (CFR 21, 2011). Certified colors can either be in the form of dyes or lakes. Dyes are dissolvable in water, while lakes are the water insoluble form of the dye. Colors that are derived from natural sources including vegetables, minerals or animals are exempt from certification. Common exempt color include annatto extract (yellow), caramel (yellow to tan), beta-carotene (yellow to orange), grape skin extract (red or green, depending on the variety) and dehydrated beets (bluish-red to brown) Labeling laws require any product containing a certified color to be labeled with the specific name, i.e. FD&C Blue No. 1 or its abbreviated name Blue 1. If a color additive is exempt from certification, it may either be labeled as the name of the ingredient, or collectively as “artificial colors” (FDA 2010).

Over the years, there have been many health related concerns regarding artificial colors. One of the issues currently being discussed is the link between food additives, including colors, and childhood attention deficit hyperactivity disorder (ADHD). Also, FD&C Yellow No. 5 (Tartrazine) is believed by some to cause allergic reactions; however, the FDA has reported that it causes hives in fewer than 1 in 10,000 people (FDA 2010). Other unsubstantiated concerns include the following: FD&C Yellow No. 5 is rumored to trigger asthma attacks, induce sensitivities among those allergic to aspirin, bring about male infertility, cause the male sex organs to shrink and lower sperm count (Ackendorf 2011; Welch 2011); FD&C Red No. 40 (Allura red) is alleged to cause eczema; FD&C Red No. 3 (Erythrosine) is rumored to be linked to thyroid tumors; and FD&C Blue No. 1 and No. 2 (Brilliant Blue FCF and Indigotine) are allegedly been associated with brain tumors (Welch 2011). As mentioned earlier, many of these concerns have not been verified.

Color and Food Palatability

On a basic level, the color of a food is linked to its palatability. This is illustrated by a separate study reported by Moskowitz (1978), “Moir prepared a buffet of foods for a dinner with scientific colleagues of the Flavor Group of the Society of Chemistry and Industry in London. Many of the foods were inappropriately colored, and during the dinner several individuals complained about the off-flavor of many of the foods served. Several of the individuals reported

feeling ill after eating some of the foods, despite the fact that only the color was varied. The rest of the food was perfectly wholesome, with the requisite taste, smell and texture” (Moir 1936). Cardello (1996) also reported similar outside findings “In this study, subjects ate a meal of steak, french fries, and peas under color-masking conditions. Halfway through the meal, normal lighting was restored to reveal blue steak, green french fries and red peas. The mere sight of the food was enough to induce nausea in many of the subjects. The stark novelty of the colors used in this study leads one to ask whether certain colors are innately preferred or rejected” (Wheatley 1973).

Appropriateness of Color in Foods

In separate regions within the U.S. and other countries, colors have different associations (Wheatley 1973). In Western countries, black is symbolic of death and mourning, while in many Asian countries, the color white is symbolic of death. A study found that the color red was either associated with love, safety, danger, strength, and warmth, depending on where in U.S. the respondents were located (Garber and Hyatt 2000).

Color can also evoke different associations within foods. Garber and Hyatt (2000) point out that “a red apple is presumed ripe and sweet, and a red steak raw and unappetizing”. The same dilemma is seen with other food colors; green grapes are sweet and ripe, while a green apple is either tart or unripe, and a green orange is either unripe or moldy. Brown in a steak means cooked and ready to eat, while a brown apple is rotten (Garber and Hyatt 2000).

Color preferences in regarding foods also vary with people’s location. Brown eggs are more common and, therefore, preferred in New England; while New Yorkers typically buy white eggs (Kanig 1955; Lawless 1995). In Wisconsin, it is expected that cheddar cheese should be yellow, while in New York both white and yellow are acceptable for cheddar cheeses (Lawless, 1995). The preferred color for butter in the Midwest is a deep yellow while a whiter butter is acceptable in other parts of the country (Kanig 1955).

Kanig (1955) suggested the colors blue and violet are typically considered “inedible” in foods because people associate the color blue with poisonous compounds. He believed that lighter shades of blue and purple may be more palatable than pure versions of these colors. He also suggested that green may be the most suitable color for foods, in general. Birren (1963) illustrates that colors of red, red-orange, peach, pink tan, brown, yellow light, and clear green are

appropriate and appetizing for foods. On the other hand, purplish reds, purple, violet, greenish yellow, gray, mustardy, and olive tones are poor colors for foods (Birren 1963).

Many people are neophobic, meaning they have a fear of new things or experiences and therefore, are resistant to consuming familiar foods that are unusually colored (Lawless 1995). A baker in the Midwest tried to sell tomato colored and flavored bread and found that people only purchased bread that looked like bread (Kanig 1955). Bright colors that are appropriate for cake and cookie frosting would not be appropriate for mashed potatoes (Birren 1963). The popular children's book, *Green Eggs and Ham* (Dr Seuss 1960), emerged because the main character did not want to eat ham and eggs because they were green in color. Crystal Pepsi, a clear version of the original brown cola, was unsuccessful (Triplett 1994) because it is believed that Pepsi failed to understand how color has an impact on flavor expectations of a product. A clear cola leads consumers to expect a lighter cleaner flavor including fewer calories. Because the clear cola had the same taste profile as the brown cola it made the product unpalatable, even by consumers who drank Pepsi (Triplett 1994; Garber and Hyatt 2000).

Introducing Novel Colors into the Marketplace

Many manufacturers are introducing products with unusual food colors into the marketplace, and most of these novelty colored products are designed for children. In 2000 Heinz launched a green colored ketchup (USA today 2000), and more recently their ketchup has also been sold in a purple color or a "mystery color," which could either be pink, orange, or teal. Kraft has created a macaroni and cheese that features pasta in the shape of the Blues Clues characters and contains blue paw print pasta. Parkay Fun Squeeze butter-flavored spread is available in Shocking Pink and Electric Blue, and Kellogg has a cereal, Disney Mickey's Magic, which turns the milk blue. Ore Ida has frozen French fries that are Kool Blue colored (USA today 2002). Recently, Pepperidge Farm has introduced yellow, orange, and purple colors into their classic Goldfish crackers (Food Business Review 2010). Although many new products have been introduced by various companies the marketplace should be monitored in order to determine if these new colored products are successful.

Because of these new products' potential to be rejected based on their color Garber *et al.* (2001) discusses three potential strategies marketers can use to be successful when launching novel colored food products. The first strategy involves teaching consumers to associate the new

color with a given flavor, thus this new color becomes a visual cue in identifying the product's flavor. Products that have been successful using this strategy include mint chocolate chip ice cream (colored green) and Mountain Dew soda (a bright yellow color) (2001).

The second strategy that can be employed to create a successful product containing new food color is to guide the product's flavor perception by highlighting the incongruent color as part of the product's flavor. Because the consumer is made aware of the mismatched color to flavor, the "amusing" nature of the incongruence is noticed allowing the consumer to share in the fun that color brings. A successful product using this strategy is Gatorade and its Blue Raspberry drink. This works because the incongruence between the color and flavor (blue, an atypical coloring for raspberry flavor), is signaled in the name allowing the consumer to know the color/flavor pairing is intentional and was created for their entertainment (Garber et al. 2001).

The third strategy is to disconnect the flavor from the color so the consumer is unable to connect the two, thus disallowing the realization that color and flavor are incongruent. This can be achieved in several ways; the easiest way is to use the product packaging to mask the color of the product inside, requiring consumers to have flavor expectations based on the label and packaging, not the actual product. Another way to disassociate flavor from color is to select colors and flavors that do not have strong associations. Gatorade has been successful using this strategy with their *Frost line* of beverages referring to winter themes instead of flavors. The colors and names used suggest images of ice, cold, and snow; these themes fit with the idea of hydration, and thirst quenching, i.e., "Alpine Snow" (a whitish color) and "Whitewater Splash" (a clear green color). To ensure consumers do not link color with flavor, the ingredient statements for these beverages lists "natural flavors" only instead of specific ingredients that may cue a flavor association (Garber et al 2001).

While these three strategies may help to market products with novel food colors it is important to understand the associations and expectations that the novel color imparts on the food product. Additionally, it is important to be aware of how color impacts the sensory properties of the food or beverage product.

Chapter 2 - Effect of Color on the Sensory Properties of Foods and Beverages

Acceptability, sensory characteristics, safety, and aesthetics of food are all affected by color (Clydesdale 1993). Because color is everywhere it affects people at some level of consciousness (Kostyla and Clydesdale 1978). Many early cultures consumed foods exclusively based on color because emotional and physical properties associated with a particular color, they believed, would be passed to the individual after consumption (Cardello 1996).

The topic of color and its effect on taste and flavor perception has been investigated for over 70 years (Spence *et al.* 2010). Although this topic has been studied extensively, the effect of color on the sensory properties of foods and beverages is not completely straight forward due to contradictory data. For example, Lavin and Lawless (1998) wrote “The literature on the effects of color on taste and flavor judgments is consistent in its inconsistency” and Bayarri *et al.* (2001) suggested “the possible influence of color on flavor perception is under discussion and no clear conclusions have been attained yet”. It is important to understand the effects of color on all sensory related characteristics because many attributes are interrelated (Dubose *et al.* 1980). This review covers research focused on understanding the interaction between color and different sensory properties within foods and beverages.

Effect of Color on Flavor or Odor Identification

Food coloring influences individuals’ ability to identify flavors (Spence *et al.* 2010). Many studies published in this area explore flavor and odor identification in foods and beverages when they are uncolored, colored appropriately, or colored inappropriately. Results from these studies demonstrated that people were more likely to identify odor/flavor correctly when the color was appropriate.

DuBose *et al.* (1980) explored panelists’ ability to identify flavors of fruit colored beverages. The study’s purpose was to determine if atypical coloring had an effect on flavor identification. Cherry, lime, orange, and unflavored beverages were colored red, orange, green, or colorless. Cherry beverages colored red, orange beverages colored orange, and lime beverages colored green were considered typical color/flavor combinations. Any other flavor/color combination was considered atypical. For cherry flavor 70% of panelists were able

to correctly identify the flavor when colored red, but only 33% were able to correctly identify the flavor when colored green. Both orange and lime beverages illustrated similar patterns of correct flavor identification when beverages were typically colored. Additionally, cherry colored green was described as lime by 26% of panelists, and lime colored orange was described as orange by 41% of panelists; these results indicated many panelists associated the beverage's flavor with its color.

In another study, Zampini *et al.* (2007) observed similar results. They also wanted to understand the impact of color on flavor identification, but participants in this study were told that "they would be tricked by the color of the solutions (i.e., that the color of the solutions would often not correspond to the flavor typically associated with that color)". Participants were presented with solutions that were unflavored, or flavored with strawberry, orange, or lime and were uncolored, or colored with red, green, or orange colors. Within the colors, two intensity levels were presented (standard coloring or double coloring). Lime flavor interaction between flavor and color was found to be significant ($p < 0.001$), and lime flavored solutions were identified correctly more often when colored green (both standard and double coloring) or colorless compared to when colored orange or red. Similar findings were true for orange flavored solutions. Although panelists were told that color would often not correspond to the flavor of the solution, results indicated that color was considered as the flavor was evaluated.

Stillman (1993) also studied the influence of color on flavor identification, and in his study, subjects were asked to write on a slip of paper the flavor they identified with the fruit beverage. All beverages were raspberry or orange flavored, however they could be colored red, orange, green, or colorless. Raspberry, orange, lime, lemon, and pineapple accounted for 94% of the flavors identified. Correct identification was higher for raspberry flavor when it was colored red than with raspberry flavor combined with any other color. With orange flavor, both orange and red coloring allowed for higher correct identification than with green or colorless samples.

Research conducted by Zampini *et al.* (2008) examined the effect of both color and fruit acids on flavor identification in fruit flavored beverages. It was hypothesized that the presence of fruit acids would help participants correctly identify the flavor. The participants were presented with beverages flavored orange and blackcurrant that were uncolored, yellow, orange, gray, or red in color and could potentially contain fruit acids. Participants were asked to identify the flavor from a list of 18 possible choices. Results showed that respondents were able to

correctly identify the flavor when the color was appropriate to the flavor. The blackcurrant flavor was correctly identified by 64% of participants when colored gray (significantly higher than when combined with any other color). The orange flavor was identified correctly by 63% of participants when colored orange (higher than presented in any other color). There was also a significant interaction between flavor and fruit acids; both flavored beverages were correctly identified more often in the presence of fruit acids.

Oram *et al.* (1995) studied understanding how age influences people's ability to identify flavor based on color. In this study, four drinks that were flavored chocolate, orange, pineapple, or strawberry and were colored brown, orange, yellow, or red. Each flavor had a color pairing that was considered typical, i.e. chocolate-brown, orange-orange, pineapple-yellow, and strawberry-red. Subjects were split into two age demographics, 2-18 years old (children) and 19 years old or older (adults). Subjects were asked to pick the flavor of a beverage from a card which listed the four choices as well as picture of each flavor. When the color of the beverage matched the flavor (typical pairing) there was over 80% correct identification of the flavor among both children and adults, whereas, when the pairing was atypical, correct flavor identification decreased significantly. Children were more likely to choose the flavor based on the color of the drink when the pairing was atypical, but adults were more likely to choose the flavor based on the flavor of the drink they tasted (not the color).

Realizing that color helps people identify flavor, Garber *et al.* (2000) designed a study to investigate the influence of label information and color on flavor identification. Respondents were presented with one beverage from the possibilities shown in Table 2.1 and asked to identify the flavor by selecting from a list of 15 fruit flavors. All beverages tested were orange flavor regardless of color.

TABLE 2.1.
 EXPERIMENTAL DESIGN WITH FOOD COLOR AND LABELING AS FACTORS TO
 DETERMINE FLAVOR EXPECTATIONS OF ORANGE FLAVORED BEVERAGES
 (GARBER *ET AL.* 2000)

		FOOD COLOR		
		PURPLE (Uncharacteristic)	ORANGE (Characteristic)	CLEAR (None)
LABELING	GRAPE DRINK (Incorrect)	Congruent Food Color and Labeling	Incongruent Food Color and Labeling	Incorrect Labeling Only
	ORANGE DRINK (Correct)	Incongruent Food Color and Labeling	Congruent Food Color and Labeling	Correct Labeling Only
	FRUIT DRINK (None)	Uncharacteristic Food Color Only	Characteristic Food Color Only	No Flavor Identification

To test for effect of labeling and food color authors had respondents rate liking of each beverage. Results indicated that manipulating beverage color significantly impacted respondents' ability to correctly identify flavor ($p=0.044$). Those presented with orange colored beverages were able to identify the flavor more often than those presented with clear or purple colored beverages. Conversely, those presented with purple beverages incorrectly identified the flavor as grape more often than those presented with a clear or orange colored beverage. Mean liking ratings were higher for beverages in which the color and labeling were congruent compared to those that were incongruent, regardless if the color of the beverage was characteristic of its flavor.

Hyman (1983) researched the influence of color on flavor identification, and in the first part of his study, he had subjects identify the flavor of either clear carbonated water (blindfolded), brown carbonated water (blindfolded), brown carbonated water (non-blindfolded) or red carbonated water (non-blindfolded). Results indicated that when blindfolded most subjects were able to correctly identify the carbonated water's flavor. When seen, most of the subjects were also able to correctly identify the flavor; however, a few were impacted by the color and gave responses such as weak cherry soda or flat root beer. The second part of his study had subjects identify the flavor of a white birch beer (blindfolded), and the flavor of white, red, brown, or yellow birch beer, not blindfolded. When subjects were blindfolded, 60% correctly identified the flavor, but when allowed to see, 70% correctly identified the white birch beer's flavor, 50% correctly identified the flavor of the brown or yellow colored birch beers, and only

35% correctly identified the red birch beer's flavor. This study supports the hypothesis that flavor identification is influenced by color.

Zellner *et al.* (1991) studied the effect of color on odor identification, and in this research subjects were presented with combinations of 10 odors and five colors then asked to identify the odor as quickly as possible. Five of the 10 odors were typically associated with the five colors and classified as typical odor/color combinations, and the other five odors were classified as atypical odor/color combinations. As seen in previously mentioned studies, the typical odor/color combinations had more correct odor identifications than those with atypical odor/color combinations. Over 50% of the incorrect identifications were based on the color of the solution. The time it took a subject to identify an odor was also recorded among those who correctly identified the odor. Statistical analysis showed that when the odor/color combination was typical, the response time was faster than when it was atypical showing that the color/odor combination affects more than flavor identification.

The effect of color on odors was also studied by Morrot *et al.* (2001). In this study, subjects were asked to taste a red and white wine and then select odors describing each wine. A list was provided to facilitate the language development; subjects were allowed to add their own descriptors. After the list was completed, subjects were instructed to indicate if the odor best described the white or red wine. The following week two wines were presented to each subject; both were the same white wine described the previous week. However one was colored to look like the red wine. Subjects were presented with the individual list of odors and were instructed to indicate if each odor listed best described the white or red colored white wine. In general red wines were described by odors of red fruit or dark colors while the descriptors of white wines tended to be light, clear, or yellow in color. Therefore, when subjects described odors present in the white wine colored red, the descriptors were more similar to red wine than to white wine descriptors.

A study by Stevenson and Oaten (2008) explored subjects' ability to discriminate between odors when the samples were colorless, colored appropriately, or colored inappropriately. Six odors were placed into three separate pairs based on appropriate color association: strawberry and cherry odors (red), grass and mint odors (green), and lemon and grapefruit (yellow). An example of an inappropriate pairing would be grass and mint odors colored red. Triangle test methodology was used to determine if the participants could

discriminate between the odors. Results indicated that discrimination between the two odors occurred less frequently when they were inappropriately colored.

A study by Levitan *et al.* (2008) examined how color and people's expectations affected their ability to discriminate flavor in Smarties chocolate candies. Smarties are candies (similar to M&M's) that come in eight different colors, and when produced in the United Kingdom (UK) all colors, except for orange, are plain milk chocolate; the orange colored candy shell has orange flavored chocolate inside. However, Smarties produced for any other market contain milk chocolate inside all colored shells including the orange color (Levitan *et al.* 2008). Participants were asked in a questionnaire about prior knowledge of the Smarties, including their belief that different colored candies had different flavors. Three pairs of UK Smarties (orange color has a different flavor than any other color) were presented to the participants using the following color combinations: green and red, green and orange, and red and orange. For each pair, participants were asked to indicate if the flavor was the same or different. Participants evaluated the pairs sighted and blindfolded. Results of the questionnaire found that 81% believed they were familiar with the candy and over half of the participants believed the orange color had a different flavor. Approximately 35% also felt that there were other colors of Smarties besides orange that had a distinctive flavor.

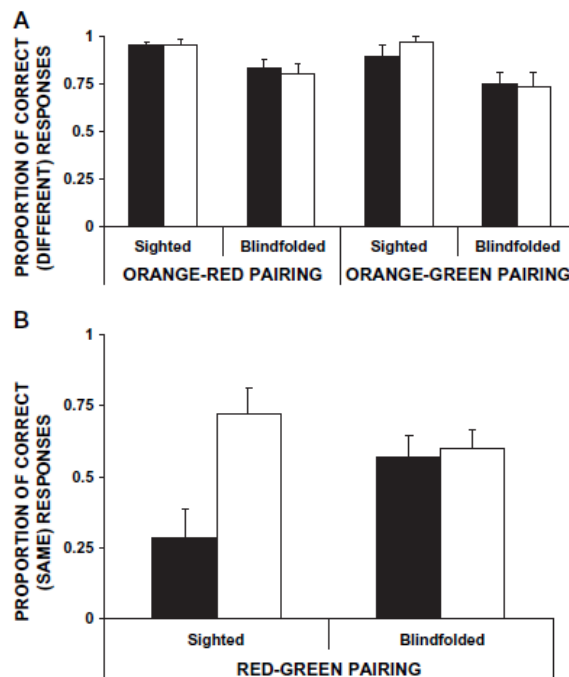


FIG. 1. RESULTS (LEVITAN *ET AL.* 2008) OF A SAME-DIFFERENCE TEST SHOWING PROPORTION OF CORRECT RESPONSES FOR DIFFERENT COLOR PAIRINGS OF SMARTIES CANDIES. IN THE TOP CHART (A), BLACK BARS REPRESENT THOSE WHO BELIEVE ORANGE COLORED SMARTIES HAVE A DISTINCTIVE FLAVOR AND WHITE BARS ARE THOSE WHO DO NOT. IN THE BOTTOM CHART (B), BLACK BARS REPRESENT THOSE WHO BELIEVE NON-ORANGE SMARTIES HAVE A DISTINCTIVE FLAVOR AND WHITE BARS ARE THOSE WHO DO NOT

Results of the same-difference test can be seen in Figure 1. When orange was one color in the pair the correct response was “different”; participants were less likely to identify the pair as different when they were blindfolded than when they were sighted. Whereas, when the pair was red and green, the correct response was “same.” Participants who believed that non-orange colored Smarties had a distinctive taste were less likely to correctly identify the pair as the same when they evaluated the pair sighted compared to the group who believed all non-orange Smarties tasted the same. Overall, participants were better at discriminating between two different flavored samples than being able to label two samples that did not differ in flavor “the same”. Participants, who believed that non-orange colored Smarties had a distinctive taste, were

able to correctly identify the sample as being the same in the red-green pairing more often when they were blindfolded. The authors concluded that food color can be a powerful influence on people's ability to discriminate flavor.

The influence of color on odor identification was studied by both expert panelists and non-expert panelists (Shankar *et al.* 2010 b). The expert panelists in this study were members of a trained descriptive panel who had over three years experience evaluating food and beverages for a major flavor corporation. The non-expert panelists consisted of employees within the same company who worked in non-Research & Development jobs such as human resources, advertising, and sales. At the beginning of the experiment each panelist was shown a lineup of seven colored beverages (i.e., purple, pink, yellow, green, blue, orange, and red) and was asked to identify a beverage color that could only be one flavor in their mind. They were also to indicate what flavor the beverage would be. The two most commonly chosen color/flavor combinations were orange color/orange flavor and purple color/grape flavor. The flavor chosen became the "expected flavor" and the chosen color was the "target color".

The purpose of the test was to determine if the presence of the "target color" would increase the identification of each panelist's "expected flavor." To do this, each panelist was presented with eight different uncolored drinks and asked to identify the odor. Two odorants within the set were included because they had color/odor combinations that could be considered similar to the "target flavor" but were different enough that they would not be confused as the "target flavor". Following this evaluation, the same drinks were presented again, this time the two confusable flavors were colored the target color and again panelists were asked to identify the flavor. The confusable odorants used for the purple color were cranberry and blueberry, while the confusable odorants used for the orange color were grapefruit and lemon. Results of this study showed that non-experts selected their "expected flavor" in the uncolored beverages 9% of the time, but that number rose to 38% when beverages were colored the "target color". Flavor experts also selected the "expected flavor" 9% of the time (when uncolored), but this number rose to 52% when the beverage color was the "target color." In both cases of experts and non-experts the addition of color significantly influenced perception that the "target flavor" was present in the beverage. A comparison between the experts and non-experts' responses illustrated that color had an influence on both groups of panelists equally and that training did not stop the expert panelists from being influenced by color.

Matching Color to Flavor or Odor

Flavor perception can be influenced by the appearance of foods and beverages (Zampini *et al.* 2007), and visual cues provide information to people about the identity of the food or beverage (Shankar *et al.* 2010).

A study by Koch and Koch (2003) was aimed at determining which taste related attributes, characteristic of sodas, were associated with different colors. The eight attributes selected were sweet, sour, bitter, salty, citrusy, syrupy, fruity, and bubbly; and the 10 colors used were red, green, yellow, blue, brown, orange, purple, black, gray, and white. The colors selected were colors common to soft drinks and their packaging. Participants were asked to indicate on a 10-point rating scale association with colors and taste attributes. For example, “on a scale from 1 to 10 with 10 being the most sweet, how sweet is the color red? And on a scale from 1 to 10 with 10 being the most sour, how sour is the color green?” In order to assess if association between color and flavor was positive or negative, scores of 1-3 were considered negative associations and scores of 7-10 were considered positive associations.

TABLE 2.2.

RESULTS OF ASSOCIATIONS BETWEEN COLOR AND TASTE ATTRIBUTES
CHARACTERISTICALLY ASSOCIATED WITH SODA (KOCH AND KOCH 2003)

Sweet	Sour	Bitter	Salty	Citrusy	Syrupy	Fruity	Bubbly
Positive Associations							
Red Orange	Green Yellow		White	Yellow Orange	Brown	Red Yellow Orange	
Negative Associations							
Green Brown Black Gray	Red Blue Brown Purple Black Gray White	Red Blue Gray White	Red Green Yellow Blue Brown Orange Purple Black Gray	Red Blue Brown Purple Black Gray White	Green Blue Black Gray White	Brown Black Gray White	Red Green Brown Black Gray

Based on results from Koch and Koch (2003), shown in Table 2.2 the authors were able to see that attributes of sweet, sour, salty, citrusy, syrupy, and fruity all have colors positively associated with them, while all attributes have colors that were negatively associated with them.

In the case of syrupy the only color positively associated with it was brown, and the same was true with salty and the color white. Both bubbly and bitter attributes were not positively associated with any color. Gray, purple, and blue were the only colors not positively associated with a taste attribute.

Zampini *et al.* (2007) also wanted to determine if certain colors were associated with flavors. In this study participants were presented with solutions that were colorless or colored red, green, orange, yellow, blue, or gray then asked to choose from a list the flavor they felt matched closest to the color. The list included 22 flavors: different fruits, spices, mint, lettuce, yogurt, cream soda, toffee, and flavorless options.

TABLE 2.3.

RESULTS OF ASSOCIATIONS BETWEEN COLOR AND FLAVOR ATTRIBUTES BASED ON COLORED SOLUTIONS (ZAMPINI *ET AL.* 2007)

Color	χ^2	ρ	Associated Flavors
Green	32.33	<0.001 ^a	Lime (69%) > apple (20%), melon (11%)
Orange	82.01	<0.001 ^a	Orange (91%) > aniseed (5%), toffee (4%)
Yellow	120.64	<0.001 ^a	Lemon (89%) > pear (5%), apple (4%), melon (2%)
Blue	67.34	<0.001 ^a	Spearmint (86%) > raspberry (9%), cream soda (5%)
Gray	41.94	<0.001 ^a	Blackcurrant (53%), licorice (40%) > cherry (4%), aniseed (4%)
Red	3.64	0.16	Strawberry (46%), raspberry (27%), cherry (27%)
Colorless	69.85	<0.001 ^a	Flavorless (51%) > cream soda (16%), vanilla (15%), aniseed (15%), spearmint (2%), melon (2%), pear (2%)

Zampini *et al.* (Table 2.3) observed that lime flavor was most often associated (more than 60% of responses) with green color, orange flavor with orange color, lemon flavor with yellow color, and spearmint flavor with blue color. In the case of gray color, both blackcurrant and licorice were flavors that matched, and the same was true of strawberry, raspberry, and cherry for red color.

Understanding how color and flavor associations differ between cultures was studied by Shankar *et al.* in 2010. Participants in the UK and Taiwan were presented with seven colored beverages (red, orange, yellow, green, blue, brown and clear) and asked to write down the flavor.

TABLE 2.4.
RESULTS OF COLOR/FLAVOR ASSOCIATIONS FROM RESPONDENTS IN UK AND
TAIWAN AFTER LOOKING AT COLORED SOLUTIONS (SHANKAR *ET AL.* 2010)

Color	British participants (N=20)	Taiwanese participants (N=15)
Brown	Cola (14), cherry (3), blackcurrant (2)	Grape (6), mulberry (3), cranberry (3)
Blue	Raspberry (8), mint (4), blueberry (3)	Mint (7), cocktail (3)
Yellow	Lemon (11), pineapple (2), grape (2)	Yellow soda (4), white wine (2)
Orange	Orange (13)	Cranberry (2), strawberry (2), apple (2)
Green	Mint (11), lime (4), apple (4)	Mint (5), apple (3), lime (2), kiwi (2)
Clear	Water (16), lemon (2)	Water (14)
Red	Cherry (8), strawberry (4), cranberry (3), raspberry (3)	Cranberry (5), strawberry (2), cherry (2), wine (2)

Adapted from Shankar *et al.*, they found that clear, red, and green colors had consistent flavor expectations between the two sets of participants (Table 2.4). In both groups of participants clear beverages corresponded to water; mint, lime, and apple were associated with green; and cherry, strawberry, and cranberry were associated with red. For other color associations, cultural differences were significant. British associated the color brown with cola flavor while Taiwanese participants thought brown color was grape flavored. Taiwanese participants associated blue with mint, while British participants associated blue with raspberry. The flavor associations for yellow and orange colors also differed between the two groups. Shankar *et al.* concluded that differences in expected flavor may have resulted from different commercial products, as well as fruits and vegetables availability in each market.

Gilbert *et al.* (1996) used a questionnaire developed by Raider and Tellegen (1987) to understand the relationship between odor and color. Using this methodology subjects were presented with a list of 11 color names (red, orange, yellow, green, blue, purple, brown, white, pink, gray, and black) and were allotted five “points.” For each odor, subjects were asked to assign each of the five “points” to five colors that best represented the odor (Gilbert *et al.* 1996). Results showed all 20 test odors had significant color correlations. For some odors only one color had characterization properties, i.e., cinnamic aldehyde and red, or caramel lactone and brown. While for other odors several colors were used for its description. For the odor “civet artificial,” which can be described as an animal odor, the colors of brown, black, white, and gray were used.

Associations of odor and color were studied by Dematte *et al.* (2006) to determine colors associated with specific odors. Respondents were asked to smell an odor and match it to one of 10 colors shown on a computer screen that they felt most closely matched the odor. It was found that brown and yellow colors were associated with caramel aroma; green color with cucumber aroma; green, brown and gray colors with leather aroma; yellow and orange colors with lemon aroma; turquoise color with spearmint aroma; and pink and red colors with strawberry aroma. As seen in similar studies, sometimes odor was best described by only one color, and other times multiple colors can be used to describe odor. Also consistent with other findings were the associations between yellow color and lemon, blue/turquoise color and spearmint, and red color and strawberry.

Österbauer *et al.* (2005) studied the neurophysiological basis for why odors are associated with color. To do this they scanned subjects' brains via functional magnet resonance imaging (fMRI) while presenting the subjects with pairs of odors and colors. Prior to the experiment, subjects were asked to match 10 colors with 17 different odors. In the preliminary study 13 of the 17 odors were only matched to one color. Based on these findings the odor/color pairs considered congruent (lemon-yellow, strawberry-red, spearmint-turquoise, or caramel-brown) were used for the main study. Subjects were asked to rate the odor/color combination on a 4-point rating scale indicating how well the odor and color fit together. The pairs were presented in a random order (sometimes the subject was presented with a congruent pair and sometimes it was not). While the subjects evaluated the pairs their brains were scanned. Results of the pairing task found that congruent combinations of lemon-yellow, spearmint-turquoise, and caramel-brown were congruent and no other color was a better match for that odor. The same trend was found for the red-strawberry combination, although it was not significantly better than yellow-strawberry or brown-strawberry combinations. When the subjects smelled colorless odors, the area in the brain stimulated was the piriform/amygdaloid region, the right orbitofrontal cortex, and left insular cortex. Scanning congruent combinations of color and odors also activated the orbitofrontal and insular cortices, but this combination lead to increased activation strength as the subject found congruency to increase. This was a significant finding because it indicated that color may influence olfactory processing in these two brain regions.

Skrandies and Reuther (2008) did a study to determine the effect of taste, odor, and color on the brain. In this study pairs of words were presented to subjects and they were asked to rate

the pairs on a 7-point scale for appropriateness. The first word in the pair was an odor or taste word, and the second word in the pair was a color or food word. Color words were used in 79 of the 144 pairs used. Using the appropriateness scores the combinations were classified as being appropriate (average scores between 5.5 and 7.0) or inappropriate (average scores between 1.0 and 2.5). Subjects' brains activity was measured via electroencephalogram (EEG) while being presented with either the appropriate or inappropriate word pairs. Global field power (field strength) was measured by the EEG, and results showed that the field strength was significantly higher in appropriate word pairs than in inappropriate word pairs. Field strength was stronger for appropriate pairs containing color words than inappropriate color word pairs this was not observed between appropriate or inappropriate food word pairs. Field strength measurements also were higher for color words paired with taste compared to color words paired with odors. These findings showed that subjects related color more easily to taste than to odor.

Effect of Color on Basic Taste Perception

Evaluating if color and odor have the ability to modify specific taste qualities is important because many people confuse smell and taste sensations (Frank *et al.* 1989). Depending on the taste (sweet, salty, sour, or bitter) or flavoring being examined, certain colors evoke a strong response (Gifford and Clydesdale 1987). A majority of studies published have assessed the relationship between color and sweetness, although color's impact on all basic tastes has also been evaluated.

Maga (1964) conducted a study to determine if color had an impact on basic taste thresholds. In this study solutions with increasing concentrations of sodium chloride (salt), citric acid (sour), caffeine (bitter), and sucrose (sweet) were evaluated colored red, green, yellow, or colorless. To evaluate the samples subjects were told to start the evaluations with the first beaker which only contained water and continue tasting the increasing concentrations of solutions until they could positively identify the basic taste present. The series of evaluations was repeated for each taste and color combination. Results showed coloring the solutions had an impact on sweet, sour, and bitter tastes. In most cases the taste concentration needed to be stronger before the subjects were able to recognize the taste in the colored solutions. For sour taste the lowest threshold occurred in a colorless solution, but when red was added they did not detect the taste until a slightly higher concentration. Although sourness in both yellow and green solutions was

not detected until the concentration was significantly higher. For bitterness a colorless solution allowed for the lowest detection level, and the bitterness of yellow and green solutions were detected only at significantly higher levels than that of clear. Detection of bitterness in red colored solutions was at a concentration level significantly higher than the concentration needed to detect the taste for green, yellow, and colorless solutions. Green coloring allowed sweet to be detected at a concentration significantly lower than that of the colorless, red, and yellow solutions. Additionally, the concentrations of sucrose were significantly increased in the yellow and red solutions before detection occurred when compared to the colorless solution. Color had no impact on the threshold of salt concentrations.

A study by Pangborn (1960) was conducted to understand the effect of color on sweetness perception. In this study assessors were presented with pairs of solutions and were asked to indicate whether the first sample had higher, lower, or the same amount of sweetness and flavor intensity as the second sample. The solutions were combinations of sucrose level (8%, 10%, and 12%), artificial flavorings (apricot, peppermint, and cherry at low and high levels), and different colors (orange, red, and green). To mask the color the solutions were evaluated both in natural daylight and under red lighting (except for green). Pangborn (1960) found that coloring the solutions green did not have an effect on the judges' ability to correctly identify the higher intensity sample among sweetness and peppermint level combinations. She also found that when the differences in sucrose concentrations were small between pairs, sweetness perception was enhanced in orange colored apricot and red colored cherry solutions.

In the same study by Pangborn (1960) judges were asked to evaluate pairs of either aqueous solutions or pear nectars for sweetness. In both solutions and pear nectars, sucrose and food colors (red, green, and yellow, or no color) were added. When uncolored the pear nectars have an opaque white color, therefore after the coloring was added the nectars appeared pastel in color. Results showed that in aqueous solutions colors did not affect the judges' ability to discriminate sweetness. With the pear nectar judges tended to rate the red nectars as sweetest and the green nectars as least sweet. Pangborn hypothesized that this may be due to an association with green to tartness.

Based on the findings that red colored nectars enhanced sweetness while green nectars suppressed sweetness (Pangborn 1960), Pangborn and Hansen (1963) designed a study to understand the effect of color on both sweetness and sourness. In this study, panelists were

asked to indicate which sample was sweeter and which sample was more sour between pairs of pear nectars. The pear nectars were manipulated to have different levels of sucrose and citric acid. The authors found that panelists were able to correctly identify the sweeter sample more often when the pairs were uncolored versus when colored. This was true also for correct identification of the more sour sample. In the first set of pairs panelists discriminated between 5% and 5.2% sucrose, and results indicated that the red colored nectars were perceived as being less sweet. In the second set of pairs the sucrose concentration was held constant with results showing both blue and colorless samples perceived as being less sweet. In the third set of pairs panelists discriminated between 0 and 0.01% acid; results indicated the colorless sample was perceived as being more sour. In the fourth set of pairs acid concentration was held constant, and results showed that red was perceived as being less sour while blue was perceived as being more sour. Sweetness results in this study were not consistent with the previous study where red was seen as more sweet, and green was less sweet (Pangborn 1963). However, it was evident that color does have an effect on perceived sweetness and sourness in pear nectars.

Strugnell (1997) conducted a study to understand color's effect on sweetness where sweet solutions (1% sucrose, 5% sucrose, 1% fructose, 5% fructose, and 5% glucose) were presented to assessors in a set of clear and colored blue, green, red, and yellow; all colors kept the sweetener and level constant. Assessors were asked to rank the solutions based on sweetness. In general Strugnell found there was little pattern to the color ranking. For 5% sucrose solutions, both red and clear solutions were ranked as being sweetest significantly more often than the other colors. For the sweetener solutions and levels blue was rated the least sweet significantly more often than the other colors. Red being observed as sweeter in the sucrose solution was consistent with Pangborn's finding (1960).

Kostyla (1978) studied the effect of color on sweetness and sourness, and the colors of cherry, raspberry, and strawberry flavored beverages were manipulated for each fruit flavor, thus increasing amounts of red (four levels), blue (four levels), green (four levels), and yellow (four levels) coloring were added to the beverages. A total of 16 beverages, for each flavor, were evaluated by the panelists for sweetness and sourness intensity using magnitude estimation methodology. In magnitude estimation methodology panelists were told to taste a reference sample and assign it a number greater than zero. Then one at a time, each test sample was tasted, and they rated its intensity magnitude against the reference. For example, if the sample tasted

three times as sweet as the reference, it would be assigned a number three times as large. The reference chosen for each flavor was the same basic beverage without the additional coloring added (each flavor had a low level of color as part of the base). Kostyla (1978) found that the addition of red color increased the perceived sweetness in all three beverage flavors, and the addition of blue color decreased the perceived sourness in all three beverage flavors. A decrease in perceived sweetness in both cherry and strawberry flavors but not raspberry resulted from the addition of yellow color. There were no consistent correlations between either sweetness or sourness with the addition of green color.

Several studies have found interactions between red coloring and perceived sweetness. Johnson and Clydesdale (1982) researched this further in their study where five different concentrations of sucrose solutions and five different shades of red (selected to resemble cherry) were manipulated. The sweetness intensity, as well as color intensity were rated by the panelists via magnitude estimation. The reference sample chosen for this study contained the middle shade of red and a 4% sucrose concentration, which was the middle sucrose range used (determined to be similar to the sweetness of commercial fruit drinks). As with previous studies, the authors found that color had a significant effect on sweetness. At sucrose concentrations lower than the reference, the two darkest shades were perceived to be sweeter than the reference, as well as the lightest shade. At all sucrose concentrations the darkest red was rated sweeter than the other color shades. Darker red solutions containing 1% less sucrose, than in lighter solutions, were perceived to be higher in sweetness; this indicates beverages could be formulated to be darker in red color with less sucrose and still have the same perceived sweetness.

Another study by Johnson *et al.* (1982) explored the relationship between sweetness and red color, specifically in cherry flavored beverages. The methodology used was similar to the methodology used in Johnson and Clydesdale (1982). The only difference in this study was the colored sweetened solutions contained 1% cherry flavoring. The reference chosen for this experiment was the middle color within the red color range, and the sucrose percent was 4% (middle sweetness range), also chosen to simulate the sweetness in commercial fruit drinks. As in the previous study (Johnson and Clydesdale 1982), panelists rated sweetness using magnitude estimation methodology. The authors found that the addition of cherry suppressed some sweetness perceived by the red color/sugar in the solutions by comparing the slopes of lines (increase in sweetness compared to increase in sugar) between this study to their previous study.

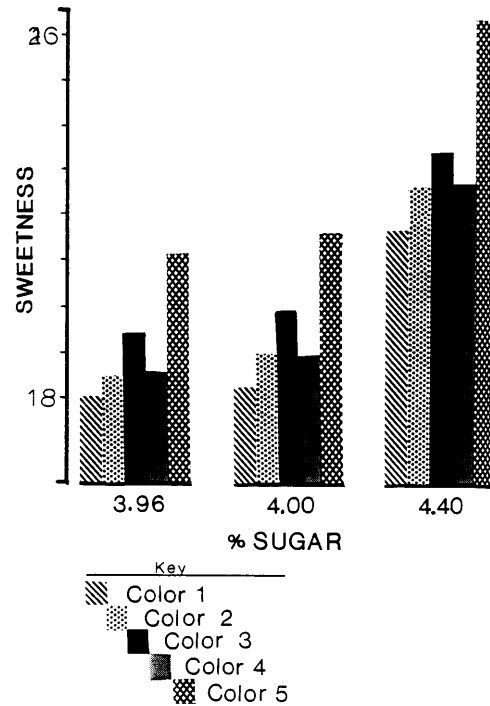


FIG. 2. RESULTS (JOHNSON *ET AL.* 1982) SHOWING THE SWEETNESS FOR CHERRY FLAVORED AND RED COLORED SOLUTIONS AT 3.96%, 4.0% AND 4.4% SUCROSE; COLORS 1-5 INCREASE IN RED INTENSITY FROM LIGHTEST TO DARKEST

Looking at sweetness of cherry flavored red sweetened solutions, the results were consistent with the previous study (Johnson and Clydesdale 1982). As illustrated in Figure 2, the darkest color red was consistently perceived as being sweetest for all sucrose levels. With the exception of color 4 the increase in color intensity resulted in an increase of perceived sweetness. As indicated by Johnson and Clydesdale’s research, there is potential to formulate beverages at lower sucrose concentrations with the same perceived sweetness by increasing color intensity.

The consistency in results between the two studies (Johnson and Clydesdale 1982; Johnson *et al.* 1982) inspired Johnson *et al.* (1983) to research the effect of red color and sweetness in strawberry flavored drinks. As with the previous two studies, levels of red color and sucrose were manipulated in test solutions containing 1% strawberry flavor. The panelists evaluated the sweetness intensity using magnitude estimation, and the reference selected was mid range for both sucrose concentration and redness. Comparing the slopes for perceived sweetness/sucrose concentration between the red strawberry flavored solutions to the unflavored

red solutions from a previous study, the authors concluded that adding the strawberry flavor increased sweetness perceptions. The opposite result was found when adding cherry flavor (Johnson *et al.* 1982). As illustrated in the other two studies, the darker red colors had higher sweetness perception at the same sucrose concentration.

In a study by Johnson (1982), beverages made of 1% raspberry flavor, different sucrose concentrations and levels of raspberry red color (combinations of red and violet) were varied. Magnitude estimation methodology was used for panelists to rate a sample for sweetness; the reference sample chosen was both a color and sweetness level central to the variants being tested. Results of this study indicated that the lightest color consistently received the lowest sweetness scores regardless of sucrose concentration; however there was inconsistency in the results for the other colors. At lower sucrose concentrations color 4 (second to the darkest) was rated low in sweetness, while color 2 (second lightest) was rated sweetest. In higher sucrose concentrations color 4 was rated as sweetest, and color 2 was rated one of the least sweet. The perceived sweetness of raspberry beverages did not increase with the intensity of red color. These results showed there was an interaction with color, flavor, and perceived sweetness; however, it was not consistent with previous findings in cherry and strawberry beverages (Johnson *et al.* 1982; Johnson *et al.* 1983) that found the sweetness to increase with the intensity of the red color.

A study by Frank *et al.* (1989) also researched the effect of red coloring, sweetness, and strawberry flavor. Panelists were instructed to rate the sweetness of solutions on a 21-point scale, where 0 indicated “no sweetness” and 20 indicated “very sweet.” The solutions consisted of combinations of sucrose concentrations, colorless, or red solutions, with or without the addition of a strawberry flavor. Half of the respondents were instructed to sip and spit the solutions before evaluating the sweetness, while the remaining respondents were instructed to swallow the solutions before evaluating sweetness. In both evaluation conditions the solutions with the strawberry odor were perceived as having higher sweetness intensities than the solutions without the strawberry odor at the same sucrose concentrations. This finding was consistent with the findings of Johnson *et al.* (1982). Inconsistent to previous findings, there was no increase in sweetness due to color in both evaluation conditions. The authors had two hypotheses as to why they did not see an increase in sweetness due to color: 1) the red color selected was not dark enough, considering other findings (Johnson and Clydesdale 1982; Johnson *et al.* 1982; Johnson *et al.* 1983) suggested sweetness perception increased with the intensity of red color, or 2) half of

the solutions were not colored, thus allowing panelists to realize the coloring did not necessarily correlate with sweeter solutions. This realization would not have been possible in the previous studies (Johnson and Clydesdale 1982; Johnson *et al.* 1982; Johnson *et al.* 1983) because all solutions tested were colored red.

The effect of green and yellow coloring on sweetness perception in lemon and lime beverages was studied by Roth *et al.* (1988). In this study panelists were instructed to rate the beverages for sweetness using magnitude estimation methodology. For the lemon beverages, the lemon flavor was held constant at 0.04% while concentrations of sucrose and five levels of yellow coloring were manipulated. In the lime beverages the lime flavor was held constant at 0.03% while five levels of green color and sucrose concentrations were manipulated. For both the lemon and lime beverages the reference sample used was middle of the set for both sucrose concentration and color intensity. The addition of color resulted in an increase of sweetness as seen in previous studies (Johnson and Clydesdale 1982; Johnson *et al.* 1982; Johnson *et al.* 1983); however, the rate of sweetness perception increase was much higher for the lemon/yellow beverages than for lime/green beverages and strawberry or cherry/red (Johnson *et al.* 1982; Johnson *et al.* 1983). Results showed also that color had an effect on sweetness for both lemon and lime samples; although, this effect was not linear in regards to color intensity. Analysis of variance (ANOVA) results showed a significant interaction between color and sweetness in both lemon and lime beverages when the sucrose concentration was 4.4%. At that concentration in lemon beverages the darkest and lightest yellow colors were perceived as sweetest, while in lime beverages the lightest and second darkest greens were perceived to be sweetest.

Lavin and Lawless (1998) decided to conduct a study looking at the effect of green and red colors on sweetness with both adults and children based on previous findings (Oram *et al.* 1995; Johnson and Clydesdale 1982; Johnson *et al.* 1982; Johnson *et al.* 1983; Pangborn 1960). In this study (Lawless and Lavin) three groups of children (ages 5-7, 8-10, and 11-14 years old) and adults were asked to rate the sweetness of colored sweetened fruit beverages. The youngest children were asked to select which of the two samples was sweeter while the other three age groups were instructed to rate the sweetness on a 9-point scale that ranged from “not sweet at all” to “very sweet”. All samples had the same sweetness level, and strawberry beverages were colored light or dark red while key lime beverages were colored light or dark green.

TABLE 2.5.
 FREQUENCY COUNTS FOR THE SWEETER SAMPLE BETWEEN DARK AND LIGHT
 RED (STRABERRY) OR GREEN (KEY LIME) BEVERAGES (LAVIN AND LAWLESS
 1998)

Age group	Light red	Dark red	Sign Test	Light green	Dark green	Sign test
5-7	19	18	NS	19	18	NS
8-10	24	24	NS	25	23	NS
11-14	48	30	$p < 0.05$	33	45	NS
Adult	19	50	$p < 0.01$	45	24	$p < 0.05$

NS=not significant; $p > 0.05$.

Results of this study showed that there were no differences between the darker and lighter colors in the perception of sweetness in children ages 5-7 and 8-10 (Table 2.5). In children ages 11-14 the lighter red sample was perceived as sweeter than the darker red sample. Adults seemed to be the most influenced by color, thus rating the darker red sample sweeter than the lighter red sample. However, in the lime beverages the light green sample was found to be sweeter than the dark green sample. Adults found the darker red sample to be sweeter than the lighter red sample staying consistent with previous findings, and if green decreases perceived sweetness then the finding of a lighter green sample being sweeter was also consistent. The authors expected the younger children would find the darker sample to be sweeter, but they appear not to have been influenced by the color change.

Pangborn *et al.* (1963) researched the effects of color on sweetness in dry table wine; to do this dry white table wine was colored yellow, brown, pink, red, and purple to simulate the colors of sauterne, sherry, rosé, claret, and burgundy wines, respectively. Two different levels of sucrose were added also to the colored wines. Two sets of panelists (experienced wine tasters or trained panelists with no wine tasting experience) were presented with pairs of wine and were asked to rate which of the two was sweeter. The authors found the trained panelists were able to correctly identify the sweeter sample more often in the uncolored wines than in the colored wines. The wine tasters correctly identified the sweeter colored wine sample more often than the trained panelists. When the concentration of sucrose was held constant the pink wine was found to be the sweetest, although not significantly different from any other color. These results indicated that color did have an effect on the perceived sweetness in wine.

In a study by Alley and Alley (1998) solutions were colored (red, blue, yellow, green, or uncolored) and were rated for sweetness intensity by junior high students. This study was different from other studies because the effect of color on sweetness was evaluated in both liquid and solid form (gelatin). They rated the sweetness on a 10-point scale from “not at all sweet” “to very sweet”.

TABLE 2.6.

AVERAGE PERCEIVED SWEETNESS RATINGS AND THE MEAN DIFFERENCE BETWEEN LIQUID AND SOLID SAMPLES, BY COLOR (ALLEY AND ALLEY 1998)

Sample Color	Overall	Liquids	Solids	Mean difference (*)
Control (clear)	5.39	7.68	3.10	4.58
Red	5.30	7.68	2.92	4.76
Blue	5.34	7.60	3.08	4.52
Green	5.27	7.36	3.18	4.18
Yellow	5.49	7.72	3.26	4.46

All differences in rated sweetness between solid and liquid samples were significant at a $p < .001$ level.

Alley and Alley (2008) found a significant difference between the perceived sweetness of the liquid and solid samples (Table 2.6). However, they did not find a significant difference among any of the colored or uncolored samples (regardless of physical state). Their findings were consistent with Frank *et al.* (1998).

In a study by Del Castillo *et al.* (2008), color’s effect on sweetness and sourness in lemonades was evaluated. Respondents were asked to rate the sweetness and sourness of each sample on a 7-point scale. Only one solution of lemonade was used for the study, but it was poured into red, yellow, green, and blue opaque cups. Results of this study were consistent with findings by Pangborn (1960), indicating that the red color had the highest sweetness ratings, while green color resulted in the lowest sweetness ratings. Additionally, both blue and green colors were rated more sour than the red and yellow colors. The color blue adding to perceived sourness was consistent with findings by Pangborn and Hansen (1963).

A different approach was taken by Gifford and Clydesdale (1986) when they researched the effect of color on salt perception. Panelists were asked to rate saltiness using magnitude estimation methodology; the reference sample was middle of the sample set for both color and salt concentration. The authors found there was a linear relationship between perceived saltiness and salt concentration for each color evaluated. Although not significant, the lines intersected,

thus indicating that there was some effect of color on saltiness perception; this was consistent with Maga (1974) who found that color did not impact saltiness perception.

Another study by Gifford and Clydesdale (1987) researched the effect of color on salt perception in chicken flavored broths. Similar to their previous study (1986), panelists were asked to rate saltiness using magnitude estimation methodology. The samples used were chicken flavored broths formulated with varying concentrations of salt and intensities of color. As with previous studies the control selected was middle range for both salt concentration and color. It was found that color did not have a significant effect on salt perception, however, the slopes calculated were not parallel indicating that color did have a slight effect on salt perception although not consistent.

Effect of Color on Flavor and Odor Intensity

A central part of a person's experience with beverages and foods is influenced by color because it not only suggests identity but intensity of flavor (Shankar *et al.* 2010 a). These next studies investigate the effect of color on flavor and odor intensity.

Bayarri *et al.* (2001) wanted to understand the impact of color on sweetness and fruit intensity in fruit flavored drinks. Commercial fruit beverages (flavored orange, peach kiwi, and berry) were used for this study. Within each fruit flavor category color was manipulated resulting in four different levels; sweetness was held constant. Panelists rated one set (consisting of four colored beverages) in one flavor category at one time and were asked to rank them for both sweetness intensity and flavor intensity.

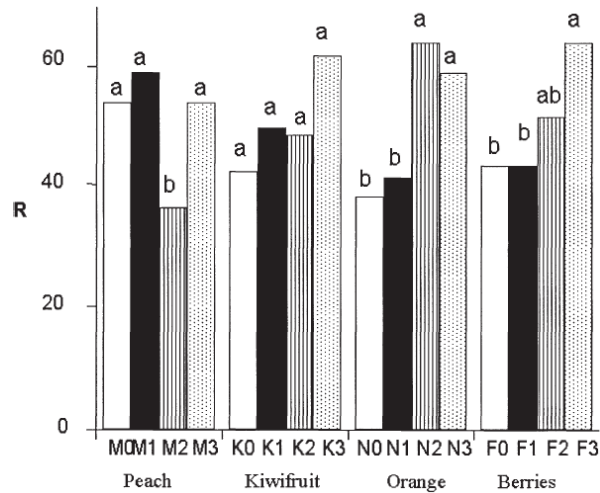


FIG. 3. RANK SUM FOR FRUIT FLAVOR INTENSITY IN PEACH, KIWI, ORANGE, AND BERRY BEVERAGES THAT DIFFER IN COLOR INTENSITY (BAYARRI *ET AL.* 2001)

The authors found different levels of color in the beverages did not change sweetness intensity perceived by panelists. However, there were significant differences in fruit intensity (Figure 3). The authors concluded that color had an impact on the fruit flavor intensity of peach, orange, and berry beverages.

Christensen (1985) studied the effects of color on aroma and flavor intensity using two subject groups: elderly adults (ages 65-85) and young adults (ages 21-40). The foods manipulated in this study were grape jelly and processed cheese. The grape jelly was manipulated to have three color levels (low, medium, and high) and three flavor levels (low, medium, and high); the cheese was manipulated also to have three flavor levels (low, medium, and high) but only two color levels (medium and high). Subjects were presented with pairs of either grape jelly or cheese and asked to indicate which sample had the more intense aroma or flavor. The jelly study's results indicated both elderly and young adults were similar in their ability to discriminate between samples. The pairs were sorted into three situational groups: 1) same [where the same color was presented in the pair]; 2) reinforcing [samples either contained a low flavor/low color combination, or a high flavor/high color combination]; or 3) opposing [samples either contained a high flavor/low color combination, or a low flavor/high color combination]. In pairs where the difference in flavor tested was low versus high, subjects could not correctly identify the sample in the pair as often in the opposing situation compared to the

same or reinforcing situations. There were no significant differences in correct answers for aroma discrimination between flavor levels (medium/high) within the three situations. In the cheese study the young adults were able to correctly identify the more intense flavor in the opposing situation more often than the elderly adults. On the other hand, the elderly adults were able to correctly identify the more intense odor in the opposing situation more often than the young adults. Significant differences among the three situations were not found for the cheese, but there was a trend of less correct answers with the opposing situation. Based on these findings, the author concluded that an increase in color did not correlate to an increase in flavor or odor intensity. However, a trend was observed for situations where flavor strength was inversely related to color strength (opposing situation). In these situations, the number of correct answers decreased.

To further clarify the effect of color on perceived flavor intensity among elderly and young adults, a study was conducted by Chan and Kane-Martinelli (1997). Panelists were asked to rate the intensities of overall flavor, chicken flavor, and saltiness of chicken bouillon (containing three different levels of yellow color). Panelists were asked to rate the overall flavor, chocolate flavor, and sweetness of chocolate pudding containing three different levels of brown color. Color significantly affected the overall flavor intensity ratings of chicken bouillon samples in the young adult population, yet had no effect on the elderly adults' intensity ratings. Color also did not have any effect on any of the intensity measures in the chocolate pudding samples, regardless of age group.

In another study by Christensen (1983), the effect of color on aroma and flavor intensity was studied using five different food products. Soy analogue bacon strips, orange breakfast drink, raspberry gelatin, and margarine were manipulated to be uncolored or in their normally colored form; American cheese was colored normally or bright blue (abnormally colored). Subjects were presented with pairs of the same food in different colors and asked to identify the sample with the stronger aroma or flavor. The weaker sample was assigned a score of 10, and the subjects were instructed to assign a value to the more intense sample as it related to the weaker sample (i.e., if flavor intensity of the stronger sample was three times stronger than the weaker sample the subject would give it a score of 30).

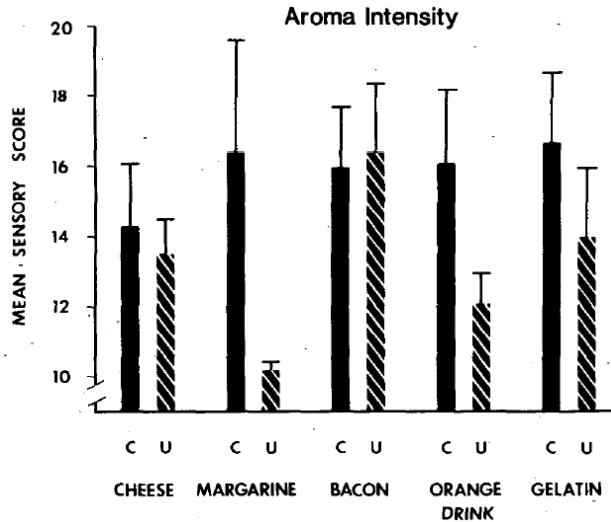


FIG. 4. MEAN SCORES ASSIGNED TO COLORED (C), UNCOLORED OR ABNORMALLY COLORED (U) FOOD BASED ON AROMA INTENSITY (CHRISTENSEN 1983)

As illustrated in Figure 4, for all foods except bacon, the appropriately colored sample was rated higher in aroma intensity. In all foods the flavor intensities were rated slightly higher in the appropriately colored food than the inappropriately food, although the effect was not significant. The author concluded the reason color did not have a greater impact on the bacon samples was due to browning in the preparation which minimized the color differences within the samples.

In a study by Petit *et al.* (2007) the effect of color, flavor, and the oral sensation cooling (makes the mouth feel colder, when the actual temperature does not drop) was investigated. Prior to the study associations among flavors, oral sensations, and colors were evaluated, and the authors found that melon flavor, green color, and cooling were found congruent by 60% of respondents. The combination of pineapple flavor, purple color, and cooling was found incongruent by over 90% of respondents. In this test model beverages were prepared that contained different levels of fruit flavor, color, and cooling compound. The concentration levels for each beverage were determined according to a response surface design (Petit *et al.* 2007). The same levels of ingredients were used to formulate the model beverages, regardless of whether they were part of the congruent or incongruent scenarios. Trained panelists were instructed to rate both the flavor and cooling intensities using a labeled magnitude scale (LMS).

The LMS is represented with a vertical line, and the top anchor is labeled as “strongest imaginable” (Petit *et al.* 2007). Results from the beverages in the congruent scenario did not find an impact on perceived flavor or cooling intensity due to the green color. However, purple color had some impact on flavor intensity in the incongruent scenario. Further analysis found purple in the second lightest shade resulted in the perception of higher pineapple intensity than for any other purple shade. Overall, the authors found little evidence of color’s impact on flavor and cooling regardless of congruency among the components.

The influence of color and label information on flavor perception was studied by Shankar *et al.* (2009). Participants were presented with two brown and two green M&M’s and were instructed to rate the chocolate flavor intensity of each candy on a 7-point scale, with 1 indicating “not very chocolaty” and 7 indicating “very chocolaty”. To understand the effect of label four randomly colored M&M’s were presented to participants, one at a time. As they were presented with the candy they were told either that it was milk or dark chocolate. To evaluate the effect of color and label, participants were given two green and two brown M&M’s one at a time. As they were presented with the candy they were told either that the candy was milk or dark chocolate (Green/Milk Chocolate, Brown/Milk Chocolate, Green/Dark Chocolate, Brown/Dark Chocolate).

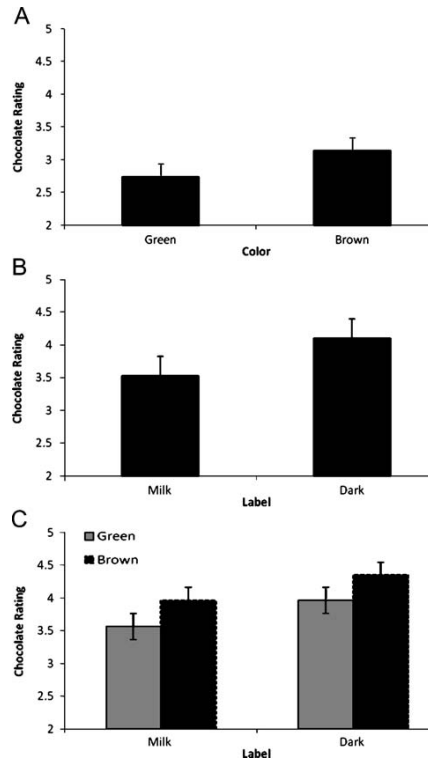


FIG. 5. MEAN CHOCOLATE INTENSITY RATINGS FOR CHOCOLATYNESS OF M&M'S UNDER TESTING CONDITIONS OF COLOR, LABEL, AND BOTH COLOR AND LABEL (SHANKAR *ET AL.* 2009); CONDITION A-COLOR ONLY (GREEN VS. BROWN), CONDITION B-LABEL ONLY (MILK VS. DARK CHOCOLATE), CONDITION C-BOTH COLOR AND LABEL (GREEN, BROWN, MILK CHOCOLATE, AND DARK CHOCOLATE)

Color was found to have an effect on chocolate flavor intensity (Figure 5). Brown M&M's were found to be significantly more chocolaty than green M&M's. Label was also found to influence perception of chocolate flavor intensity and M&M's designated as "dark chocolate" were found to be more chocolaty than M&M's labeled "milk chocolate." In the color/label condition both label and color were found to have effects on chocolate flavor intensity; however, ANOVA calculations indicated that there was not an interaction between the two.

In a study by Zellner and Kautz (1990) the effect of color on perceived odor intensity was researched. The first of three experiments was designed to illustrate if perceived intensity of odors can be enhanced by the presence of colors that have been shown to be associated with that

odor. To do this, subjects were asked to rate the odor intensity of solutions using a 100 point scale, where 0 indicated “no odor,” 50 indicated “moderate odor,” and 100 indicated “the strongest odor imaginable.” The solutions were presented in sets of four: 1) colorless and odorless (N); 2) colorless with odor (O); 3) colored and odorless (C); and 4) colored with odor (OC). Within each set the odor and color were correlated (Figure 6): strawberry was colored red, mint was colored green, lemon was colored yellow, and orange was colored orange.

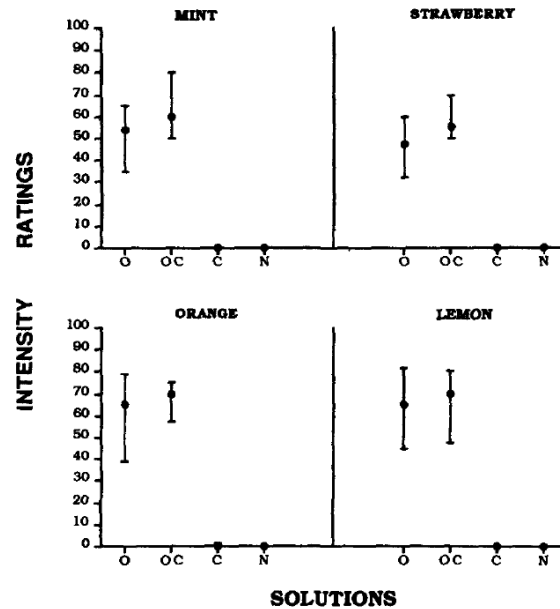


FIG. 6. RESULTS SHOWING MEAN ODOR INTENSITY RATINGS OF OC (ODOR PLUS COLOR), O (ODOR, NO COLOR), C (ODORLESS WITH COLOR), AND N (NO ODOR OR COLOR) SOLUTIONS SCENTED MINT, STRAWBERRY, ORANGE, AND LEMON (ZELLNER AND KAUTZ 1990)

For both the strawberry and mint odors the addition of color significantly increased the perceived intensity of the odor. Color did not enhance the odor intensity in orange or lemon odorants.

In the second experiment the authors investigated whether the color increased odor intensity ratings were due to a response bias (when a subject answer questions the way they think the questioner wants them to answer) or a true perceptual change. To do this, subjects were asked to smell a reference sample of strawberry odor (half of the respondents were shown a clear sample and the other half were shown a colored red sample). Respondents were then presented with several other samples of strawberry odorant at different concentrations (including one with

the same level as the reference) and asked to indicate if each test sample's odor was stronger or weaker than the reference. If a respondent was presented with a colorless reference, then all test samples were colored red or vice versa. Comparison of the reference with the test sample at the same odor concentration showed the colored sample's odor to be significantly stronger than those of the colorless sample. This finding supports the hypothesis that color enhancing odor intensity ratings was caused by a perceptual change and not a response bias.

In the third experiment the authors investigated if an enhanced odor intensity with the addition of color only occurs when the color used was appropriate to that odor. Thus, subjects were asked to rate the intensity of odorants on a 100-point scale (described in the first experiment) (Zellner and Kautz 1990). The solutions presented were in sets of six: 1) color with an appropriate odor; 2) color with an inappropriate odor; 3) colorless with odor; 4) appropriately colored and odorless; 5) inappropriately colored and odorless; and 6) colorless and odorless. As in the first experiment (Zellner and Kautz 1990), the appropriate color/odor combinations were: strawberry colored red, mint colored green, and lemon colored yellow. Any other combination of odor/color was considered inappropriate. The authors found of all three odor types color with inappropriate odor samples had significantly higher intensity ratings when compared to the odor sample that was colorless. In both colored mint and lemon solutions, the appropriately colored solutions had higher intensity ratings compared to the odor sample that was colorless. No significant differences were found between the samples that had color with an appropriate odor versus those with color and an inappropriate odor. These results indicated that color enhances the perceived intensity of odors.

To further clarify the effect of color on odor intensity, Zellner and Whitten (1999) conducted a series of experiments. In the first of three experiments, panelists were asked to rate the odor intensity of solutions containing either strawberry or mint odors that were either uncolored or colored with three different intensities: light, medium, or dark. If the strawberry odor was colored, it was always red, and similarly, the colored mint odor was always green. Panelists rated the odor intensities with the same 100-point scale describe in Zellner and Kautz (1990). In the second experiment panelists were presented with glass jars containing either a clear solution or a solution with the same color levels as the first experiment. They were then asked to judge how likely each color would be to contain the odor based on sight alone.

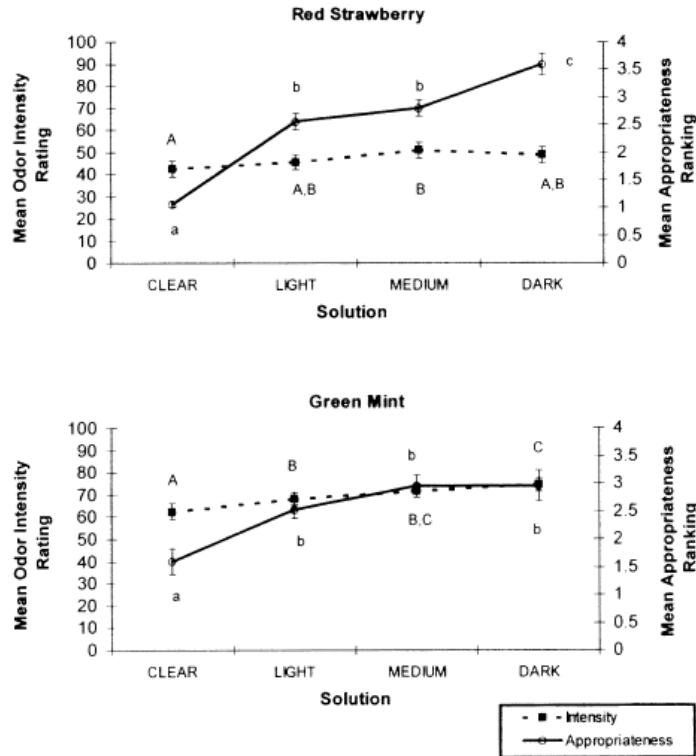


FIG. 7. MEAN ODOR INTENSITY RATINGS AND MEAN APPROPRIATENESS RANKING FOR RED STRAWBERRY ODOR SOLUTIONS AND GREEN MINT ODOR SOLUTIONS (ZELLNER AND WHITTEN 1999)

Results for both the first and second experiments are illustrated in Figure 7. With red color and strawberry odor the strawberry aroma was perceived to be higher in the medium red solutions compared to the clear solution. Looking at the appropriateness of different colors to strawberry flavor, all red colors were found to be more appropriate than the clear solution with dark red being the most appropriate. In the case of green color and mint odor all three green colors were perceived to have higher odor intensities and be more appropriate to the mint odor. Additionally, the darkest green color was perceived to have the strongest odor intensity.

In the third experiment the effect of color on odor enhancement and color appropriateness was studied. In this study, two odorants were chosen because each odor could be colored appropriately with two different colors. The odor methylsalicylate is the characteristic odor in wintergreen (appropriately colored green) and root beer (appropriately colored brown). The same is true for benzaldehyde, one of the characteristic odors in almond (brown) and cherry (red). For each odorant/color combination a set of eight samples was presented to panelists consisting of:

clear with odor, clear and odorless, light colored with odor, light colored without odor, medium color with odor, medium color without odor, dark color with odor, and dark color without odor. The odor was identified to the subjects, wintergreen or root beer (methylsalicylate) or almond or cherry (benzaldehyde), before they evaluated the aroma of any the solutions to influence which color they found to be appropriate to the odor. Subjects were asked to rate odor intensity on a 100-point scale and rank the colors for flavor appropriateness using the same methodology as reported in the first two experiments (Zellner and Whitten 1999).

In all four odor situations color had a significant effect on odor intensities. For green-wintergreen, green-root beer, brown-wintergreen, and brown-root beer, a similar pattern in regards to odor intensities emerged; whereas, medium and dark colors resulted in higher aroma intensities than in the light color and clear. This indicates that labels did not have an effect on aroma intensity, however, label did have an effect on color appropriateness (e.g., in green-wintergreen and brown-root beer all color levels were more appropriate than the clear, but in brown-wintergreen and green-root beer the appropriateness decreases as the color darkened). In the benzaldehyde experiment subjects rated the red-odor intensities of those labeled almond higher than those labeled cherry.

Color significantly affected the odor intensity ratings in all four scenarios (brown-almond, red-almond, brown-cherry, and red-cherry), but the results were not consistent. Although, for all color/odor combinations the clear sample was rated as having the lowest, or one of the lowest, odor intensities. For brown-almond the medium color was found to have the highest intensity ratings. For red-almond all three colors had higher intensity ratings than the clear sample. For brown-cherry both light and medium colors were rated as having more aroma than the clear. For red-cherry the darkest sample was perceived as having more aroma than the clear sample. As seen with the methylsalicylate study, the effect of label on appropriateness was significant. All colors were seen as more appropriate than clear in the appropriate color/odor pairing, while the darkest color was one of the least appropriate colors when the pairing was inappropriate. Consistent throughout the study was that odor containing colored solutions was perceived as having higher odor intensities than the odor containing uncolored solutions.

In a study by Kemp and Gilbert (1997) the effect of odor intensity on color matching was evaluated. Five odors were selected based on results of Gilbert *et al.* (1996) indicating those odors were strongly correlated to specific colors. The concentration of each odorant was varied

(high, medium, and low level). Subjects were asked to smell each odorant and select a color chip from the 1,487 chips found in the Munsell Book of Color that best matches the aroma; next subjects were asked to rate the odor intensity on a line scale that had “no odor” anchored on the left and “strong odor” on the right (Kemp and Gilbert 1997). The authors found that the odor intensity increased with the increase in odor concentration for four of the five odorants. Additionally, within each odorant group there was a correlation between intensity and color; this indicated that weaker odors were linked to lighter colors, and stronger odors were linked to darker colors.

In a study by Koza *et al.* (2005) the effect of color on odor intensity was investigated both orthonasally (smelled) and retronasally (tasted). Subjects either smelled or tasted solutions and rated them for fruit odor intensity or fruitiness intensity on a 101-point scale, where 0 indicated “no fruitiness,” 50 indicated “moderately fruity,” and 100 indicated the “most intense fruitiness imaginable” (Koza *et al.* 2005). The solutions were presented to subjects in sets of 4 that consisted of: 1) odor and color (OC); 2) odor and colorless (O); 3) odorless with color (C); and 4) odorless and colorless (N). Each set was repeated twice (in the first set subjects were allowed to see the solutions and in the second set they were blindfolded). A “B” was placed before each of the second set of samples to indicate the blindfolded condition (Figure 8).

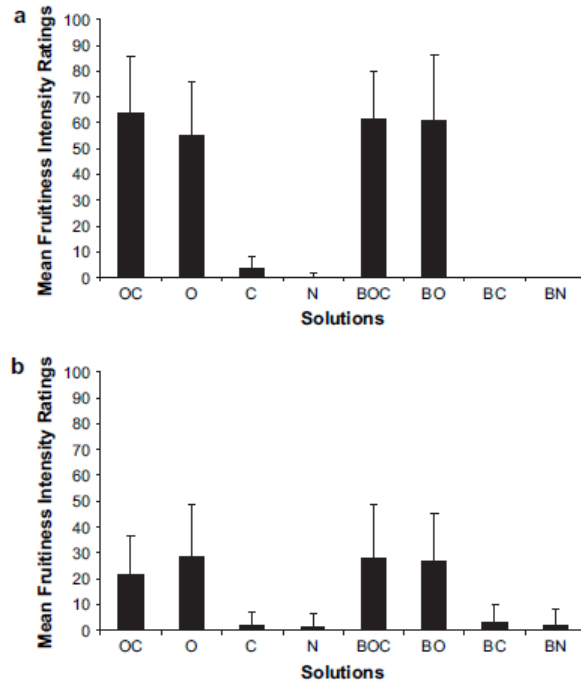


FIG. 8. MEAN ORTHONASAL (PART A) AND MEAN RETRONASAL (PART B) FRUITINESS INTENSITY SCORES BASED ON FRUIT FLAVORED SOLUTIONS (KOZA *ET AL.* 2005)

When the solutions were evaluated (orthonasally), the solution that contained color and odor (OC) was found to be significantly fruitier than the solution that contained odor but no color (O). The solution that was colored without any odor (C) also had higher fruitiness intensities compared to the solution that was odorless and colorless (N). When blindfolded the two solutions with odor were found to be fruitier than the solutions without odor. When the solutions were tasted (retronasally) the colored solution containing odor (OC) was found to be less fruity than the odorous solution that was uncolored (O). The effect of color was not seen in the solutions that did not contain odor (C and N) or in the blindfolded samples. The conclusions were color increased odor intensities when smelled, however, when tasted color reduced the flavor intensity ratings. These findings were consistent with findings from Christensen (1983) who found that color enhanced both the odor and taste of foods, although, only the odor results were significant.

A study by Kappes *et al.* (2006) was conducted to see the effect of color on the attribute ratings from a trained panel. They were looking to see if color causes any halo, horn, or halo-

attribute dumping effects. Halo effects occur when an attribute is rated more positively/higher than normal due to logically unrelated attributes in a product. Conversely, a horn effect occurs when the attribute is rated less positive/lower. In addition to halo/horn effects, halo-attribute dumping occurs when panelists were only asked to rate one group of attributes versus all the attributes associated with the product and in turn rate the single group of attributes higher (Kappes *et al.* 2006). In this study six carbonated beverages (both clear and brown in color) were evaluated with three treatments: 1) as is; 2) mixed but with no color added; and 3) mixed with caramel color added. For all products and treatments trained panelists were asked to rate mouthfeel, aroma, aroma-by-mouth, taste, and aftertaste attributes. All differences noted by the panelists could be attributed to halo/horn effects because there were no significant differences in physical property measurements.

Halo effects were observed several times in this study (e.g., when only the mouthfeel attributes were measured the intensity ratings for body and mouthcoating were significantly increased with the addition of caramel color). The addition of color resulted in an increase in vanilla and caramel aroma when all product attributes were measured. Additionally, horn effects were also observed. Adding color resulted in a significant decrease in the intensities of bite, burn, numbing, and carbonation when only the mouthfeel attributes were measured. When all the product attributes were measured a decrease in citrus aroma and aroma-by-mouth was seen with the addition of color. Halo-attribute dumping could also be seen when the mouthfeel intensities for bite, burn, numbing, and astringent were significantly higher than when they were evaluated alone compared to when they were evaluated with all the other attributes (Kappes *et al.* 2006).

Effect of Color on Quality, Freshness, Thirst Quenching, and Refreshment

Color can be a major factor affecting a consumer's perception of quality (Francis 1995). Specifically, a consumer's first impression of product begins with its appearance. Color makes up a portion of appearance along with size, shape, and texture. Francis (1995) points out that if a consumer finds the color to be unacceptable, flavor and texture (other factors in determining quality) may never be evaluated. Color can be directly linked to quality for certain food products. Both home gardeners and the tomato products industry have found a correlation between mature tomatoes and superior flavor, but it is hard to measure maturity. In tomatoes,

flavor and color develop simultaneously, thus darker tomatoes are seen as being of higher quality than lighter tomatoes. Orange juice is another food product in which the quality is related to the color. Within the juice industry certain orange varieties such as Valencia are preferred, and these varieties produce deep orange colored juices. It is believed that most consumers have an association with darker orange colored juices being of higher quality (Francis 1995).

A study by Schutz (1954) was conducted to understand the effect of color on preference and quality. In the first part of this study subjects were asked to look at two different orange juice samples (one was a juice from frozen concentrate, yellow in color, and the other was not from frozen concentrate and looked orange) and indicate which color they prefer for orange juice. Results indicated that the orange colored juice was preferred significantly. In the second part of Schutz's experiment (1954) subjects were asked to taste two different orange juice samples (one juice was the same yellow colored frozen from concentrate sample as in part one; the second was the same frozen from concentrate with added food color to make it look orange) and asked to indicate liking for each sample on the traditional 9-point hedonic scale, which ranges from "like extremely" to "dislike extremely." Results showed that the juice's color did not impact scores (i.e., the two juices were not different in liking).

In the third part of the experiment subjects were asked to rate their liking for three orange juice samples using the hedonic scale. Half of the subjects in this study were presented with the yellow colored frozen concentrate sample, followed by two orange colored non-frozen concentrate samples that were found to be inferior in quality in previous studies. The other half of the subjects received the same three samples in the same order, only the frozen concentrate sample was colored to be the same color as the non-frozen concentrate samples.

TABLE 2.7.
RESULTS (SCHUTZ 1954) HIGHLIGHTING THE EFFECT OF COLOR ON LIKING AND
QUALITY OF ORANGE JUICE

	Condition 1, N=20			Condition 2, N=20		
	<i>Color</i>	<i>Quality</i>	<i>Mean Rating</i>	<i>Color</i>	<i>Quality</i>	<i>Mean Rating</i>
First sample	Yellow	Good	7.35	Orange	Good	7.35
Second sample	Orange	Poor	5.35	Orange	Poor	6.10
Third sample	Orange	Poor	5.70	Orange	Poor	6.05
Average 2 nd & 3 rd			5.52			6.08
Difference between averages			0.56			
Significance of difference	Trend only—approximately 20% level					

Mean ratings for both the good quality samples (frozen concentrate) were not different from each other regardless of color (Table 2.7). This finding was consistent with the results from part two of Schutz’s (1954) study. There was a trend for the juices of inferior quality to receive higher liking ratings when they were presented by the orange colored good quality juice as opposed to the good quality juice colored yellow. The author concluded that color does have an impact on preference based on appearance, however, when the juices were tasted color was not the driving factor in determining ratings.

As Francis (1995) illustrated that color is a factor consumers use to determine quality, Fenko *et al.* (2009) wanted to determine if color is a factor in the perception of freshness as well. Freshness was chosen to be an attribute of interest in beverages because it has been linked with thirst-quenching and refreshing attributes (Fenko *et al.* 2009). A pre-study found that smells associated with soft drinks were peppermint and bergamot lemon, and smells not associated with freshness were patchouli, almond, and rose. Colors associated with freshness in soft drinks were clear and light green, and those not associated with freshness were dark brown or dark green. Because of the pre-study the soft drinks used were formulated with rose or peppermint aromas, as well as light green and dark green colors and manipulated to fit four main conditions: 1) fresh color and fresh smell (C_FS_F); 2) fresh color and non-fresh smell (C_FS_{NF}); 3) non-fresh color and fresh smell (C_{NF}S_F); and 4) non-fresh color and non-fresh smell (C_{NF}S_{NF}). Participants were asked to rate each of the beverages for freshness on a 9-point scale ranging from “not at all” to “very.”

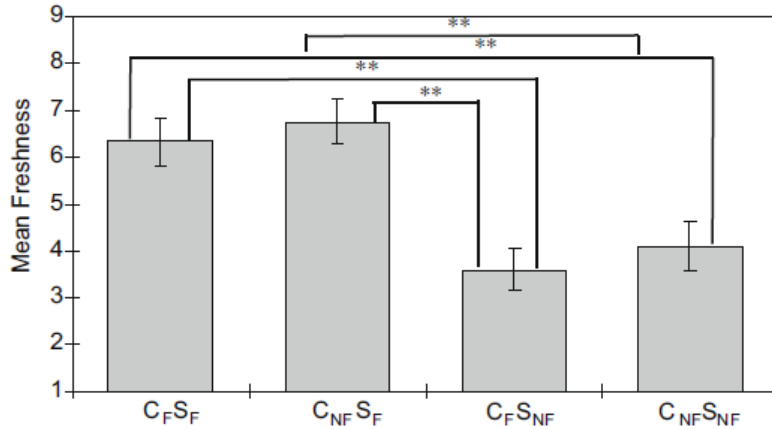


FIG 9. MEAN FRESHNESS RATINGS FOR SOFT DRINKS CONTAINING DIFFERENT COMBINATIONS OF ODORANT AND COLOR (FENKO *ET AL.* 2008)

**** indicates a significant difference at 0.01 level**

Results of the experiment are shown in Figure 9. The authors found that a beverage consisting of a fresh color and odor received higher freshness scores than a beverage which did not have a fresh color and odor. Keeping the color consistent (regardless of being perceived as fresh or unfresh) and changing the odor from fresh to not fresh resulted in significantly lower freshness scores. Keeping the odor consistent (regardless of being perceived as fresh or unfresh) and changing the color from fresh to not fresh did not result in a difference in freshness scores. The data indicated that freshness in soft drinks was driven by odor and not color.

Clydesdale *et al.* (1992) designed a study to clarify color's impact on quenching thirst in fruit-punch flavored beverages. Results of a preliminary questionnaire indicated that sweetness along with brown, clear, orange, and red colors were expected to be the most thirst quenching. Based on these results, Clydesdale *et al.* (1997) created a full factorial design manipulating acid levels, sugar levels, and red color levels in a fruit punch base. Panelists rated the beverages ability to quench thirst on a 7-point scale from "least" to "most". Results from this initial design found that low levels of both acid and sugar were found to be more thirst quenching than higher levels of acid or sugar alone. Additionally, the lower level of color and sugar was found to quench thirst the most. After reformulating color based on several panels, three separate consumer studies were conducted. In the consumer studies acid and sugar levels were kept constant and only color level differed in the samples shown.

The three consumer studies conducted by Clydesdale *et al.* (1992) yielded different results in regards to quenching thirst. In the first test (n=59) the reddest sample was found to be the most thirst quenching; in the second test (n=121) color did not have a significant effect on the ability to quench thirst; and in the third test (n=100) a yellow-orange sample was found to be the most thirst quenching. An effect of color on thirst quenching was not seen when the data from all three consumer tests were combined. Although not significant, the authors found a correlation between color and thirst quenching in two of three consumer studies.

A study by Zellner and Durlach (2002) was designed to explore color's role in refreshing foods and beverages. In their study respondents were presented with a questionnaire asking their opinion about food and beverages in respect to being refreshing (Table 2.8).

TABLE 2.8.

QUESTIONNAIRE USED TO UNDERSTAND RESPONDENTS' OPINIONS ABOUT REFRESHING FOODS AND BEVERAGES (ZELLNER & DURLACH 2002)

1. List ten foods or beverages you find refreshing.
2. List ten sensory characteristics of refreshing foods or beverages.
3. Would a refreshing food or beverage be more likely to be certain colors and not be other colors? (Answer yes or no)
4. What color(s) would a refreshing food or beverage be likely to be?
5. What color(s) would a refreshing food or beverage not be likely to be?
6. List at least five flavors you find refreshing and five flavors you do not find refreshing.

The authors found that color (question 2, Table 2.8) was a characteristic of refreshing foods and beverages by only 24% of respondents, however, 77% responded “yes” to question 3 (Table 2.8) indicating that a refreshing food or beverage was more likely to be certain colors. Colors associated with refreshing foods and beverages were clear, red, orange, yellow, and white. Colors that were not associated with refreshing foods include black, brown, green, gray, and purple. Results of this study were consistent with Clydesdale *et al.* (1992) who found that brown, clear, orange, and red colors were expected to be the most thirst quenching. The only inconsistency was found with brown color. Clydesdale *et al.* (1992) hypothesized that brown was considered refreshing due to its association with colas. Further investigation by Zellner and Durlach (2002) showed that those who listed a brown food to be refreshing (usually listed it as ice tea or cola) also listed brown as being a refreshing color.

In another study by Zellner and Durlach (2003) the effect of color on refreshment was studied based on expectations, and after tasting products. In this study subjects were split into two groups: the expectation group and the taste group. Regardless of which group a subject was placed in, they were all presented with 18 solutions that differed in color and were flavored with lemon, mint or vanilla flavoring. Subjects were asked to rate how refreshing each solution was on a 100-point scale where 0 indicated “not refreshing,” 50 indicated “moderately refreshing,” and 100 indicated “the most refreshing beverage imaginable.” Subjects in the expectation group based their ratings on appearance only while subjects in the taste group were instructed to taste the solution prior to rating. The flavor of the solution was identified to the subjects.

TABLE 2.9.

MEAN REFRESHMENT RATINGS FOR FLAVOR/COLOR COMBINATIONS AMONG SUBJECTS WHO ONLY LOOKED AT THE BEVERAGES (EXPECTATIONS GROUP) (ZELLNER AND DURLACH 2003)

	Clear	Brown	Red	Orange	Yellow	Green	Blue	Purple
Lemon	75.23	21.93	51.79	52.23	50.20	38.80	34.68	39.80
Mint	72.95	18.38	51.91	55.63	43.57	59.66	47.79	49.14
Vanilla	71.21	37.45	55.09	52.95	47.91	35.23	36.70	41.68

TABLE 2.10

MEAN REFRESHMENT RATINGS FOR FLAVOR/COLOR COMBINATIONS AMONG SUBJECTS WHO TASTED THE BEVERAGES (TASTE GROUP) (ZELLNER AND DURLACH 2003)

	Clear	Brown	Red	Orange	Yellow	Green	Blue	Purple
Lemon	40.63	26.66	35.22	35.27	39.48	38.75	38.31	40.88
Mint	40.27	29.97	27.58	39.80	37.89	39.98	38.59	38.98
Vanilla	42.91	40.50	36.97	42.94	39.50	41.73	41.75	42.20

Mean refreshment ratings for the expectation group are shown in Table 2.9. When subjects were told the solution was lemon, the clear solution was expected to be the more refreshing than every other color except for orange. Lemon solutions colored brown were expected to be the least refreshing, and blue lemon solutions were expected to be less refreshing than orange colored lemon solutions. Similar results were seen with the mint solutions where clear was expected to be the most refreshing and brown the least. Green colored mint solutions

were expected to be more refreshing than yellow mint. As with the previous two flavors, clear vanilla was expected to be the most refreshing; scores were significantly higher for all colors except red. Unlike other flavors, brown vanilla refreshing ratings were at par with every colored solution. Mean refreshment ratings for the taste groups are shown in Table 2.10. After tasting the beverages, subjects felt that lemon solutions colored brown were less refreshing than lemon solutions that were uncolored, purple, or yellow. With the mint flavored solutions, orange colored mint beverages were found to be more refreshing than brown mint. Additionally, all colors (except brown) were rated as being more refreshing than the red mint solution. For vanilla flavored solutions all colors delivered the same amount of refreshment. Color was a significant factor in both expected and perceived refreshment. Although the refreshment ratings differed between the expectations and taste groups, clear was usually rated as being the most refreshing and brown was the least. These results were consistent with Zellner and Durlach (2002) who found clear to be associated with refreshment while brown was not.

Effect of Color on Consumer Acceptance

Two primary factors that have the capacity to influence food acceptability include color and flavor (Maga 1974). Additionally, if the color of a product does not meet consumer expectations they may react negatively to it (Tepper 1992). Because of this perception understanding the effect of color on consumer acceptance is critical for industry. The following studies focus on color's effect on consumer acceptance.

A study by Walsh *et al.* (1989) sought to determine the effect of color on candy choice in children. The candies selected for the study were M&M's, Skittles, and a store brand of chocolate candy. These candies were selected because all three types had similar shape, size, and colors. Both the M&M's and store brand chocolate candy have colorful shells that are filled with a chocolate center, whereas, Skittles have colorful shells that are indicative of the candy's flavor. The authors selected only green, yellow, orange and red candies because they determined these colors were associated normally with food products (Walsh *et al.* 1989; Birren 1956). A total of 120 children were surveyed, consisting of two ages (5 and 9 years old) with an equal split between boys and girls. To determine the effect of color and candy choice each child was presented with 12 separate plates (each containing one type of candy in the same color) then

asked to choose which plate they wanted most. That plate was taken away; the process was repeated until only one plate was left.

TABLE 2.11.

RESULTS SHOWING CHILDREN’S PREFERENCE FOR COLOR BROKEN DOWN BY CANDY TYPE AND DEMOGRAPHICS (WALSH *ET AL.* 1989)

Choice	Skittles		M&Ms		Private Label	
	Color	%	Color	%	Color	%
5 year olds						
1 st	Red	40	Green	40	Green	33
2 nd	Green	23	Red	33	Red	27
3 rd	Orange	18	Orange	13	Orange	27
4 th	Yellow	18	Yellow	13	Yellow	13
9 year olds						
1 st	Red	42	Green	32	Red	37
2 nd	Green	30	Red	27	Green	25
3 rd	Orange	15	Orange	22	Orange	20
4 th	Yellow	13	Yellow	50	Yellow	18
Boys						
1 st	Red	33	Green	33	Green	33
2 nd	Green	30	Red	27	Red	28
3 rd	Orange	22	Orange	23	Orange	25
4 th	Yellow	15	Yellow	17	Yellow	13
Girls						
1 st	Red	48	Green	38	Red	30
2 nd	Green	23	Red	33	Green	30
3 rd	Yellow	17	Yellow	17	Orange	20
4 th	Orange	12	Orange	12	Yellow	18

The authors found that the color choices of the children were not influenced by age, sex, or candy type (Table 2.11), because the preferred color choices were fairly consistent. Red and green colors were selected as top choices more often than orange and yellow. When children were probed as to why they chose the color they did, almost half of them were not able to give a reason. “I liked the color” or “It is my favorite color” was the reason given by 37% of children. Only 15% of the responses were related to the flavor expectations of the candy, and typically occurred only for Skittles. The authors concluded that children’s color preference among the candies was correlated to their color preferences in non-food items.

The influence of color on liking, appropriateness, distinctive flavor, and sweetness/sourness was evaluated by Norton and Johnson (1987). In this study four flavors of

yogurt (banana, lemon, raspberry, or strawberry) were each colored with increasing amounts of food coloring, thus for each flavor there was an uncolored, light, medium, and dark level. Banana and lemon flavors were colored shades of yellow, while raspberry and strawberry flavors were colored shades of red. Eighteen subjects were asked to rate each yogurt on a 7-point scale for: liking/disliking, appropriateness/inappropriateness of color, sweetness/sourness, and distinctive/indistinctive flavor. Results of this study indicated that color level significantly influenced the appropriateness of color ratings. Both the uncolored and high color levels were found to be less appropriate than both low and medium color levels (when the appropriateness scores for all four flavors were averaged together). There was also an interaction between flavor and color that significantly impacted ratings for sweetness/sourness. Color did not have a significant effect on liking.

Tuorila-Ollikainen (1982) designed a study to understand the effect of color on pleasantness of appearance, and how consumers' attitude to artificial colors impacts their ratings. Two hundred thirty two subjects were presented with two samples of soda at the same time in which one sample was clear and the other was colored pink. The subjects were asked to rate both samples for pleasantness of appearance on a 5-point scale where 1 indicated "very unpleasant" and 5 indicated "very pleasant." Half of the subjects were told the sodas were strawberry flavored while the other half received no information about the samples. One month later all subjects filled out a survey (in their homes) designed to understand their attitudes towards artificial colors in foods. Results indicated that the colorless sample received higher pleasantness ratings in the group that was not given any information about the samples. Whereas, when the subjects were told the beverages were strawberry flavored, the colored sample received higher pleasant ratings. Results of the survey on artificial colors classified the subjects into three categories: 1) positive towards artificial colors, 24%; 2) neutral towards artificial colors, 37%; and 3) negative towards artificial colors, 39%. The author found a significant correlation between the subjects' pleasantness ratings and their attitudes towards artificial colors. Subjects who were classified as being either positive or neutral towards artificial colors rated the colored sample higher than those who were negative towards artificial colors.

In a follow up study, Tuorila-Ollikainen *et al.* (1984) sought to determine how color, fruit flavor, and sweetness impact overall liking in fruit flavored sodas. A total of 448 subjects

participated in the study, 50% were college students (average age 20 years) and 50% were school children (average age 11 years). Two fruit flavored sodas (pear and raspberry) were used in this test, and the subjects (divided equally among young adults and children) only evaluated samples within one flavor camp. Within each flavor levels of sucrose, color, and fruit flavor were manipulated and each subject evaluated four of eight possible samples. Subjects rated each soda for pleasantness of appearance, odor, taste and sweetness, and overall liking on a 10-point scale, anchored on each end.

Following the sample evaluation, subjects were also asked to rate each attribute (appearance, odor, taste, and sweetness) using a 4-point scale where 1 indicated “indifferent” and 4 indicated “extremely important” to assess if any of the attributes had an impact on their overall liking scores. Authors found that both age groups agreed on the two highest rated samples for each flavor. Within the pear flavor, children ascribed higher liking scores to all samples that contained the higher sucrose concentration. Across both age segments and flavors overall liking was found to be highly correlated to pleasantness scores of sweetness and taste; pleasantness of appearance was not correlated to overall liking. When subjects rated each attribute based on importance the relative importance was the same among both age groups, and the most important attribute was taste followed by sweetness, odor, and appearance in that order. The subjects’ reporting of importance was consistent with the correlations to the attribute the authors calculated (Tuorila-Ollikainen *et al.* 1984). Based on values assigned to the importance question, it can be seen that children assigned higher ratings to sweetness, while young adults assigned higher scores to odor and appearance.

In the second part of the study by DuBose *et al.* (1980) color and flavor levels of both cherry and orange flavored beverages were manipulated to understand their effect on overall acceptability. Flavor levels consisted of no flavor added (F_0), low ($F_{.5}$), medium (F_1), and high ($F_{1.5}$) and color levels of clear, low, medium, and high. Orange flavored beverages (when colored) were colored orange, and red colorant was used for cherry flavored beverages. Twenty-seven subjects rated the cherry beverages, and 25 subjects rated the orange beverages for overall acceptability, color acceptability, and flavor acceptability using a 9-point hedonic scale. Each subject rated the beverages twice, one time they were not given any information about the samples, and the second time they were warned that the dyes used in the beverage were shown to cause cancer in laboratory rats (Dubose *et al.* 1980).

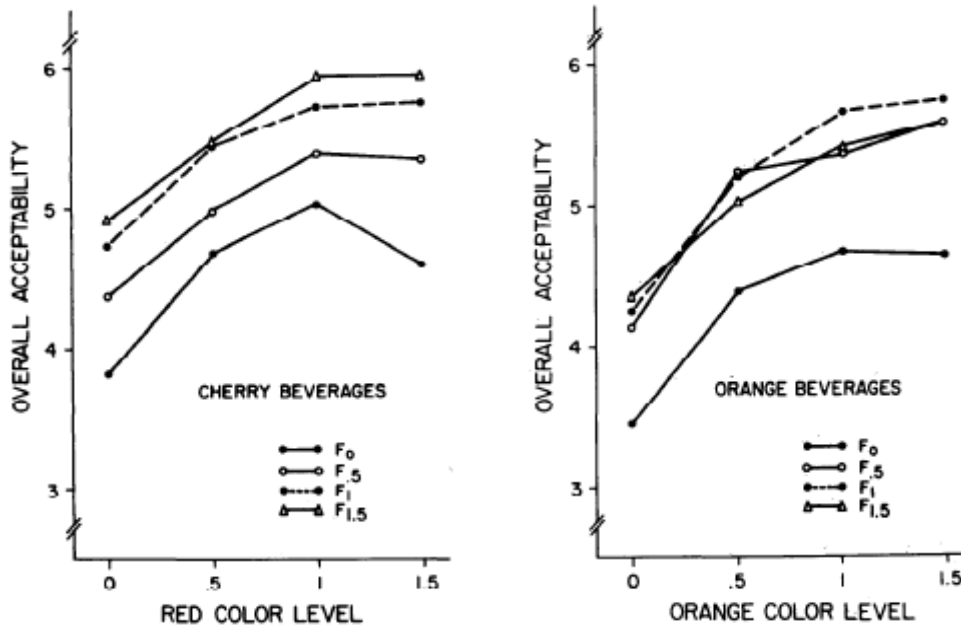


FIG. 10. OVERALL ACCEPTABILITY RATINGS FOR ORANGE AND CHERRY BEVERAGES CONTAINING DIFFERENT LEVELS OF COLOR AND FLAVOR (DUBOSE ET AL. 1980)

Overall acceptability of both orange and cherry beverages was impacted by both color and flavor level (Figure 10). In general overall acceptability increased as flavor and color levels increased. The same was true for acceptability of fruit flavor, although in the cherry beverages the flavor level had more of an impact than the color level. Acceptability of color also increased with the increase in color in both beverages. The information about the dyes causing cancer did not have any impact on acceptability ratings.

Part three of DuBose *et al.* (1980) explored the effect of color on acceptability in a food system. White cake was manipulated to have increasing amounts of yellow color (none, low, medium, and high) and lemon flavor (none, F₀; low, F_{.106}; and moderate F_{.212}). Again, subjects rated overall acceptability, acceptability of color, and acceptability of lemon flavor for each sample.

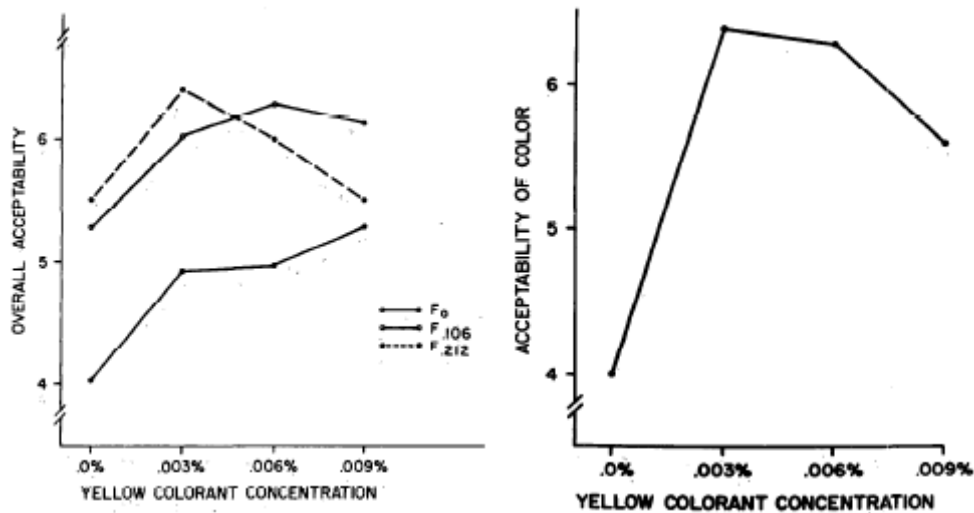


FIG. 11. OVERALL ACCEPTABILITY AND COLOR ACCEPTABILITY RATINGS FOR CAKE CONTAINING DIFFERENT LEVELS OF YELLOW COLOR AND LEMON FLAVOR (DUBOSE *ET AL.* 1980)

An interaction between flavor level and color level affected the overall acceptability of the cakes (Figure 11). The overall acceptability scores in the flavorless cake increased with an increase in color. The highest overall acceptability scores in the low flavor level occurred with the medium level of color, while in the moderate flavor level they occurred at the low color level. Color acceptability was highest at the low and moderate color level but dropped with no color or high levels of color. Regardless of acceptability attribute measured, color significantly affected the scores.

The effect of color variation on consumer acceptance of orange juice was studied by Tepper (1993). In this study, two samples of orange juice were rated by consumers for color, orange flavor and sweetness using a 5-point just about right scale and overall liking using a 9-point hedonic scale. One of the two samples contained a small amount of green coloring (other than the color they were identical). The samples were evaluated one at a time by 348 consumers.

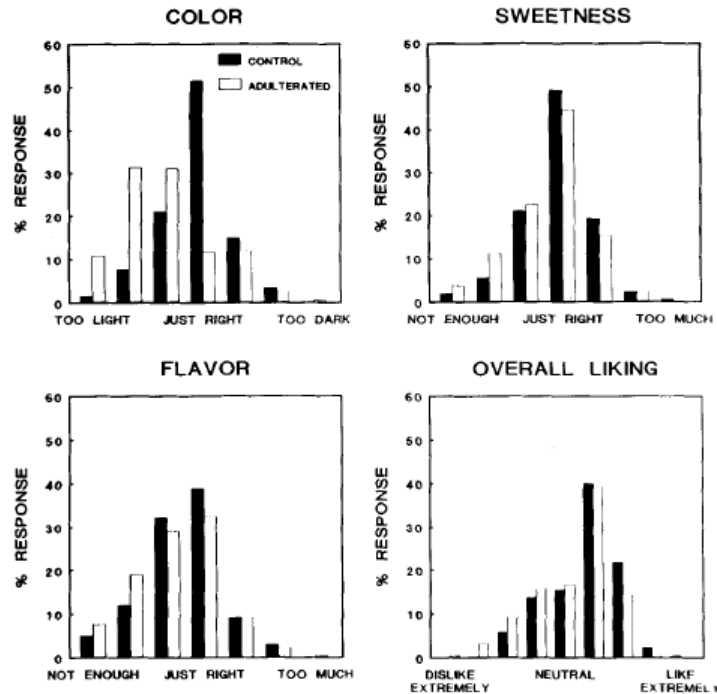


FIG. 12. RESULTS ILLUSTRATING THE DIFFERENCES BETWEEN THE CONTROL ORANGE JUICE AND THE ADULTERATED ORANGE JUICE (GREEN COLOR) ON THE ATTRIBUTES OF COLOR, SWEETNESS, FLAVOR, AND OVERALL LIKING (TEPPER 1993)

As seen in Figure 12, color of the juice had the highest effect on color ratings where the control sample was rated “just about right” for color, and the adulterated (slightly green) sample was shifted towards being “too light.” Although not as pronounced, there were significant differences between the control and the adulterated sample for both sweetness and flavor with the adulterated sample receiving more “not enough” scores for both attributes. There were attribute differences between the two products, but the samples did not differ in liking scores. These results were consistent with those of Schutz (1954) who found when other factors were present within a food system, color may not be as important in determining ratings.

In a study by Parpinello *et al.* (2009) the relationship between color and consumer preference was examined in Italian Novello red wines. Typically the color of a Novello red wine is a bright red-bluish color. However, the regulations on what makes up a Novello wine allow for it to be made from several varieties of grapes; this leads to compositional variability of the

product, including color (Parpinello *et al.* 2009). Fifteen wines were evaluated by consumers for color liking on a 9-point hedonic scale. Each consumer evaluated five of the 15 wines that were placed into three groups to ensure color variability. Each wine was evaluated by 100 consumers per group with a total of 300 consumers used for the study. The authors found that there were significant differences in liking among the wines, and the wines with higher scores were characterized by high color intensity. Conversely, wines with low color intensity were not liked as well.

In another study by Maga (1973) the effect of color and freshness on preference of potato chips was studied. Traditionally, potato chip manufacturers would remove the darker colored chips because they assume consumers object to the dark color (Maga 1973). In this study both dark and regular chips were presented to panelists once a week for four weeks. Each week, panelists were given three tasks: 1) identify the odd sample in a triangle test between dark and regular chips while blindfolded; 2) select which of the two types of chips they preferred for odor and flavor, while blindfolded; and 3) visually select between the dark or regular colored chips which had the preferred color. On the fourth week (in addition to the tasks listed) panelists were presented with samples of both regular and dark chips from each week of storage and asked to rank them in order of preference while blindfolded.

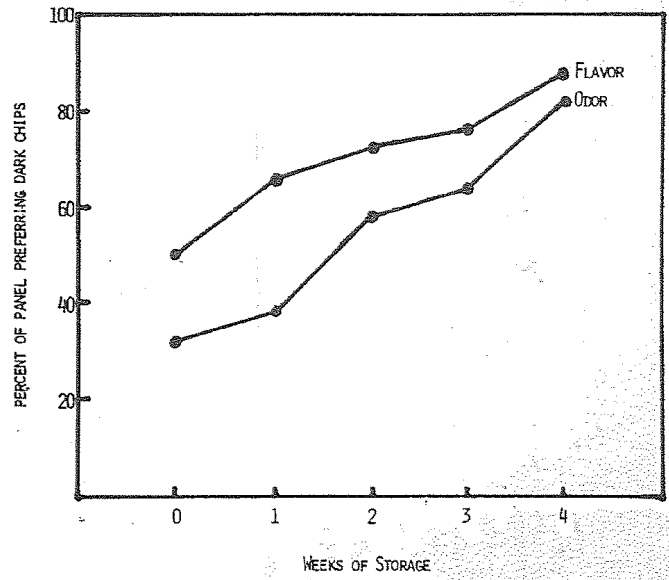


FIG. 13. RESULTS SHOWING THE PERCENTAGE OF PANELISTS PREFERRING DARKER CHIPS TO LIGHTER CHIPS OVER TIME BASED, ON FLAVOR AND ODOR (MAGA 1974)

The author found the panelists visually preferred the regular colored chips over the darker chips only 55% of the time. Also, triangle tests did not find a significant difference between the two colored chips for the first two weeks of storage. Figure 13 shows the increase in preference for both odor and flavor of the darker chips over time when the panelists were blindfolded. Ranking results at the end of the shelf life showed that all five of the darker colored samples were among the top six samples when panelists were blindfolded. The author also noted that darker colored chips that had been stored for several weeks were preferred over fresher regular colored chips.

Chapter 3 - Conclusion

Color has a major impact on the sensory properties of foods and beverages, and has a significant effect on the ability to identify flavor or odor within a beverage or food, i.e., when color was appropriate to flavor or odor correct identification of the flavor was observed. Conversely, inappropriate combinations of color with odor or flavor lead to incorrect flavor identification. Many incorrectly identified flavors or odors were based on flavor associated with the color presented. When discriminating between two flavors it was easier for respondents to do so when color appropriately matched the assumed flavor.

Certain colors are more appropriate in foods and beverages than other colors. Multiple studies have shown associations between color and food related flavors. In particular, red was associated with strawberry, cherry, and raspberry; green with lime, mint, and apple; orange with orange flavor; yellow with lemon flavor; blue with spearmint or raspberry flavor, brown with cola or caramel; gray with black currant or licorice; and clear was expected to be flavorless, lemon, or vanilla flavor.

Color also has an effect on the perception of basic tastes in both unflavored solutions and finished food and beverages. Most studies have found a correlation between the color red and an increase in sweetness perception. Several studies found that as the intensity of red increases, so does the sweetness perception. A few studies found that blue and green colors can decrease sweetness perception, or increase sourness perception. No studies to date have found a correlation between color and salt perception.

The highest concentration of inconsistencies within color research was found when investigating color impact on flavor or odor intensities. A color's ability to impact odor or flavor intensity depends a great deal on the color being manipulated, as well as the flavor or odor being measured. There were several studies that did not find a correlation between color and flavor or odor intensity; however, there were also several studies that found a correlation between the two indicating flavor or odor's intensity will increase with an increase in color intensity.

Consumers use color to determine the quality of food and beverages and color can enhance both thirst quenching and refreshment perception. Color can influence higher product liking scores and inappropriately colored products often receive lower acceptance scores. In

certain product types, such as potato chips and Novello red wine, there was some evidence that darker colors are liked more than lighter colors.

In creating new products developers and marketers must use caution when manipulating colors and conduct research to understand how colors will impact the new product's sensory properties. As seen in this review, there are not that many studies that focused on overall liking and many of these studies were conducted using small base sizes. Additionally, the products evaluated differed in obvious color changes. It has been shown that appropriately colored products receive higher acceptance scores, thus it is recommended to conduct additional research to understand how different shades and tints of an appropriately colored product may impact acceptance scores and additionally determine what is the best method for determining the most appropriate shade or tint that will result in the highest liking scores.

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