Effects of Color Alterations in Genetically Modified Organisms on College Students

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ABSTRACT

This study introduces a new aspect to the knowledge of genetically modified organisms (GMOs) that showcases changes in color (e.g., purple tomatoes, pink pineapples, and golden rice). It has been established that these specific GMOs can increase nutritional intake, but there is a gap in the consumers' perceptions of these alterations. This research investigates how modifications that alter the color of food products affect consumer attitudes towards GMOs; it specifically focuses on the college student demographic (18-25), as they have shown significant dietary deficiencies. A survey study consisting of 50 participants ($n = 50$) was conducted using a Likert scale from 1-5 to rate college students' perceptions of both unmodified and genetically modified foods. The medians of these two entities were later compared using the Wilcoxon signed-rank test, revealing a statistically significant effect of color changes on consumer perceptions ($z = -3.993$, $p < 0.001$), with a calculated effect size of -0.56, displaying a moderate to large negative shift in perception. These results suggest that genetic modifications that alter food color can significantly impact consumer acceptance. This study not only contributes to our understanding of how modifications of physical characteristics influence consumer behavior but also suggests that the success of genetically modified food products may heavily depend on sensory perceptions. This has important implications for the development and marketing strategies of GMOs, and it emphasizes the need for careful consideration of consumer preferences in genetic engineering practices.

Introduction

Since the development of genetically modified organisms (GMOs) in the 1970s, they have been applied in a multitude of settings. Examples include medicine, scientific research, and, most importantly, food (Rozas et al., 2022). In the last 25 years, GMO usage increased significantly: in 2020, 47% of the total land allocated to soybean, maize, cotton, and canola was occupied by GM crops (Brookes, 2022; Rozas et al., 2022). Furthermore, GM crops are grown in a total of 29 countries (Rozas et al., 2022). The increased use of GM technology allowed farmers to produce higher yields and expend less resources on managing pests and weeds; this resulted in higher incomes for farmers, and this change was especially significant in developing countries, where, over the time period 1996-2020, on average, farmers received $5.22 for every additional dollar spent on GM crop seeds (Brookes, 2022). Moreover, GM technology usage allowed farmers to reuse existing land, thus reducing the global land footprint; if farmers did not use GM technology and the aforementioned four crops (soybean, maize, cotton, and canola) were being produced at the same level, then an additional 23.4 million hectares (equivalent to the area of the Philippines and Vietnam combined) would have to be allocated to cultivation (Brookes, 2022).

Techniques of genetic modification include cross-breeding, mutagenesis, and genetic engineering—the most recent technique. Despite having their benefits, cross-breeding and mutagenesis are not as widely used as genetic engineering because accurate cross-breeding is too time-consuming and mutagenesis is too unpredictable (Marone et al., 2023). Transgenesis, a technique of genetic engineering, involves the transfer of DNA from one species to another; this is frequently used within the field of agricultural science, and it allows for pest resistance, herbicide resistance, and tolerance to abiotic stress (Rozas et al., 2022; Marone et al., 2023). Transgenesis can also improve the nutritional value of certain food crops (e.g., β-carotene biosynthesis in "golden rice" and "golden banana" and increased starch content in EH92-527–1 potato); these examples are typically used for food, livestock and poultry feed, biofuel, and processed food ingredients (Rozas et al., 2022). This technique also led to changes in the appearance of the crop, such as the golden color of GMO rice, which is a result of the introduction of the biosynthesis of β-carotene in the crop (Rozas et al., 2022). These kinds of changes in physical attributes are a key point of investigation in this study.

The purpose of this study is to test whether or not changes in color derived from genetic modification can influence college students' perceptions of impacted foods. The study analyzed the most significant instances of these changes, which occur in tomatoes, pineapples, and white rice. This was tested by following a quantitative procedure to survey individuals on their perceptions of unmodified and genetically modified food items.

Literature Review

As previously stated, GMOs are able to combat herbicides, which provides several benefits for the agricultural industry. An example of an herbicide-resistant crop is soybean. In 1996, a variety of this crop was developed to be resistant to glyphosate, a herbicide, and entered the US market; its usefulness lies in its ability to allow soybean growers to use herbicides to kill weeds without killing the soybean crop (Marone et al., 2023). This variety of herbicide-resistant soybean eventually spread to many other countries and became the most widely used biotech crop (Marone et al., 2023). Another example of a herbicide-resistant crop is pineapple. This crop was transformed with the *bar* gene for resistance to herbicides and tested for tolerance to "Basta," a herbicide (Marone et al., 2023). The modified pineapples were tolerant to 1600 mL/rai of "Basta" (twice as much as the recommended amount); despite the negative effects on agricultural sustainability, the increased use of herbicides would allow this crop to combat weeds, which would increase yields and profits for farmers (Marone et al., 2023). As the previous sources demonstrated, GMOs have become widely popular in the agricultural industry and are consumed in many parts of the world today (Marone et al., 2023; Rozas et al., 2022).

In addition to their resistance to herbicides, GMOs can also alleviate population pressures on the global food supply and increase the nutritional value of food crops. The global population is predicted to reach 9 billion within 30 years, and the pressure on the food supply is at an all-time high (Teferra, 2021). Furthermore, according to data from the World Bank (2021) and FAOSTAT (2021), global population growth has been increasing faster than major crop production over the past 50 years, despite agricultural innovations. However, GMOs can help combat this global issue. In the 1990s, a ringspot virus reduced the production of the Hawaiian Rainbow Papaya in the Puna district of Hawaii by 53.88% in just 4 years; however, the transgenic Hawaiian Rainbow Papaya revived the crop after it increased its production by 35.98% in just 2 years (Gonsalves & Ferreira, 2003). This example shows that GM technology can provide stability to food production and maintain food supplies. Another example of GMOs increasing global food production can be seen in the study on golden rice (a GMO) by researchers from the US Department of Agriculture: participants were given samples of golden rice (which contains β-carotene, a pigment that converts into vitamin A) and their levels of vitamin A before and after consumption were compared with a control group that consumed unmodified white rice (Tang et al., 2009). The participants displayed higher levels of vitamin A than the control group, proving that golden rice provides enhanced nutrition compared to unmodified rice (Tang et al., 2009). The increase in vitamin A intake here demonstrates the potential for GMOs to increase global nutritional intake if applied on a larger scale. However, not much is known about how the changes in color of these GMOs can influence consumption.

The possibility of increasing nutritional intake is particularly important among college students because the dietary habits of those in this demographic lack substantial amounts of nutrition, which can lead to serious health consequences later in life (Franko et al., 2008). This is shown in a report by the American College

Health Association that found that only 7% of the 3,718 students in a study consumed the recommended number of fruits and vegetables a day (ACHA, 2006). These studies demonstrate that college students are one of the most at-risk demographics in terms of dietary health.

There are also many concerns over the safety of GMOs among consumers. An article by Megan L. Norris (2015), from Harvard Graduate School of Arts and Sciences, discusses potential dangers of GMO consumption but states that research from major health groups such as the World Health Organization has invalidated these concerns. Nevertheless, public opinion on GMOs is still highly negative, as evidenced by the study on GMO sentiments from 2019-2021 by Sohi et al. (2023). Despite this, attitudes towards GMOs could have greatly changed in the 3 years since this study was conducted.

So far, it has been established that GMOs can be modified to be resistant to pests and herbicides, modified to increase nutritional value, and utilized to alleviate the global food crisis (Gonsalves & Ferreira, 2003; Marone et al., 2023; Tang et al., 2009). It has also been established that, despite evidence that says otherwise, an overwhelming majority of consumers still hold negative views of GMOs due to safety concerns (Norris, 2015; Sohi et al., 2023). What has not been established, however, is how changes in the physical characteristics of GMOs, such as the golden rice mentioned in the review by Rozas et al. (2022), can influence the perceptions of the food among its consumers. For instance, a bright, pleasant colored fruit can be more appetizing to an individual than the same fruit with a dull, unpleasant color. Witzel & Gegenfurtner's (2018) study on color perception concluded that colors are linked to object identification and communication across observers. However, this study is unrelated to how color affects one's perceptions and opinions of food items. Therefore, this study will fill these gaps by investigating how changes in color derived from genetic modification can change perceptions of particular food items. This study will focus on college students aged 18-25 enrolled at a local university who are known to have poor dietary habits.

Methods

Rationale

Survey research was the primary method of data collection for this study. More specifically, a questionnaire on a Likert scale from 1 to 5 was used in order to quantitatively measure the differences in perception between genetically unmodified food items and genetically modified fruits. This study's participants were students at a local university.

Survey studies are defined as a research method that collects information from a sample population through their responses to questions (Check & Schutt, 2011). This method was utilized due to its capability to analyze human behavior, providing data on the general perceptions of a large sample (Creswell & Creswell, 2018). This is seen in the survey study by Chen et al. (2021), which contained an analogous goal of investigating the effects of the Dark Triad psychological traits on political participation. The descriptive nature of this method fills the gap between changes in color and their impact on perceptions of fruits. Additionally, the economy and rapid turnaround of data collection provided by a survey study allows for the efficient collection and analysis of data without expending an excessive amount of resources. Due to this, an experimental study involving the distribution of actual GMOs would not be ideal since it requires significant expenditures on food items, which can be very expensive due to the relative scarcity of some of the GMOs used in this study (Creswell & Creswell, 2018). Furthermore, the acquisition of participants would be significantly compromised due to the particularities associated with this design.

The survey study will be cross-sectional rather than longitudinal due to the infeasibility of prolonged contact with such a high number of college students, and the survey was emailed to all participants at a specific point of time. However, a multitude of issues can arise from this type of distribution. For instance, a participant could potentially miss the email containing the questionnaire, and that would result in a diminished number of participants and a less diverse sample. Because of this, survey distribution via email was not as effective in reaching a desirable number of participants, so the university's Discord and Reddit was utilized to further distribute the same survey.

Participants

The original plan was to access my local university's student directory for student contact information; however, there was no such directory, making this method ineffective. As a result, I also could not obtain informed consent from the college students in this way. Instead, I collected student contact information by going to the university campus. To obtain consent, I distributed physical copies of consent forms (distributing the questionnaire during this time would not be feasible due to the fact that the participants may not have had the time to complete the questionnaire). At a later time, I used the student contact information to distribute the survey to consenting students via email so they could complete it on their own time. They were informed that they could remove their responses from the study at any given time during the survey.

The students at this university are mostly in their young adulthood (18-25). Minority enrollment at this university was 69%, white enrollment was 27%, male enrollment was 43%, and female enrollment was 53%. All of the aforementioned statistics were from the university's about section of their website. These statistics demonstrate that each demographic is represented relatively equally, and there are no disparities within a certain race or gender; this is important for the quality of the data because one specific demographic will not be represented more than another. Because students at this university are mostly in their young adulthood, participants in this study will be from ages 18 to 25. Although random sampling is more representative of the sample, convenience sampling was the only feasible option due to the given circumstances; it will also allow me to get similar numbers of participants as other studies in this field (Creswell & Creswell, 2018).

Survey and Data Analysis

The beginning of the digital survey collected the participants' emails and signatures. Following that, the questionnaire consisted of two types of questions: half of the questions were related to unmodified foods, and the other half were related to their genetically modified counterparts, with notable changes in color. These questions were meant to identify the participants' preferences for these foods through the aforementioned Likert scale from 1 to 5. Previous studies, such as the study on predicting prostate cancer by Wang et al. (2023), utilized a scale from 1 to 5 due to its ability to provide an optimal range of ratings to quantify risk factors, and this same type of rating scale can be used to determine quantifiable results for my study. In the questionnaire, the participants will rank genetically unmodified food items (tomato, pineapple, and white rice) and genetically modified food items (purple tomato, pink pineapple, and golden rice) on the Likert scale, with 5 meaning that the participant has very positive perceptions of the item and 1 meaning that the participant has very negative perceptions of the item. The image of the purple tomato used in the survey can be seen in Figure 1.

Figure 1. Image of a Purple Tomato (Yue, 2022)

Because the physical changes in color were depicted by digital photos from different sources, participants may potentially perceive the food items differently due to varying levels of brightness or saturation, making this a confounding variable in the study. To account for this, some photos were modified (i.e., increasing the brightness/saturation of the photos). An additional confounding variable was the differing levels of perceived harmfulness of GMOs among the participants, which could be an issue if participants detect patterns among the distribution of GMO and non GMO related questions. To account for this, I arranged the food items in a random sequence on the survey and did not identify whether they were modified or not to ensure single-blind testing.

The method of analysis in this study was the Wilcoxon signed-rank test, which was used for each set of unmodified and modified foods. Originally, a paired *t*-test was used to compare the central tendencies of the unmodified and modified foods, but it was unclear whether or not there would be a normal distribution of the raw data, so the nonparametric counterpart was chosen instead (Kim, 2014). Furthermore, survey participants were obtained through convenience sampling rather than random sampling, and the Wilcoxon signed-rank test is more adequate in addressing this. The data fit the Wilcoxon signed-rank test because it was ordinal and paired results are from the same participants (Creswell & Creswell, 2018). Additionally, the Wilcoxon signed-rank test was chosen over the Mann-Whitney U test because the two groups of data were related (Creswell & Creswell, 2018). The z approximation was used because of the larger sample size ($n > 20$) and statistical significance was set at 95% ($\alpha = 0.05$). To conduct the analysis, the data was exported from Google Sheets to SPSS Statistics.

Results

Fifty students ($n = 50$) participated in the survey. Some results were modified or excluded due to the survey participant not meeting the requirements; examples include failing the age requirement (18-25), not completing the entire survey, or not providing a signature. The Central Limit Theorem could be applied because $n > 30$, but convenienc e sampling could potentially yield uneven distributions, so I therefore continued with the Wilcoxon signed-rank test (Creswell & Creswell, 2018). The null hypothesis was defined as having no differences in the central tendencies towards unmodified and modified foods; the alternative hypothesis was defined as having unequal central tendencies of unmodified and modified foods.

Table 1. Unmodified and Modified Tomato

Statistic	Tomato (Unmodified)	Purple Tomato (Modified)	*z*-value	*p*-value	Effect Size (*r*)
Median	4	3	-3.993	< 0.001*	-0.56
Mean	3.72	2.70			
Sample Size (*n*)	50	50			

* Denotes significance $p \leq 0.05$

Table 1 introduces the Wilcoxon signed-rank test results of the tomato category. These results allowed me to reject the null hypothesis (H_0) and yielded statistical significance ($z = -3.993$, $p < 0.001$). Therefore, the alternative hypothesis (H_1) was accepted. This means that there *is* a significant difference between the central tendencies towards unmodified and modified tomatoes. The analysis demonstrated that the purple tomato (*Mdn* = 3) was rated significantly lower than the unmodified tomato (*Mdn* = 4). The effect size ($r = -0.56$) demonstrated that the change in color from genetic modification had a strong, negative effect on the perception of the tomato.

Table 2. Unmodified and Modified Pineapple

Statistic	Pineapple (Unmodified)	Pink Pineapple (Modified)	*z*-value	*p*-value	Effect Size (*r*)
Median	4	3	-4.288	< 0.001*	-0.61
Mean	3.80	2.72			
Sample Size (*n*)	50	50			

* Denotes significance $p \leq 0.05$

Table 2 introduces the Wilcoxian signed-rank test results for the pineapple category. These results allowed me to reject the null hypothesis (H_0) and yielded statistical significance ($z = -4.288$, $p < 0.001$). Therefore, the alternative hypothesis (H_1) was accepted. This means that there *is* a significant difference between the central tendencies towards unmodified and modified pineapples. The analysis demonstrated that the pink pineapple (*Mdn* = 3) was rated significantly lower than the unmodified tomato (*Mdn* = 4). The effect size ($r = -0.61$) demonstrated that the change in color from genetic modification had a strong, negative effect on the perceptions of the pineapple among the participants.

Table 3. Unmodified and Modified White Rice

Statistic	White Rice (Unmodified)	Golden Rice (Modified)	*z*-value	*p*-value	Effect Size (*r*)
Median	5	4	-3.528	< 0.001*	-0.50
Mean	4.62	3.90			
Sample Size (*n*)	50	50			

* Denotes significance $p \leq 0.05$

Table 3 introduces the Wilcoxon signed-rank test results for the white rice category. These results allowed me to reject the null hypothesis (H_0) and yielded statistical significance ($z = -3.528$, $p < 0.001$). Therefore, the alternative hypothesis (H_1) was accepted. This means that there *is* a significant difference between the central tendencies towards unmodified and modified rice. The analysis demonstrated that golden rice (*Mdn* = 4) was rated significantly lower than unmodified white rice (*Mdn* = 5). The effect size ($r = -0.50$) demonstrated that the change in color from genetic modification had a strong, negative effect on the perceptions of the rice among the participants.

Discussion

This study introduces a new viewpoint to the current knowledge of GMOs that showcases alterations in color (e.g., purple tomatoes, pink pineapples, and golden rice). The literature review established that GMOs, such as golden rice, can increase nutritional intake, and the color of foods has significant implications for the identification of food items (Tang et al., 2009; Witzel & Gegenfurtner, 2018). This study aimed to investigate the impact of alterations in color resulting from genetic modification on college student's perceptions of affected foods. More specifically, it targeted tomatoes, pineapples, and white rice. Its findings demonstrated that there were statistically significant differences between perceptions of unmodified and modified foods due to alterations in color.

In each pair of food items, the genetically modified versions were rated significantly lower than their unmodified versions. Since the possibility of negative perceptions of GMOs impacting ratings was accounted for through the single-blind methodology, color differences were the sole factor in determining this relationship. Each Wilcoxon signed-rank test yielded negative *z*-values with large effect sizes, which means that perceptions of the GMOs in this study were rated significantly lower than average due to alterations in color. The study by Sohi et al. (2023) has already explained that negative perceptions of GMOs can be caused by the knowledge of the food item being genetically modified, which is signified by the GMO label. This could be caused by several reasons, but one prominent reason is a limited scientific understanding of the modification process (Wunderlich & Gatto, 2015). This study was able to introduce other factors that contribute to the negative perceptions of GMOs by identifying the impact of physical changes such as color rather than just the GMO label.

Interestingly, shifts in perceptions were more significant in pineapples and tomatoes than in white rice. This could potentially be explained by Witzel & Gegenfurtner's (2018) study on color perception, where it stated that colors can be perceived more differently when they belong to different color categories. This can be tied to Schomaker & Meeter's (2012) study, which demonstrated that increased novelty corresponds with enhanced visual perception. The differences in color resulting from genetic modification in pineapples and tomatoes could be more novel than the differences in color in white rice, which could prompt increased visual perception. This increased visual perception could add to the unfamiliarity of the purple tomatoes and pink pineapples, which could potentially correlate with more negative perceptions. However, this explanation has not been proven yet, demonstrating new areas of research regarding this topic.

Conclusion

The study involved several limitations. First, although this study intended to encompass all GMOs with alterations in color, the only color modifications were from red to purple (purple tomato), yellow to pink (pink pineapple), and white to gold (golden rice). These are very limited sets of colors, and it could be potentially inaccurate to generalize this to all modifications in color derived from genetic modification. Therefore, this study was limited to these food items because, although there are a multitude of foods that have been genetically modified, there are few that involve changes in color. For example, the physical appearance of Bt crops is visually identical to their unmodified counterparts; for this reason, they would not be appropriate for this study. In addition, the study only surveyed college students, meaning that it can only be generalized to this specific age group. Although this is an important demographic due to their poor dietary habits, increasing the scope of this study could provide a much greater understanding of perceptions towards genetic modifications that change color (Franko et al., 2008).

An additional limitation was the Wilcoxon signed-rank test itself. I had the option to conduct a paired *t*-test for my data analysis because, since I had more than 30 participants, normal distribution can be assumed due to the Central Limit Theorem. However, I was still not confident in using this method because convenience sampling could cause skewed distributions that would undermine the effectiveness of the analysis. I therefore chose the safer option, but there are significant drawbacks to the Wilcoxon-signed rank test. Non-parametric tests like this are considerably weaker than parametric tests because of several reasons. Parametric tests utilize normally distributed data, which means that they are significantly more likely to detect true effects accurately. With the Wilcoxon signed-rank test specifically, it analyzes differences in median values rather than mean values like those in the paired *t*-test; due to this, the Wilcoxon signed-rank test could provide inaccurate measures of central tendency.

A third limitation is that the participants could have had prior knowledge of the GMOs in this study. This would have nullified the single-blind technique and reintroduced the confounding variable of the participants' differing levels of perceived harmfulness of GMOs. This confounding variable could have significantly impacted the ratings of the purple tomato, pink pineapple, and golden rice in the survey. Since public opinion on GMOs is, on average, negative, the *z*-value ratings of these GMOs could have been exaggerated (Sohi et al., 2023).

The study only touched on modifications with color. To answer how changes in physical characteristics, not just color, can impact the perception of consumers, future research regarding other physical characteristics such as texture or shape could provide a more holistic understanding of the relationship between GMOs and perceptions. For example, the Flavr Savr tomato was modified to increase shelf life, but it has also increased the firmness of the fruit. This firmness could influence perceptions just like how color did, further exploring the impacts that modifications in physical characteristics can have on consumers.

An additional direction for future research is to expand the study to other age ranges and other demographics, such as race or sex. This is especially important because the perceptions of the color modifications in this study could vary greatly across differing demographics, and extending this study could provide key insights for each of them. Furthermore, this could identify trends in the perceptions of GMOs across generations. For example, younger generations could potentially have fewer negative perceptions than older generations, who have mostly developed skepticism towards GMOs. By expanding this study, it could have much greater relevance and provide a more comprehensive knowledge of perceptions of genetic modifications that alter physical characteristics.

Ultimately, there are a multitude of implications associated with the results of this study. For example, this study serves as a continuation of the negative perceptions of GMOs. This time, rather than the GMO label, it was the physical changes that elicited these negative perceptions. It further highlights the need for increased education regarding genetic modification and biotechnology to improve the acceptance of GMOs. The results indicate that the visual change derived from genetic modification is widely misunderstood, leading to more negative perceptions.

What could be done to address these negative perceptions is to raise the emphasis on addressing consumer preferences. For example, by maintaining the original color, the food industry can greatly increase acceptance of these GMOs. This would allow the positive traits derived from genetic modification to play a greater role in combating the global food crisis and increasing nutritional intake among consumers, with college students being the greatest beneficiaries of the latter (Franko et al., 2008; Gonsalves & Ferreira, 2003; Tang et al., 2009). Moreover, additional research regarding consumer preferences should be incorporated into the development of GMOs. This way, negative perceptions due to modifications to physical characteristics can be addressed at the developmental stage.

Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

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