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Article

Energy beverages and sugar: How sweetener type dictates specific gravity

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SUMMARY

Specific gravity can be used to measure the density of a beverage compared to water. We examined the factors that influence specific gravity in twenty different energy and sports beverages. We hypothesized that sugar content is the main contributing factor in determining specific gravity of a beverage, and that caffeine content, sodium content and carbonation are also correlated with specific gravity. We saw no correlation between caffeine content, sodium content, carbonation and specific gravity. However, caloric density was highly correlated with specific gravity. Beverages that contained real sugar had a higher specific gravity than beverages with zero-calorie sweeteners. Our data supports the fact that zero-calorie sweeteners are 200–700 times stronger than real sugars. This means a lower volume of zero-calorie sweetener needs to be added for the same sweet taste. Zero-calorie sweeteners are marketed as a healthier alternative to real sugars, but the actual health consequences are under debate. It is common for beverage companies to publish their own sponsored research on the reported health benefits of their beverages. Therefore, it is essential that independent research is conducted on these beverages. Globally, energy and sports beverages can lead to disease, therefore a better understanding of the composition of these beverages can support public health.

INTRODUCTION

Sugar-sweetened beverages (SSBs) contribute to approximately 39% of the added sugars in people's diets in the United States, and account for the largest source of added sugars in most Western countries (1). Americans between the ages of 12–19 consume more sugar beverages than any other age group (1). This is important because consuming too much sugar can be related to an increased prevalence of diabetes, obesity, and tooth decay (2). A meta-analysis of 8,601 articles suggested that consuming one 250 mL SSB each day was associated with a 17% increased risk of coronary heart disease and a 4% higher risk of mortality (3). In a study of 109,034 women followed over an average of 17.4 years, high consumption of added sugar was associated with more frequent and earlier cardiovascular disease and heart failure (3). SSB consumption is increasing rapidly worldwide (4). The detrimental health outcomes of SSBs are a worldwide public health concern.

Sports and energy beverages are highly marketed to adolescents to increase their athletic performance by boosting energy and alertness (5). However, these beverages are frequently highly caloric and contain extra additives such as preservatives and artificial coloring agents. Therefore, the health consequences of these beverages in adolescents are debatable (6). Sports beverages contain real or zero-calorie sweeteners, minerals, electrolytes, and flavors that are added to water. Sports beverages also contain other ingredients such as preservatives (sodium benzoate) and food dyes (tartrazine). However, energy beverages are different from sports beverages because they contain stimulants like caffeine (6).

Monster energy has 160mg of caffeine in 16oz. According to a pediatrician there is no established safe amount of caffeine between 0-17 years old (7). However, experts recommend no more than 100mg of caffeine per day in youth (7). In adults, up to 400mg of caffeine a day is not associated with negative effects (8). Caffeine is particularly harmful in people with pre-existing heart diseases such as long QT syndrome, which is a pattern of fast irregular heartbeats (9). There have been 92 caffeine-related deaths between 1959 and 2018 (8). Between 2009 and 2012, there were five reported deaths that could potentially be related to Monster energy beverages (8). Of youth 12-17 years old who consume caffeine, only 10% consumed more than 100mg per day, on average (5).

In addition, to beverage sweeteners, we also looked at carbonation. Beverages are frequently carbonated because many people find carbonated beverages to be enjoyable. However, carbonation changes how the brain perceives both zero-calorie and natural sugars. Carbonation can alter the taste perception of a very sweet beverage (8). Carbonation can also make a zero-calorie sweetened beverage more palatable. Carbon dioxide (CO_2) reduces sweetness perception and the differentiation between natural and zero-calorie sweeteners (10).

SSBs are usually sweetened with high-fructose corn syrup (HFCS), brown sugar, corn sweetener, dextrose, fructose, glucose, honey, lactose, malt syrup, maltose, molasses, raw sugar, and sucrose (11). Fructose is a naturally occurring sugar in many fruits, fruit beverages, and vegetables (11). Fructose is the main component in high-fructose corn syrup, which has been known to contribute to obesity in recent years (4). Sucrose (table sugar) is also in many beverages. Sugars such as brown sugar and raw sugar are types of sucrose with different processing. Lastly, glucose is the main sugar from food that helps your body gain energy. We examined the following sugars in this study: sucrose, HFCS, fructose, and glucose.

Zero-calorie sweeteners in beverages have emerged

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recently and have been marketed as a healthier alternative to sugars (1). Zero-calorie sweeteners are 200–700 times sweeter than table sugar for the same amount of solution (12). The Food and Drug Administration (FDA) regulates zero-calorie sweeteners and has approved the following sweeteners: acesulfame potassium (Ace-K), advantame, aspartame, neotame, saccharin, and sucralose. The FDA advises against excessive zero-calorie sweetener consumption. Zero-calorie sweeteners are not metabolized; therefore, they do not contribute to a beverage's calorie count. The health implications of zero-calorie sweeteners are controversial. The healthiest form of sweetener largely depends on a person's health status. For example, zero-calorie sweeteners may be more beneficial for an individual with diabetes (1). However, zero-calorie sweeteners are damaging to the microbiome, which might be particularly harmful to someone with a gastrointestinal disease strongly related to the gut microbiome, such as irritable bowel syndrome (13). A meta-analysis showed no association between zero-calorie sweeteners and body weight in children (14). In a prospective study of 103,388 people in France, increased consumption of zero-calorie sweeteners was associated with increased risk of cardiovascular disease (12, 15).

One example of how one zero-calorie sweetener can negatively impact health can be seen with saccharin. Saccharin was the first approved zero-calorie sweetener. In 1977 the FDA proposed to ban saccharin because a study showed that rats who consumed saccharin had an increased prevalence of bladder cancer (16). Another experiment gave the maximum acceptable daily intake of saccharin to seven volunteers who had good blood glucose control (17). After five days of saccharin consumption four of the seven volunteers developed significantly worse glucose tolerance. This article hypothesized that this change could be caused by a change in the gut microbiome due to the zero-calorie sweeteners (17). However, this result is debatable, because a different randomized control trial showed no difference in gut microbiota composition between people who consumed high levels of zero-calorie sweeteners and people who did not (18). Saccharin is still on the market today and is believed to be safe below its acceptable daily intake (18). In addition to the previously mentioned sugars, we also examined the following zero-calorie sweeteners in this study: sucralose, Stevia, acesulfame potassium. Aspartame and Stevia are plant-based zero-calorie sweeteners.

As the health consequences of zero-calorie beverages are not fully known, we sought to better understand differences between various SSBs and zero-calorie beverages. Density is one way to study the differences in composition between beverages. Specific gravity is a way to measure density in relation to water. Therefore, we aimed to understand the specific gravity contributions of sucrose, glucose, high fructose, and their "sugar-free version" in common beverages and whether specific gravity can differentiate between zero-calorie and naturally sweetened beverages. We hypothesized that beverages with a higher real sugar content would have the highest specific gravity. Additionally, we hypothesized that sugar plays the biggest role in determining the specific gravity. Our results showed that sugar is the most important factor to predict beverage specific gravity. Additionally, we saw that specific gravity is related to calorie content, but not carbonation or caffeine content. In the future, we would like to conduct a similar experiment testing more beverages, and a wider range of beverages. We encourage independent research to be conducted on the safety and contents of energy and sports beverages, as a large part of the current research is conducted by beverage companies.

RESULTS

To look at how differences in beverage composition impact specific gravity we measured the specific gravity of 20 different beverages **(Table 1)**. The 20 beverages consisted of energy and sports drinks with differences in carbonation, caffeine, and sweetener used. To measure specific gravity of each beverage, we placed 50mL of room-temperature beverage into a graduated cylinder and gently placed a hydrometer in the beverage and recorded the specific gravity measurement from the hydrometer.

First, we looked at the effect of carbonation on specific gravity. The physical bubbles in a carbonated beverage can create an inaccurate density measurement, therefore, we removed carbonation before measuring density. We found no significant difference in the median specific gravity of carbonated (1.0095) and non-carbonated (1.0095) beverages ($p=0.9691$, $W=47$) **(Figure 1)**. These data show that carbonation does not influence a beverage's specific gravity. Next, we tested caffeine to see if it was a large contributor to a beverage's density. Caffeine in mg per mL and specific gravity were not correlated ($p=0.754$, $rho=0.0748$). Each of the beverages that contained sugar and caffeine had approximately 500 times more sugar than caffeine by weight. Therefore, it is not surprising that specific gravity is not associated with caffeine **(Figure 2)**.

Beverage	Sugar Content (g/mL)	Calorie Content (kcal/mL)	Main Sweetener Type	Sodium Content (mg/mL)	Caffeine Content (mg/mL)	Carbonated
Monster Energy Ultra Strawberry	0.00	0.00	Sucralose	0.30	0.34	Yes
Monster Energy	0.09	0.37	Sucrose	0.22	0.34	Yes
Monster Energy Low Carb	0.03	0.11	Sucralose	0.26	0.34	Yes
Gatorade	0.06	0.24	Sucrose	0.16	0.00	No
Gatorade Zero	0.00	0.00	Sucralose	0.16	0.00	No
Powerade	0.05	0.21	HFCS	0.10	0.00	No
Powerade Zero	0.00	0.00	Sucralose	0.10	0.00	No
Vitamin water Energy	0.05	0.21	Fructose	0.00	0.05	No
Vitamin water Zero Sugar	0.00	0.00	Stevia	0.00	0.03	No
Bodyarmor	0.07	0.30	Sucrose	0.02	0.00	No
Bodyarmor Lyte	0.01	0.02	Sucralose	0.02	0.00	No
C4 Energy Zero Sugar	0.00	0.00	Acesulfame Potassium	0.04	0.13	Yes
C4 Energy Zero Sugar Natural	0.00	0.00	Stevia	0.04	0.13	Yes
Celsius Sparkling	0.00	0.00	Sucralose	0.01	0.13	Yes
Storm Clean Energy	0.00	0.00	Sucralose	0.14	0.13	Yes
Red Bull Zero Sugar	0.00	0.00	Acesulfame Potassium	0.13	0.32	Yes
Red Bull Energy Sugar Free	0.00	0.00	Acesulfame Potassium	0.13	0.32	Yes
Prime Energy	0.00	0.00	Sucralose	0.10	0.20	Yes
Red Bull Energy	0.09	0.38	Sucrose	0.04	0.30	Yes
Celsius	0.00	0.00	Sucralose	0.01	0.13	Yes

Table 1: Nutrition information for each of the 20 beverages. Sugar content, calorie content, main sweetener type, sodium content, caffeine content, and carbonation status of the experimental beverages. Sugar, calorie, sodium, and caffeine content shown as unit/mL to account for differences in overall volume of beverages.

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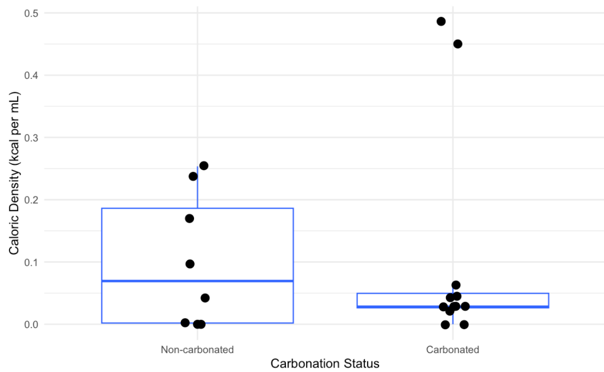

Figure 1. Specific gravity is not significantly different between carbonated and non-carbonated beverages. Box and whisker plots showing the distribution of specific gravity values for carbonated and non-carbonated beverages. Specific gravity was measured after carbonated beverages were microwaved to remove carbonation. Wilcoxon Rank Sum test showed no significant difference in specific gravity between carbonated and non-carbonated beverages. Wilcoxon Rank Sum results, w=47, P value = 0.9691.

Then, we looked at calorie density and sodium content. We recorded calorie density as calories (kcal) per mL, as beverages had different volumes. There was a strong positive correlation between calorie density and specific gravity ($p<0.0001$, rho = 0.8171) **(Figure 3)**. We observed no association between carbonation and calorie density (p=0.9072, W=46) **(Figure 4)**. Calorie density was the only beverage characteristic associated with specific gravity. We recorded sodium content as a continuous variable as milligrams per mL of beverage. There was no significant correlation between sodium content and specific gravity (p=0.064, rho = 0.4232. **(Figure 5, Table 2).**

Sucralose was the most frequent sweetener seen in 45% of the beverages, and HFCS was the least frequent seen in 5% (**Table 1**). Each of the beverages sweetened with sucrose had a high specific gravity. The beverages with the lowest specific gravity were sweetened with acesulfame potassium, Stevia, and sucralose. Red Bull Energy had the highest specific gravity (1.045) and Powerade zero, vitamin water zero, and C4 natural energy all had a specific gravity of 1. The median specific gravity of all beverages was 1.01, the mean 1.012, and the standard deviation 0.011 **(Figure 6).** The differences in specific gravity that we observed between zero-calorie and real sugars were not very large. The median percent difference between theoretical and measured specific gravity was 0.1%. This represents accurate testing without any sign of systemic error. For context, the specific gravity of kefir, a beverage with high protein content, is 1.81, honey is 1.4, water is 1, and olive oil is 0.92.

We estimated theoretical specific gravity using the specific gravity formula. We assumed that other additives to the beverages such as caffeine and sodium had a minimal impact on specific gravity. We calculated percent difference to determine the difference between experimental and theoretical values. The lowest percent difference was 0% and the largest difference was –8.897%. The median percent difference was 0.1% **(Table 2).** Overall, the difference between the experimental and theoretical percent differences were relatively small and reassuring that the experiment was accurate.

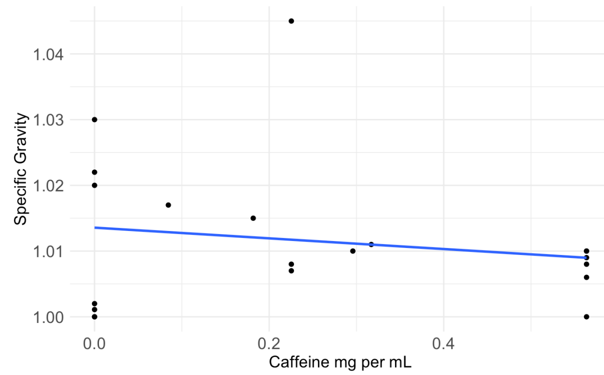

Figure 2. Caffeine content does not influence specific gravity. Association of specific gravity values and caffeine (mg/mL)in energy beverages. Red Bull Energy was an outlier. The Wilcoxon Rank Sum test showed no significant difference in specific gravity by caffeine content in energy and sports beverages (p= 0.6333, W=39).

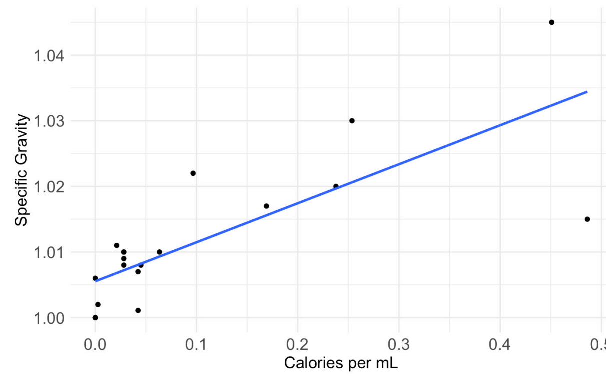

Figure 3. Higher caloric density is correlated with higher specific gravity. The association between caloric density and specific gravity. Calories per mL was recorded to account for the different volumes of beverages. The blue line shows the best linear fit. A Spearman's Rho test showed a very high correlation between the caloric density and specific gravity (Spearman's Rho= 0.87458, $p<0.0001$).

DISCUSSION

Zero-calorie sweeteners are at least 200 times more concentrated than real sugar (8). Therefore, the quantity of sweeteners to make a beverage taste sweet is much lower for zero-calorie flavored beverages versus real sugar. Through this experiment, we determined that sugar is the most important factor to predict beverage specific gravity. Zero-calorie beverages have a specific gravity close to water, whereas real sugar beverages have a higher specific gravity. Therefore, this experiment demonstrated a novel method for studying the difference between zero-calorie and real sweetener types.

Red Bull Energy was the most caffeinated beverage in this study. It weighs 369 g and has 111 mg of caffeine; therefore, red bull energy is approximately 0.03% caffeine by mass. Red Bull Energy has 150 mg of sodium (0.04% w/w) and 34 g of sugar (9.2% w/w) **(Table 1)**. Since it is 9.2% sugar we predicted that it would have a high specific gravity compared to drinks with less sugar by mass. We also expected that the caffeine and sodium molecular were not concentrated enough to strongly influence specific gravity. However, we accurately

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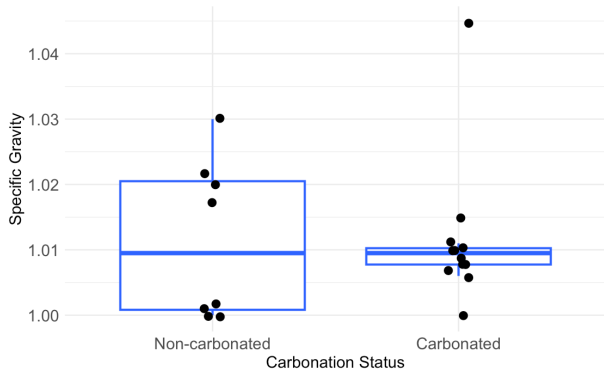

Figure 4. Carbonated beverages either have a high or low caloric density. In the 12 carbonated beverages, 2 had very high caloric density (measured as kcal/mL) and the remaining 10 had low caloric density reflecting the use of zero-calorie sweeteners. In non-carbonated beverages there were some beverages with low or no caloric density and the other with a medium number of calories. In the selected beverages, carbonation was used in either very sweet beverages or beverages with zero calories. Caloric content was recorded from the nutrition label on every beverage. A Wilcoxon Sum Rank test tested the association between carbonation status and calories (kcal) per mL. There was no strong correlation (p value = 0.9072, W=46).

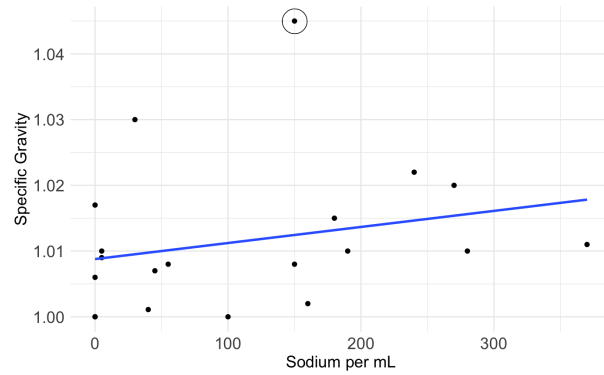

Figure 5. No correlation between sodium content and specific gravity. Monster Energy Ultra Strawberry, denoted with the black circle, was an outlier (sodium was 150 mg/mL, and specific gravity was 1.045). Sodium content was recorded from the nutrition label on every beverage and converted to mg/mL. The blue line shows the best fit. A Spearman's Rho test showed no significant correlation between the amount of sodium content and specific gravity (Spearman's Rho= 0.4181, p<0.06657).

predicted that Redbull Sugar Free would have a lower specific gravity, as it uses a zero-calorie sweetener.

Previous studies indicate that carbonation can strongly influence the taste of a beverage (17). Carbonation can reduce sweetness perception for a highly caloric beverage. Additionally, carbonation can reduce the ability to discriminate between zero-calorie sweeteners and can make them taste better. In this study, the two beverages with the highest caloric content were Red Bull Energy and Monster Energy **(Table 2)**. Many of the beverages with zero-calorie sweeteners as the main sugar source were also carbonated, such as Prime Energy, C4 Energy Zero Sugar, C4 Energy Zero Natural Sugar, and Celsius **(Figure 5)**. These data support the claims made by Sternini about which beverages use carbonation (15).

When determining specific gravity, carbonation would cause an inaccurate result due to the bubbles of carbon dioxide changing the fluid dynamics in the beverages. Therefore, all carbonated beverages were microwaved to remove carbonation. Two beverages, Monster Energy Ultra Strawberry and Monster Energy Low Carb were at a colder temperature than the other 18 beverages while doing specific gravity testing. Density is inversely related to temperature, so the density of Monster Energy Ultra Strawberry and Monster Energy Low Carb might have been inaccurately high. The sample size of 20 beverages was too small to allow for parametric testing and if a larger sample size was collected then a larger variety of statistical tests could have been used. If we repeated this study, we would test additional beverage characteristics such as; protein content, artificial coloring, vitamin content and preservatives. We would also conduct multiple trials. This would allow for a more complete understanding of beverage specific gravity. Another limitation was that we only recorded the first listed sugar type. In the ingredient list, the first ingredient is the greatest quantity by weight. However, since zero-calorie sweeteners are lower in weight than caloric sweeteners, it is possible that the sweetener type was biased to consider caloric sweeteners over non-caloric ones or beverages that may contain multiple sweeteners.

Calorie density and specific gravity were overall correlated, however there are some beverages where specific gravity is higher or lower than would be expected by calorie density. An example of this is Monster Energy that had 14.375 kcal per mL (the second highest) and had a specific gravity value of 1.015, which was much lower than the highest specific gravity. This could be due to either an experimental error, or perhaps another beverage ingredient which influenced specific gravity. Energy beverages are highly marketed products that have many supposed health benefits. It is common for beverage manufacturers to pay for studies about their own beverages. For instance, the manufacturer of Celsius Energy claims that the beverage boosts the metabolic rate (19-24). They additionally claim that Celsius increases athletic ability. The Celsius website highlights six studies to support these claims (19-24). However, each of these six studies were funded by Celsius, which could create misleading marketing. Additionally, these studies have flawed methods: small sample size, the disproportionate ratio of men to women, a homogeneous study population that could benefit Celsius, and data correctors due to statistical errors (19-24). Research funded by a company about their own product frequently leads to confirmation bias. Therefore, it is essential that independent research be conducted on the composition and safety of energy and sports beverages.

MATERIALS AND METHODS

Beverage selection

Twenty sports and energy beverages were selected at a local grocery store **(Table 1)**. When possible, the low calorie and full calorie beverages from the same brand were selected, for example, Gatorade and Gatorade Zero. Eight non-carbonated beverages were selected, 13 were caffeinated, and 7 beverages had real sugar. The main sweetener type for each beverage was recorded as the first sweetener listed

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Beverage	Theoretical SG	Measured SG	Percent Difference
Monster Energy Ultra Strawberry	1	1.011	1.1%
Monster Energy	1.114	1.015	-8.897%
Gatorade	1.058	1.02	-3.554%
Gatorade Zero	1	1.002	0.2%
Powerade	1.042	1.022	-1.922%
Powerade Zero	1	1	0%
Vitamin water Energy	1.046	1.017	-2.72%
Vitamin water Zero Sugar	1	1	0%
Bodyarmor	1.106	1.03	-6.843%
Bodyarmor Lyte	1.004	1.001	-0.311%
C4 energy zero sugar	1	1	0%
C4 energy zero sugar natural	1	1.006	0.6%
Celsius sparkling	1	1.009	0.9%
Storm clean energy	1	1.01	1%
Red Bull zero sugar	1	1.007	0.7%
Monster energy low carb	1.013	1.01	-0.265%
Redbull energy sugar free	1	1.008	0.8%
Prime energy	1	1.008	0.8%
Redbull energy	1	1.045	4.5%
Celsius	1	1.01	1%

Table 2. Comparison of theoretical and measured specific gravity. Theoretical specific gravity of a beverage as calculated from the specific gravity formula it assumes that a beverage is only composed of sugar and water. The percentage difference between measured and theoretical difference is shown. The largest difference is –8.897% for Monster Energy. SG = specific gravity.

on the beverage ingredients list on the nutrition label. To standardize sweetener types, if the sugar was reported as dextrose, it was re-coded to glucose, and if the sugar was reported as beet sugar, it was re-coded to sucrose.

Measurement of specific gravity

Density is the ratio of mass to volume of a specific material. Specific gravity is a way to measure the density of liquids compared to water; the specific gravity of water is one. Specific gravity is a substance's density divided by water density. Therefore, the specific gravity of sugar solutions can be calculated from the sugar mass in grams and the solution volume using the following equations (25, 26).

$$SG = \frac{\rho_{solution}}{\rho_{water}}$$

$$\rho_{solution} = \frac{mass_{solution}}{volume_{solution}}$$

A hydrometer is a device used to measure specific gravity. When a hydrometer is gently placed in a graduated cylinder, it adjusts the position of where the hydrometer floats. A hydrometer in a solution with high specific gravity will float higher in the graduated cylinder, and a denser measurement will be read (27).

All 12 carbonated beverages were microwaved for 30 seconds to remove carbonation. After the carbonated beverages were microwaved, they were placed in a dish bin with room temperature water to ensure that the specific gravity was measured at room temperature. All data was collected at the same room temperature (22°C) conditions, except Monster Energy Ultra Strawberry and Monster Energy Low Carb. 150mL of each energy beverage was poured into a 200mL graduated cylinder. A Haoguo Triple Scale Alcohol Hydrometer was gently placed to measure the specific gravity of each of the 20 beverages. The specific gravity results were measured after the position of the hydrometer was stabilized. The main sweetener type for each beverage was recorded as the first sweetener listed on the beverage ingredients list on the nutrition label. To standardize sweetener types, if the sugar was reported as dextrose, it was re-coded to glucose, and if the sugar was reported as beet sugar, it was re-coded to sucrose.

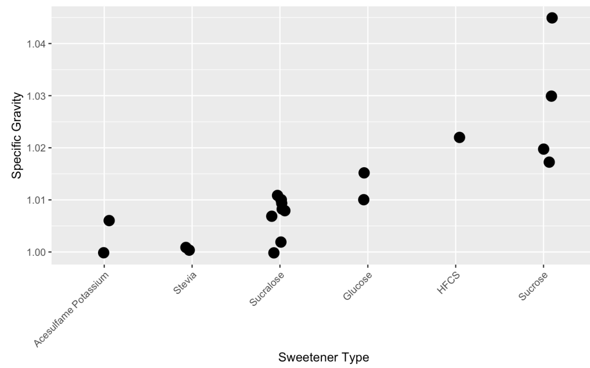

Figure 6. Beverages with real sugar have higher specific gravity than beverages with zero-calorie sweeteners. Specific gravity of beverages by different sweetener type. Zero-calorie sweeteners include: acesulfame potassium, Stevia, and sucralose. Real sugars include fructose, HFCS glucose, and sucrose.

Statistical methods

Given inclusion of fewer than 40 test subjects (beverages), non-parametric methods were used to test the association or correlation between specific gravity and independent variables. Using the R software, the Wilcoxon Sum Rank test was used to determine the association between caffeine status and specific gravity, and between carbonation status and specific gravity. Additionally, Spearman's Rho tested the correlation between sodium per mL and specific gravity and between calories per mL and specific gravity. A p-value and a correlation coefficient were reported. All figures were created using the R software and ggplot2.

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APPENDIX

R code:

```
 ```{r setup, include=FALSE}
knitr::opts_chunk$set(echo = TRUE)
```
```{r cars}
library(tidyverse)
library(readr)
#LACSEF_2024_Data_Master_Data_Sheet <- read_csv(...)
View(LACSEF_2024_Data_Master_Data_Sheet)

summary(LACSEF_2024_Data_Master_Data_Sheet)
SGData<-LACSEF_2024_Data_Master_Data_Sheet
#this runs a Wilcoxon Sum Rank test to the association between Carbonation and Specific Gravity
result <- wilcox.test(SG ~ Carbonated, data = SGData, alternative = "two.sided", exact = FALSE)
print(result)
SGData$Carbonated <- as.factor(SGData$Carbonated)
#this code makes a box and whisker plot with data points showing distribution of specific gravity by carbonation status
p <- ggplot(SGData, aes(x = Carbonated, y = SG)) +
  geom_boxplot(fill = "white", fill = "#3366FF", color = "#3366FF") +
  geom_point(position = position_jitter(width = 0.05), size = 3, color = "black") +
  labs(x = "Carbonation Status", y = "Specific Gravity" ) +
 theme_minimal()+
  theme(axis.text=element_text(size=14),  axis.title = element_text(size = 14), title = element_text(size = 14))
p
```
```{r}
SGData$Caffeine <- as.factor(SGData$Caffeine)
p <- ggplot(SGData, aes(x = Caffeine, y = SG)) +
  geom_boxplot(fill = "white", fill = "Red", color = "Red") +
  geom_point(position = position_jitter(width = 0.05), size = 3, color = "black") +
  labs(x = "Caffeine Status", y = "Specific Gravity", axis.text=element_text(size=14)) +
  theme_minimal()+
  theme(axis.text=element_text(size=14),  axis.title = element_text(size = 14),
    title = element_text(size = 14))
p
result <- wilcox.test(SG ~ Caffeine, data = SGData, alternative = "two.sided", exact = FALSE)
print(result)
```
```{r}
SGData$Caffeine <- as.factor(SGData$Caffeine)
p <- ggplot(SGData, aes(x = Caffeine, y = SG)) +
  geom_boxplot(fill = "white", fill = "Red", color = "Red") +
  geom_point(position = position_jitter(width = 0.05), size = 3, color = "black") +
  labs(x = "Caffeine Status", y = "Specific Gravity", axis.text=element_text(size=14)) +
  theme_minimal()+
  theme(axis.text=element_text(size=14),  axis.title = element_text(size = 14),
    title = element_text(size = 14))
p
result <- wilcox.test(SG ~ Caffeine, data = SGData, alternative = "two.sided", exact = FALSE)
print(result)
```
```{r}
p<- ggplot (SGData, aes(x=Sodium_per_ounce, y=SG))+
geom_point() +
geom_smooth(method = lm, se=FALSE, fullrange = TRUE) +
labs ( y="Specific Gravity", x="Sodium per ounce") +
  theme_minimal()+
  theme(axis.text=element_text(size=14),  axis.title = element_text(size = 14), title = element_text(size = 14))
p
spearmanresult <- cor.test (SGData$SG, SGData$`Sodium_per_ounce`, method = "spearman")
```
```

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````
print(spearmanresult)
```
```{r}
SGData$Carbonated <- as.factor(SGData$Carbonated)
p <- ggplot(SGData, aes(x = Carbonated, y = Calories_per_ounce)) +
  geom_boxplot(fill = "white", fill = "#3366FF", color = "#3366FF") +
  geom_point(position = position_jitter(width = 0.05), size = 3, color = "black") +
  labs(x = "Carbonation Status", y = "Calories per ounce" ) +
  theme_minimal()
p
result <- wilcox.test(Calories_per_ounce ~ Carbonated, data = SGData, alternative = "two.sided", exact = FALSE)
print(result)
```
```{r}
p <- ggplot(SGData, aes(x = Sugar_Type, y = SG)) +
  geom_point(position = position_jitter(width = 0.1), size = 4, color = "black") +
  labs(x = "Sweetener Type", y = "Specific Gravity" ) +
  theme(axis.text.x = element_text(angle = 45, vjust = 1, hjust = 1))
p
```
````
````