

Brewing Coffee Samples: The coffee samples were brewed using a drip coffee maker (Mr. Coffee, 12 Cup Switch Coffee Maker) following the brewing instructions on the package for coffee grounds to water ratio for each sample (Table 1). The measured coffee grounds were placed in a clean paper filter (coffee filters, Harris Teeter, unbleached) after filling the coffee maker reservoir with cold deionized water (DI). The coffee pot and filter basket were washed and rinsed with DI water after each coffee-making cycle.

Determination of pH Values: The pH readings were recorded using a pH meter (Accumet AB 150, Fisher Scientific, Pittsburgh, PA) after calibration with standard pH buffers (4.0, 7.0, and 10). The pH values of each coffee sample were measured in triplicate by placing the pH electrode into the sample after cooling down the sample to room temperature (~25 °C). The pH electrode was rinsed thoroughly with DI water and wiped clean between measurements

Determining Total Dissolved Solids (TDS): TDS refers to the total concentration of dissolved substances including

minerals, salts, ions, and other organic and inorganic compounds. The sample should be at room temperature to measure the TDS using a refractometer (Boss Refractometers, National Industrial Supply). A few drops of the coffee samples were placed onto the refractometer's prism surface after which the prism cover was gently closed to ensure no air bubbles or gaps between the prism and the liquid. The reading of TDS (%) was taken in triplicate by looking through the eyepiece of the refractometer until a clear line or boundary could be seen between the light and dark areas.

Statistical Analysis: Each experiment was performed for a total of three times and the mean and standard deviation of the results were recorded. Additionally, an analysis of variance using one-way ANOVA was conducted (SAS version 9.4) along with Tukey's test to determine the differences in the mean values of the recorded data values. In order for the results to be considered statistically significant, the p value must be less than 0.05.

Table 1. Brewing method and instructions for coffee samples

Coffee Code	Brewing Method	Instructions
XL96	Drip	2 Tbsp of coffee/8 oz of DI water
XL21	Drip	1 Tbsp of coffee/6 oz of DI water
XL43	Drip	2 Tbsp of coffee/6 oz of DI water
XL76	Drip	2 Tbsp of coffee/6 oz of DI water
XL97	Drip	35 g of coffee/500 ml of DI water
XL65	Drip	30 g of coffee/500 ml of DI water
XL54	Drip	2 Tbsp of coffee/6 oz of DI water
XL10	Drip	2 Tbsp of coffee/6.75 oz of DI water
XL32	Drip	1.5 Tbsp/6 oz of DI water
XL87	Drip	2 Tbsp of coffee/6 oz of DI water
XL98	Drip	2 Tbsp of coffee/8 oz of DI water

RESULTS AND DISCUSSION

Figure 1 shows the pH values of brewing coffee samples, which were all dark-roast in this experiment. The pH

measurements for coffee samples displayed a low acidity in sample XL96 (pH 5.74) which was significantly different ($P < 0.05$) from other samples. The higher acidity was

observed in samples XL10, XL65, and XL98 (pH 4.96, 4.99, and 5.02) respectively. The pH values for the rest of the samples ranged between pH 5.10 - 5.28 which is within the expected average pH range of the regular commercial coffee. Many factors can affect the final pH level of brewing coffee including the roasting temperature. Heat initiates a series of chemical changes in the coffee beans during the roasting process which alters the flavor profile of the coffee. Moreover, the acidity of coffee can also be affected by the type of roast. The acid composition of coffee beans changes dramatically during roasting. In addition, chlorogenic, citric, and malic acid are degraded, although quinic acid concentration increases due to the presence of CGA degradation [13]. Some bioactive chemicals such as total phenolic compounds and chlorogenic acids break down gradually throughout the roasting process, which is influenced by the roasting temperature and intensity [7].

TDS is a measurement of the concentration of dissolved solids in a liquid, typically expressed in parts per million (ppm) or as a percentage [17]. In the context of brewing coffee, TDS is often used to assess the strength

and flavor of the coffee. A higher TDS reading generally indicates a stronger and more concentrated coffee with bolder flavors while a lower TDS reading suggests a milder and potentially under-extracted brew. Figure 2 shows the TDS of brewing coffee samples. The highest TDS was observed in sample XL10 with a value of 2.7% and the lower TDS was in sample XL21 with a value of 1%. Most coffee samples had a TDS range between 1.4-2%. In an analysis of how TDS affected the sensory qualities of drip coffee, [18] concluded that coffee with a lower TDS was sweeter while coffee with a greater TDS was more acidic. The degree of grinding has a significant impact on the physicochemical characteristics of brewing coffee such as pH and TDS. To manage extraction and dispersion, roasted beans must be ground into a smaller size and, as a result, TDS decreases with increasing particle size [19-20]. The TDS in drip coffee is influenced by factors such as the coffee beans chemical composition, the size of the coffee grounds, the roasting temperature, the temperature of the water used for extraction, and the extraction time. [17, 20] indicated that the TDS decreased as the roasting time increased.

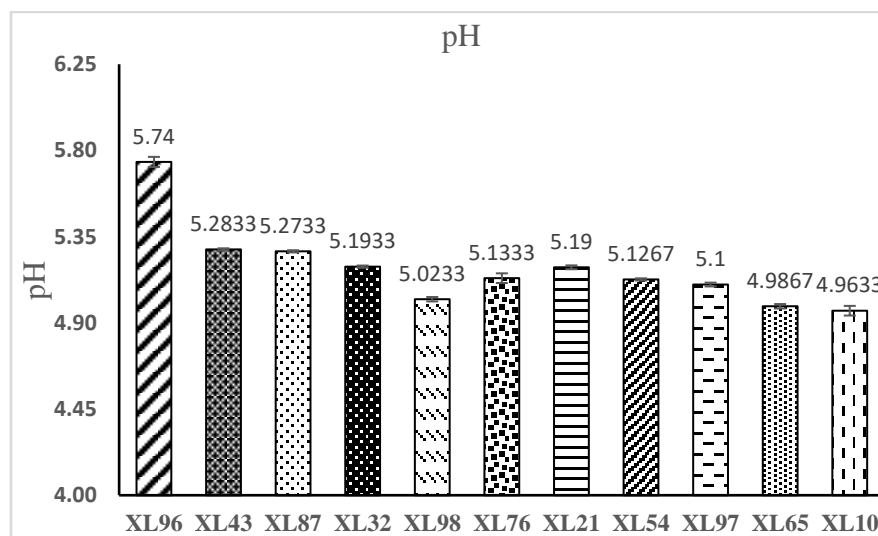


Figure 1. The acidity of coffee samples measured by pH (Each value is the mean ±SD. Sample size is n = 3 for pH. Superscripts a–f denotes significant (p < 0.05) differences between pH values of brewing coffee samples as determined by the Tukey-tests.)

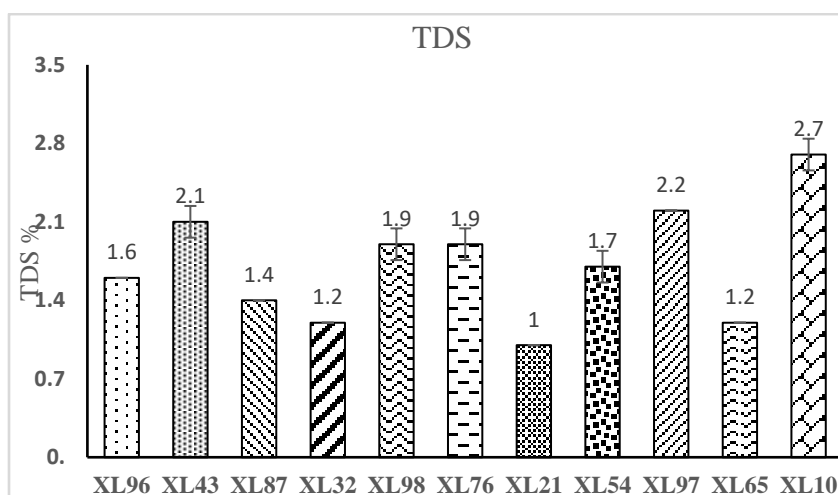


Figure 2. TDS (%) values of coffee samples. (Each value is the mean \pm SD. The sample size is $n = 3$ for TDS. Superscripts a–f denotes significant ($p < 0.05$) differences between TDS values of brewing coffee samples as determined by the Tukey-tests.)

CONCLUSION

In the present study, the pH and TDS values of different commercially packaged coffee products sold in retail stores in North Carolina were evaluated in order to investigate the accuracy of the information on coffee products labeled as low acid or acid-free. Our results showed a significant difference in pH measurements among coffee samples, with only one of the seven low-acid coffee brands tested, being significantly less acidic than average commercial coffee and above the critical pH line (pH 5.5). Based on our study, customers will have access to more accurate information when purchasing roasted coffee that has been labeled as low acid. Our results serve to emphasize the need to establish a reliable set of standards for the labeling of low-acid coffee in packaged coffee products. This effort will help the coffee industry to be better informed on how coffee processing can impact the acidity of the final product. This new standard for low-acid coffee should reference the medical definition of critical pH, include a standardized method for measuring pH, include clear information regarding acidity levels on all packaging labels, and demonstrate assurance from the industry regarding compliance with this new standard.

List of Abbreviations: TPC: Total Phenolic Compounds, CGA: Chlorogenic Acids, OAs: Organic Acids, TDS: Total Dissolved Solids, PE: Percent Extraction, DI: Deionized Water.

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Competing Interests: The authors hereby declare that there are no conflicts of interest.

Authors Contributions: All authors Abdulhakim Sharaf Eddin (ASE), Philip Junior Yeboah (PJY) and Salam A. Ibrahim (SAI) contributed equally to the manuscript. ASE: Wrote the manuscript and conducted the methodology. PJY drew the graphs and supported all laboratory activities. SAI: managed the project, designed the

experiment, conducted data analysis, edited the manuscript

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