Textural Variations of Pizza in Commercial Establishments

An Interactive Qualifying Project Report

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Degree of Bachelor of Science

by

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Abstract

The primary factors in determining the favorability of pizza are taste and texture. Although significant data regarding the mechanical properties of bread and the rheological properties of cheese has been collected, no effort has been made to combine these ingredients as a composite material. In this study the tensile properties, browning intensity, and break angle are examined to provide a detailed analysis of the overall favorability of pizza. A comparison is made between locally and nationally produced pizzas with respect to their textural properties.

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Introduction

Pizza is one of the most common foods in the United States with 93% of consumers eating pizza once per month and the average consumer eating pizza 3 times per month. Most of these pizzas are sold in the 65,000 pizza restaurants in the country that generate $40 billion worth of sales annually. Due to the high availability of pizza, the consumer has a wide variety of brands and styles to choose from. An analysis of consumer preference indicates that about 40% of people prefer to buy their pizza from a local establishment while 33% go to a restaurant that uses a brick oven. In addition, only 14% of people believe that franchises produce the most ideal pizza, suggesting that local and brick oven pizzerias have the most desirable characteristics.

Pizza, excluding those with toppings, consists of crust, cheese, and sauce. A recent survey of Worcester Polytechnic Institute students indicates that of the 3 attributes previously listed, crust is the most important part of the pizza. Of the available choices, consumers prefer a soft crust, deep dish pizza crust, or hand tossed pizza crust to any other type of pizza. Preferences not only in crust type, but in pizza as a whole, arise from the multitude of options available to the public. Further details regarding the survey are provided in Appendix A. Different restaurants use varying methods in preparing and cooking their pizza, making each one unique. The disparity in pizza production from one establishment to another accounts for the success that the pizza industry has had and results in the vast differences in the properties of pizzas from various restaurants.

One of the principle characteristics of pizza is its texture. Qualitative terms such as tough, stringy, and chewy are often used to describe the taste of food. While these descriptions convey the general behavior of the pizza, it becomes difficult for restaurants to employ these criteria as a means of quality control. Assessing the quality of a pizza using quantitative texture analysis provides for a better means of understanding the mechanical properties that consumers prefer in their pizza. Researching this type of work in regards to pizza and similar foods, such as bread and cheese, allowed for the proper development of texture tests to be determined. By testing these properties in local stores, brick oven pizzerias, and national franchise pizzas, consumer preference can be understood. This research allows restaurant owners to better understand what characteristics their customers value in a pizza.

This study has been submitted for publication in the Journal of Texture Studies in order to reach a larger audience of food scientists. This audience will be able to further expand on the research of textural properties of pizza in order to further benefit the scientific community.

Objectives

This work aims to complete the following objectives:

1. Expand on existing research in the field of food science, particularly regarding texture studies.
    (a) Measure the mechanical properties of a popular food product.
    (b) Compare the mechanical properties of pizza to those of its separate ingredients.
    (c) Establish relationships between the texture and appearance of pizza, and the manner in which it is baked.
2. Use engineering criteria to further understand consumer preference in pizza.
    (a) Use quantitative data to make inferences regarding the properties of pizza deemed most desirable by consumers.
3. Generate a greater interest in understanding the quantitative properties of pizza as a composite of bread, sauce and cheese.

Methodology

The purpose of this Interactive Qualifying Project was to determine how textural properties influence consumer preference in pizza. This goal was accomplished by conducting a series of experiments on pizza and comparing the data obtained to existing literature on the pizza's fundamental ingredients.

Research was divided into consumer favorability in pizza and textural properties in pizza and similar foods. In order to understand consumer preference, a survey was distributed to Worcester Polytechnic Institute students and compared to other surveys conducted in industry. The research on textural characteristics indicated that little information on pizza was available, so foods that show similar trends in this area were also researched. These foods include breads consisting of different flour compositions and several cheeses.

Results from the surveys showed consumer preference in qualitative terms, such as chewy, tough, etc. Since these descriptions are not feasible to use in quality control, the need for testing mechanical and visual characteristics of pizzas from various commercial establishments arose. Tensile testing and color intensity experiments were conducted as a means of obtaining quantitative data. The analysis of visual and mechanical characteristics of pizza allows industry to turn the aforementioned qualitative terms into statistics that can be reproduced and used to maintain quality control.

In order for this study to reach a broader audience of food scientists and restaurateurs, the following article was submitted to the Journal of Texture Studies. This article is presently pending review for publication.

Original Research Article

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TEXTURAL VARIATIONS OF PIZZA IN COMMERCIAL ESTABLISHMENTS

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KEYWORDS

Pizza, tensile property, Maillard reaction, chewiness, toughness, texture.

ABSTRACT

The primary factors in determining the favorability of pizza are taste and texture. Although significant data regarding the mechanical properties of bread and the rheological properties of cheese has been collected, no effort has been made to combine these ingredients as a composite material. In this study the tensile properties, browning intensity, and break angle are examined to provide a detailed analysis of the overall favorability of pizza. A comparison is made between locally and nationally produced pizzas with respect to their textural properties. Pizza samples displayed a wide range of textural properties, which may be interpreted as a measurement of the toughness or chewiness of each pizza. Nationally produced pizzas tend to have low breaking points and a high degree of elasticity while local restaurants tend to be more rigid and brittle. Pizzas with greater variation in browning had a higher chance of failure due to shear stress.

INTRODUCTION

Pizza is one of the most common foods in the United States with 93% of consumers eating pizza once per month and the average consumer eating pizza 3 times per month (Technomic 2011). The majority of these pizzas are from the 65,000 pizza stores in the US that generate about $40 billion worth of sales (Barrett 2010). The high availability of pizza (1 store per every 4588 people (Barrett 2010)), provides many options for the consumer to select their desired brand. An analysis of consumer preferences indicates that almost 40% of consumers prefer to buy their pizza from a local store while 33% go to a restaurant that uses a brick oven. Only 14% believe that franchises have the best pizza, therefore, local and brick oven pizzas have the most desirable characteristics.

The main attributes of a pizza are the crust, cheese, and sauce. A recent survey of college students (n > 800) conducted by the present authors indicates that almost 50% believe that crust is the most important trait and almost 30% think that a soft crust is ideal. Another survey conducted by Technomic, Inc. shows that people between the ages of 18 and 34 also prefer the crust of a deep dish or hand tossed pizza to other options (Technomic 2011). These preferences in style and pizzerias arise from the multitude of options available to the consumer. Each restaurant employs different techniques in making their pie, causing pizza to have a complex nature. As a result, different pizzas contain distinct properties causing consumers to prefer one establishment over another.

One of the principal characteristics of pizza is its texture. Commercial pizzerias use qualitative terms such as chewy, tough, stretchy, etc. to describe the taste of their food. Although such description highlights the general behavior of the pizza, it is empirical in nature and does not provide a means for quality control. In addition to using sensory properties, it would be vital to assess the quality of the pie through quantitative texture measurements. Research on quantitative texture analysis has been conducted on similar foods such as bread (Angioloni et al.2006; Scanlon et al 2001) and cheese (Dimitreli et al 2008; Brown et al 2003; Fife et al 2002). However, texture experiments on pizza as a composite of bread, sauce and cheese are lacking. This paper analyzes mechanical properties of different pizzerias to correlate this data to consumer preference. In addition, the textural qualities of pizzas from local and national brands were compared to understand the rationale behind customers preferring local to national brands.

MATERIALS AND METHODS

Typical cheese pizzas, approximately 300mm in diameter, were purchased in Worcester, Massachusetts from local restaurants and national franchises. Throughout the following procedure, two varieties of samples are taken. A sample of crust is defined as a sample taken from the outer edge of the pizza, where there is no sauce or cheese. Such samples are produced by making cuts tangent to the outer edge of the pizza. An interior sample is defined as one taken anywhere in the region of the pizza within the crust, containing bread, sauce, and cheese. Typical samples of each variety are depicted in Fig. 2.

The hot pizzas were purchased from local and national franchises in boxed containers and immediately transported to the laboratory. Sections for test samples were cut according to the scheme shown in Fig. 1. The sample geometry was selected so as to correspond to ASTM standard D638-08 (Type IV). The mechanical properties of the pizza were measured using an Instron model 5544 machine. Cut samples were then clamped into the Instron machine and tested using Bluehill software. Similar methods of determining the tensile properties of bread have been reported (Nussinovitch 1990). Upon testing at least 5 warm samples of each pizza, the remaining pie was refrigerated. After 24 hours, the refrigerated pie was sectioned and 5 additional cold samples of each pizza were cut and tested using the Instron machine. All broken samples were carefully wrapped and frozen for fracture analysis.

The Maillard reaction was gauged by taking photographs of the top of each crust and the bottom of each pizza using a camera at magnification of 1X. The top of the pizza is defined as viewing the pie perpendicular to the cheese layer, with the cheese facing upwards, as shown in Fig. 1. The bottom, or underside, of the pizza is defined as the perpendicular view of the pizza with the cheese facing downwards, also shown in Fig. 2. The photographs were uploaded into the GNU Image Manipulation Program, or GIMP, and the scissors select tool was used to select the portion of the picture that was the crust of the pie. The shade of yellow with an intensity value of 226 was inserted as the background color to contrast the crust. These pictures were then analyzed using MATLAB software to determine the average relative intensity of the picture, excluding the specific relative intensity of the yellow background. The relative intensity values that were low had a greater browning effect and those with high values had a lesser browning. Fig. 4 shows examples of high browning and low browning.

RESULTS AND DISCUSSION

The observed pizza samples may be divided into three general categories, with only small variations in the observed mechanical properties within each category. The three categories consist of the national franchise samples, the local franchise samples, and brick oven samples. The feasibility of dividing the samples into three categories is reinforced by Fig. 5, which shows the force-elongation curves obtained from the fresh crust of a typical sample of each pizza. All of the samples plotted in Fig. 5 are from freshly baked pizza crust, measured less than 30 minutes after baking. It is evident that the force-elongation curves from the national samples trace very similar paths, as do the local samples, while the brick oven pizza behaves differently from the other two groups. The parameters which characterize each category include the average maximum load experienced by the samples, the slope of the force-elongation curves, and the maximum extension experienced

by the samples before failure, all of which can be observed in Fig. 5.
As shown by the force-elongation curves in Fig. 5, most of the samples observed exhibit linear elastic behavior for loads less than 0.5 N. At greater loads, a considerable deviation from linear elastic behavior is observed. After each sample reaches the maximum load, which was used to calculate the samples ultimate tensile strength, additional deformation was observed as the load decreased and the sample approached its breaking point. Maximum loads were typically on the order of 1.5 to 2.5 N for samples taken from the pizza crust within 30 minutes after baking. When comparing the mechanical failure of crust and interior samples, the interior samples typically achieved lower maximum loads but experienced greater deformations before complete separation occurred. The differences between the average mechanical properties of the crust and interior samples may be observed by comparing the corresponding entries in Tables 1 and 3, respectively. Typically, complete separation of the fresh crust occurred at extensions of 8 mm to 12 mm, corresponding to strains of between 0.12 and 0.18. On average, the maximum extensions of the fresh pizza crust samples were very similar to those obtained for freshly baked bread crumb (Scanlon et al., 2000), with samples from national franchises generally extending to greater lengths than the brick oven and local samples.

While it is apparent from Fig. 5 that the pizza samples may be separated into three categories based on mechanical properties, further interpretation demands a more quantitative analysis of those characteristics. Of the mechanical properties calculated for each sample, one of the most significant is the Young's modulus. Since the pizza samples exhibit significant nonlinear behavior after experiencing strains of 1% or more, the Youngs modulus can only be consistently measured by estimating the first derivative of the stress-strain relationship close to the origin. In the case of pizza, the maximum load may be used to determine the force needed to bite off a portion of pizza, and the Youngs modulus may be interpreted as the elasticity, or stretchiness, of the pizza. In particular, the Young's modulus is roughly proportional to the maximum stress a sample can undergo before failure during the mastication process (Agrawal et al., 1996).

Of all the samples observed, the national franchises exhibited the lowest mean values of Youngs modulus. The large deformation experienced by national franchise pizzas in response to an applied load gives them a soft, stretchy texture. The local and brick oven samples, having higher values of elastic modulus, are more rigid, and have crispier textures than the national samples. Overall, the national samples displayed a Youngs modulus of about 140 kPa, compared to 250 kPa for the local samples and 400 kPa for the brick oven samples. Similar values of the Youngs modulus have been obtained for white bread crumb between the ages of 3 and 10 days (Davidou et al., 1996).

In addition to the amount of deformation experienced due to a certain load, another significant factor in the pizza's behavior is the ultimate tensile strength. The average values of ultimate tensile strength listed in Table 1 indicate that the tensile strengths of the local samples were typically 50-100% larger than those of national franchises. Samples from the brick oven pizza possessed tensile strengths roughly 50% higher than those of the local samples. Average values of the ultimate tensile strength ranged from 4 kPa, for some of the national franchise samples, to 12 kPa, for the brick oven samples. All average values of ultimate tensile strength were significantly higher than those obtained for fresh bread crumb, which is generally less than 1.5 kPa (Scanlon et al., 2000). The higher values of ultimate tensile strength for the pizza crust may be attributed to the formation of a brittle outer layer on the top and bottom of the crust, which is much more rigid than the interior crumb. The brittleness of the outer layer is responsible for many of the differences in mechanical properties between the local and national samples.

In addition to the quantitative difference in mechanical properties of the local, national, and brick oven samples, another characteristic which differentiates the three groups is the mechanism by which a sample ultimately fails. The mechanism of failure can be understood more clearly by analyzing the fracture surfaces from samples taken from each restaurant. In many of the samples, including 80% of fresh crust samples from national franchises, failure occurred along a plane with an outward normal in the direction of the axial tension; this type of break will be referred to as a flat break. The presence of a flat break suggests that failure occurs due to the normal stress exceeding the maximum allowed normal stress for the material. The geometry of the break is shown in panel A of Fig. 7, and a typical example is shown on the right side of Fig. 3.

Among the fresh crust samples from local restaurants, a substantially greater percentage, 60% of the samples, displayed a diagonal break after failure. A typical example of a diagonal break is shown on the left half of Figure 3. On closer inspection of the break, the fracture surface is not a single flat plane at a 45 incline. Like most of the observed diagonal breaks, the left half of Figure 3 displays a combination of two flat breaks, connected by a third planar surface at a sharp incline. The geometry of the break suggests that the pizza crust should be treated as a composite material, consisting of a soft crumb and a hardened outer layer, where most of the browning occurs. While each layer of the composite material appears to undergo failure due to normal stress, the failure of the crust sample as a whole is due to shear stresses acting at the interface between the two layers.

The local and brick oven samples, which have demonstrated high yield strength and a high elastic modulus also demonstrated a greater susceptibility to failure due to diagonal breaks than the national franchises. The high probability of a flat break suggests that the softer, chewier pizzas of the observed national franchises failed due to a more uniformly distributed normal stress. The greater frequency of diagonal breaks observed in local and brick oven pizzerias may imply that failure in these samples is due to a slip occurring between two layers with vastly different mechanical properties.

Although the primary motivation for dividing the observed samples into three categories was the comparison of their mechanical properties, samples within each of the three categories also exhibited similar values of several other parameters, including baking time, baking duration, and the relative browning of the pizzas upper and lower surfaces. The averages of the relative intensity values are reported in Table 5 .

The baking time and duration in Table 1 may be used to predict the impact of baking conditions on the mechanical properties of the resulting pizza. Although the mechanical properties of the samples did not show a dependence on the baking temperature, the average cooking duration appears to be proportional to the ultimate tensile strength and Youngs modulus. The local samples were generally baked for longer durations of time than the national samples, and these local samples typically had higher values of elastic modulus and ultimate tensile strength than the corresponding national samples. The brick oven pizza, however, deviated strongly from the trend shown among the other samples, by possessing high values of the elastic modulus and ultimate tensile strength, and a low baking duration.

One plausible explanation for the unusually high elastic modulus and tensile strength of brick oven pizzas, in spite of their low baking duration, is the brick surface on which the pizza is cooked. The brick has a higher specific heat capacity than metals frequently used in ovens, such as iron. Thus, when a pizza is placed inside a brick oven a larger reservoir of heat is available to the pizza, which may be sufficient to offset the bricks lower thermal conductivity and increase the speed of the cooking process. Although a rough correlation has been drawn between the duration of cooking and the mechanical properties of the local and national pizzas, several other factors may also have a large effect on these properties. The difference in mechanical properties may result from a change in dough composition; the use of different flours in bread making can result in variation in fracture stress (Zghal et al. 2001).

One explanation for the variation between the mechanical properties among the different samples is the variation in browning. In pizza dough this browning is primarily due to the Maillard reaction. The Maillard reaction, one of the most important chemical occurrences that bakery products experience during their production (Capuano et al. 2009), accounts for the aroma, taste, and browning of cooked products (Martins and Van Boekel 2005), including the dough of a pizza pie. Relative intensity values obtained to measure the extent of browning for the tested samples are listed in Table 5.

The national stores have the lowest relative intensity values for the bottom of the pizza compared to the other samples, meaning that they experience more browning on the bottom surface than the local or brick oven stores. The standard deviation of the bottom of all the samples shows that some portions of the pie experience a high amount of browning, while other spots undergo less browning. Likewise, the top of the crust of the samples experience a similar standard deviation in relative intensity. In the top portion, the national stores and local franchise 1 display similar values. Local franchise 2 experiences a very high degree of browning while the brick oven pizza undergoes the least amount of browning on the top portion of the pie. The high degree of browning on the top surface suggests that local franchise 2 is cooked using mostly convection, causing more cooking to occur on the top, while the brick oven pizza is primarily cooked through conduction through the brick surface. Furthermore, local franchise 2 experiences the largest difference in browning between its top and bottom surfaces of any sample, with significantly more browning occurring on the top portion of the pie. The brick oven pizza displays the second highest variation in relative intensity between its upper and lower surfaces, with more browning occurring on the bottom of the pizza. The two national chains and local store 1 have smaller differences between top and bottom, suggesting a more equal distribution of browning from conduction and convection.

The differences in browning between the top and bottom of the crust may contribute to the type of break that occurs in each pizza. Pizzas with a large difference in browning, such as the brick oven and local franchise 2, observed a higher percentage of diagonal fractures due to shear stress. Pies that did not display a large difference in browning between their top and bottom surfaces, such as national franchise 1, had a much higher probability of experiencing straight breaks. The method used in cooking each pizza may have strongly influenced the fracture type in the crust samples, as well as the browning. In addition to the type of cooking, the other factors can significantly affect browning include the dough composition and the baking duration. The type of flour used in making the dough has a large effect on the extent of the Maillard reaction (Zghal et al. 2001). Also, the combination of cooking time and temperature can change the extent of the reaction (Martins and Van Boekel 2005). Any of these factors may have played a role in the extent of the Maillard reaction, and thus the amount of browning observed.

In addition to samples from the fresh crust and interior of the pizza, all Instron tests were repeated for crust and interior samples which had been refrigerated for 24 hours. The force-elongation curves for fresh and refrigerated pizza samples from the same restaurant are shown in Fig. 6. Compared to the freshly baked crust, refrigerated crust samples had much steeper force-elongation curves and higher breaking points. However, refrigeration did not consistently increase the Youngs modulus or ultimate tensile strength of the interior samples. In general, refrigeration could either increase or decrease the toughness of an interior sample, with approximately equal probabilities of either occurrence.

The observation that refrigeration causes pizza crust to become more rigid agrees well with the existing literature on refrigerated bread. The hardness of bread products has been found to increase when the bread is stored at low temperatures for a long duration of time (Bárcenas 2003).

CONCLUSION

When comparing the mechanical properties of pizzas from the most profitable national franchises in the U.S. to those from local restaurants, several general trends appear. The nations best-selling pizzas demonstrated a tendency to be softer, weaker, and more elastic than the local restaurants tested. These samples typically exhibited the lowest overall Youngs modulus, the lowest ultimate tensile strength, and the longest elongation at fracture.

The mechanism by which local and national samples fail appears to differ greatly. The national samples were more likely than local samples to fail due to normal stress, with most samples exhibiting flat fracture surfaces normal to the direction of the axial load. Most of the local samples appeared to exhibit a pattern of failure due to normal stress in two distinct regions, which separate from each other due to excessive shear stress. The feasibility of treating a local sample as the composition of two distinct layers is reinforced by the large difference in browning shown between the upper and lower surfaces of the local pizzas.

Furthermore, it appears that an extremely high baking temperature is not necessary to obtain tougher pizza. Instead, the toughness of pizza appears to be dependent on other characteristics, which may include the type of oven being used, the duration of the baking period, and the chemical composition of the dough. A thorough understanding of these properties is vital to entrepreneurs in the pizza industry, since recent studies suggest that textures play an integral part in the consumer's choice of food product.

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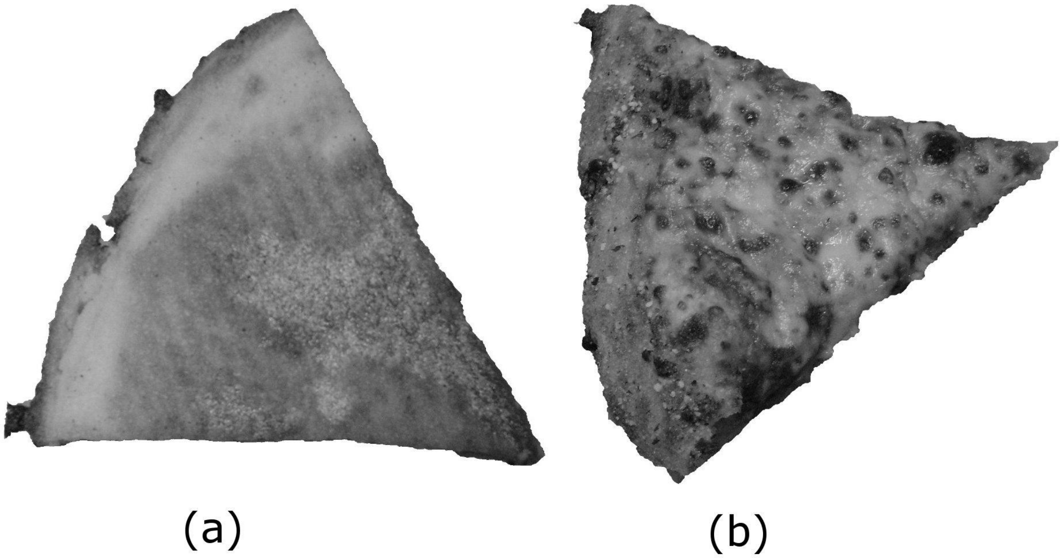

Figure 1: (a) The view of a pizza defined as the bottom. This picture is a perpendicular view of the pizza with the cheese layer facing away from the camera. (b) The view of a pizza defined as the top. This picture is the perpendicular view of the pizza with the cheese layer facing the camera.

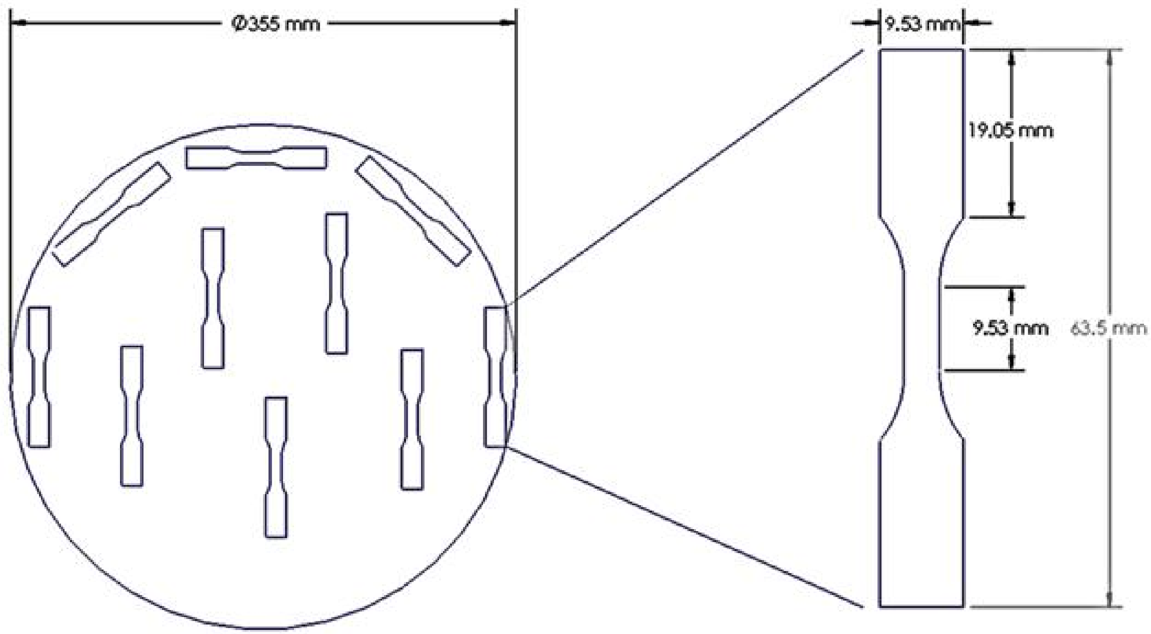

Figure 2: Arrangement of cuts on pizza and test sample used to measure the mechanical properties. The samples that are tangent to the edges are defined as crust samples. The remainder are defined as interior samples. The test sample was cut according to ASTM standard D638-08 (Type IV).

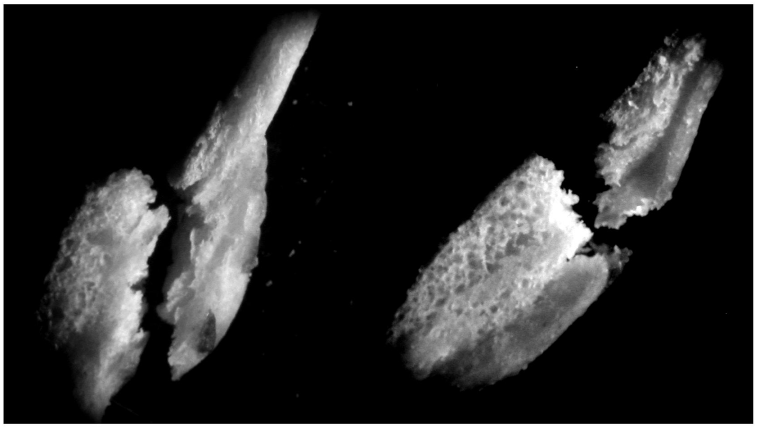

Figure 3: The sample on the left side shows a typical diagonal break for pizza samples that experienced a break due to shear stress. The diagonal type of break may be related to a high difference between the extent of browning between the top and bottom of the samples. The picture on the right side is a typical straight break that occurred in samples that experienced fracture due to normal stresses. Samples exhibiting straight breaks typically did not exhibit a large difference in the browning between the top and bottom portions of the crust.

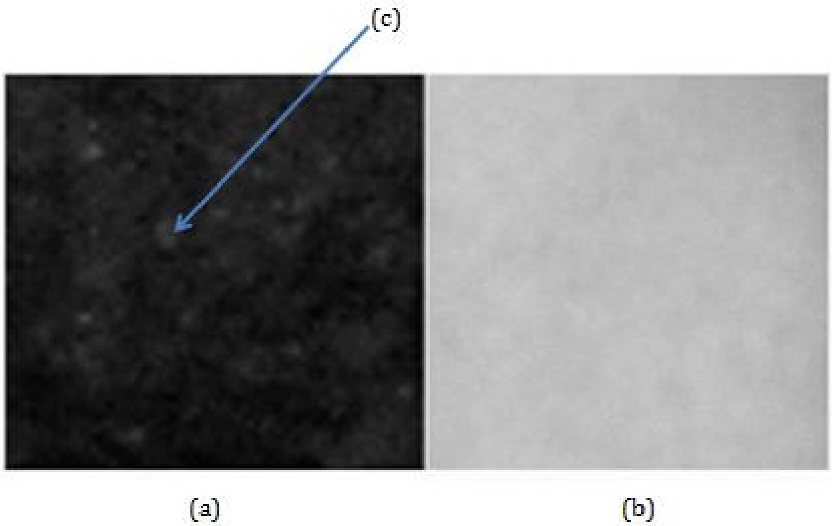

Figure 4: (a) A picture of a piece of pizza that experienced high browning after being cooked. The corresponding relative intensity value for this sample is 29 $\pm$10. (b) A picture of a piece of pizza that experienced little browning during the cooking process. The corresponding relative intensity value for this sample is 188 $\pm$ 8. (c) Even in the pizza with high browning, there are still localized regions with lower levels of browning. These sections, such as the region indicated, account for the deviation in the relative intensity value.

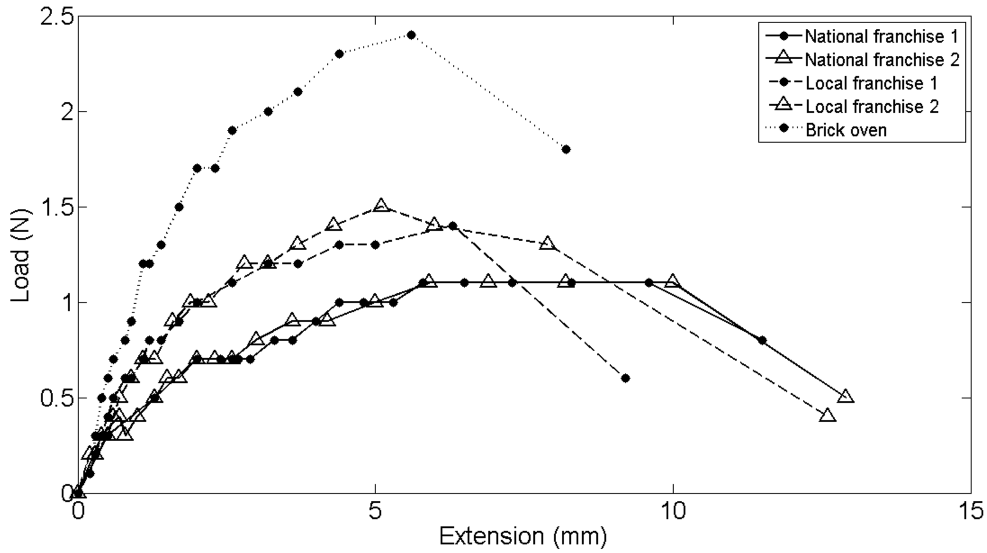

Figure 5: Force-elongation curves of crust samples taken from five restaurants, within 30 minutes of baking. All samples depicted here were extended at a strain rate of 1N/min and were cut using ASTM standard D638-08 (Type IV).

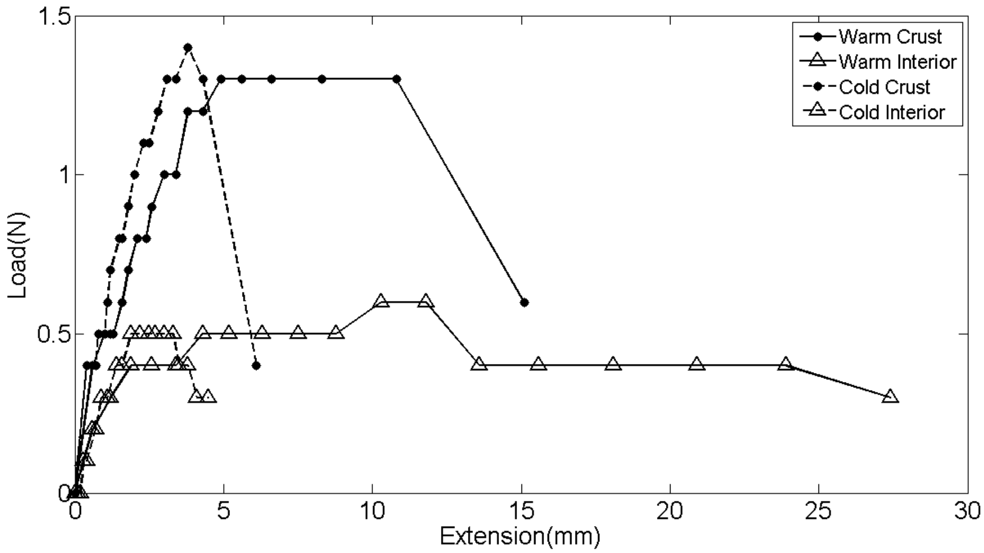

Figure 6: Force-elongation curves of samples taken from national franchise 1. Samples labeled as crust were taken from the outer edge of the pizza; samples labeled as interior were taken from the region of the pizza containing sauce and cheese. After fresh samples were tested, pizza was refrigerated for at least 24 hours prior to further testing.

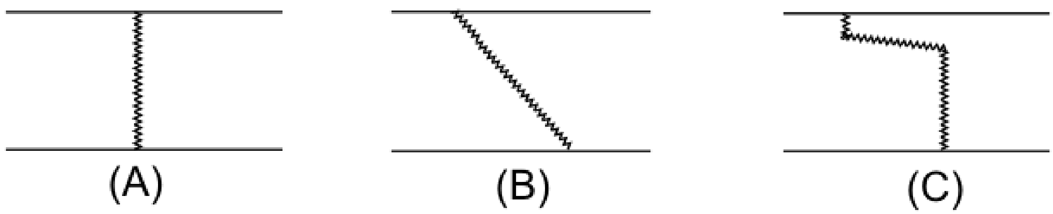

Figure 7: Predicted and observed break patterns in pizza samples. The lower and upper surfaces shown correspond to the top and bottom surfaces of the pizza crust. Most samples from national franchises broke in the manner depicted in (A), with the fracture surface perpendicular to the direction of the axial load. Most samples from local and brick oven pizzas exhibited diagonal breaks. However, in such cases the fracture surface appeared to be similar to (C), rather than (B). These inclined fracture surfaces occurred most frequently in samples with a higher variation in relative intensity between the two surfaces.

Table 1: **Young's modulus and ultimate tensile strength for fresh crust.**

Pizza	**Baking Temp. °C (°F)**	**Baking Time (sec)**	**UTS (kPa)**	**E (kPa)**
Local Franchise 1	240 (464)	750	8.3 ± 2.6	274 ± 196
Local Franchise 2	316 (600)	600	7.8 ± 0.5	228 ± 40
National Franchise 1	249 (480)	360	5.6 ± 2.1	163 ± 34
National Franchise 2	260 (500)	270	4.0 ± 1.2	117 ± 49
Brick Oven	302 (575)	330	12.0 ± 3.0	408 ± 94

Table 2: **Young's modulus and ultimate tensile strength for refrigerated crust.**

Pizza	**Baking Temp. °C (°F)**	**Baking Time (sec)**	**UTS (kPa)**	**E (kPa)**
Local Franchise 1	240 (464)	750	23.2 ± 1.6	1674 ± 1061
Local Franchise 2	316 (600)	600	12.3 ± 2.0	486 ± 524
National Franchise 1	249 (480)	360	4.36 ± 1.3	138 ± 44
National Franchise 2	260 (500)	270	10.4 ± 4.1	360 ± 218
Brick Oven	302 (575)	330	17.8 ± 6.1	1120 ± 985

Table 3: **Young's modulus and ultimate tensile strength for fresh pizza interior.**

Pizza	**Baking Temp. °C (°F)**	**Baking Time (sec)**	**UTS (kPa)**	**E (kPa)**
Local Franchise 1	240 (464)	750	9.9 ± 2.7	572 ± 237
Local Franchise 2	316 (600)	600	10.0 ± 1.7	716 ± 180
National Franchise 1	249 (480)	360	3.6 ± 0.4	71.9 ± 15
National Franchise 2	260 (500)	270	3.1 ± 0.4	415 ± 525
Brick Oven	302 (575)	330	5.1 ± 1.5	177.3 ± 42

Table 4: **Young's modulus and ultimate tensile strength for refrigerated pizza interior.**

Pizza	**Baking Temp. °C (°F)**	**Baking Time (sec)**	**UTS (kPa)**	**E (kPa)**
Local Franchise 1	240 (464)	750	8.8 ± 3.7	297 ± 189
Local Franchise 2	316 (600)	600	3.8 ± 2.4	147 ± 86
National Franchise 1	249 (480)	360	2.8 ± 1.2	104 ± 40
National Franchise 2	260 (500)	270	5.5 ± 2.8	222 ± 105
Brick Oven	302 (575)	330	6.6 ± 0.9	158 ± 50

Table 5: **Relative intensity values for the top and bottom surfaces of each pizza sample.**

Pizza	Intensity of Top	Intensity of Bottom	Difference in Intensity
Local Franchise 1	97 ± 30	126 ± 23	29
Local Franchise 2	61 ± 39	137 ± 40	76
National Franchise 1	96 ± 29	120 ± 27	24
National Franchise 2	88 ± 29	108 ± 31	20
Brick Oven	174 ± 34	125 ± 32	-49

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Appendix A

Survey

In order to obtain a better understanding of the choices consumers make regarding pizza, a survey was distributed to the students of Worcester Polytechnic Institute. The survey asked for the following ten pieces of information.

1. Participant's gender
2. Participant's age
3. What is the most important part of a pizza?
   (a) Crust
   (b) Sauce
   (c) Cheese
4. What type of crust do you prefer?
   (a) Thick crust
   (b) Thin crust
   (c) Soft crust
   (d) Crispy crust
5. How do you prefer your pizza cooked?
   (a) Light
   (b) Medium
   (c) Well Done
6. How much sauce do you prefer on your pizza?
   (a) No sauce
   (b) Light sauce
   (c) Average sauce
   (d) Heavy sauce
7. What do you look for in the ideal sauce?
   (a) Smooth
   (b) Chunky
   (c) Tangy
   (d) Sweet
8. How much cheese do you prefer on your pizza?
   (a) No cheese
   (b) Light cheese
   (c) Average cheese
   (d) Extra cheese

9. Which of these types of pizza do you prefer?
    (a) Local / Mom & Pop
    (b) Franchise
    (c) Frozen pizza
    (d) Oven baked / Homemade
    (e) Brick oven
10. What is your favorite pizzeria?
    (a) Domino's
    (b) Papa John's
    (c) Pizza Hut
    (d) Papa Gino's
    (e) Bertucci's
    (f) Uno's
    (g) Blue Jeans Pizza
    (h) Fresh Way Pizza
    (i) Tech Pizza
    (j) Morgan Dining Hall Pizza
    (k) Campus Center Pizza
    (l) Blue Bird
    (m) Wonder Bar
    (n) Fast Way
    (o) Fresh Way

The answers to questions 3, 4, 5 and 9 are of particular interest to the research paper, which emphasizes the importance of crust texture, and are shown in Figures 8, 9, 10, and 11, respectively.

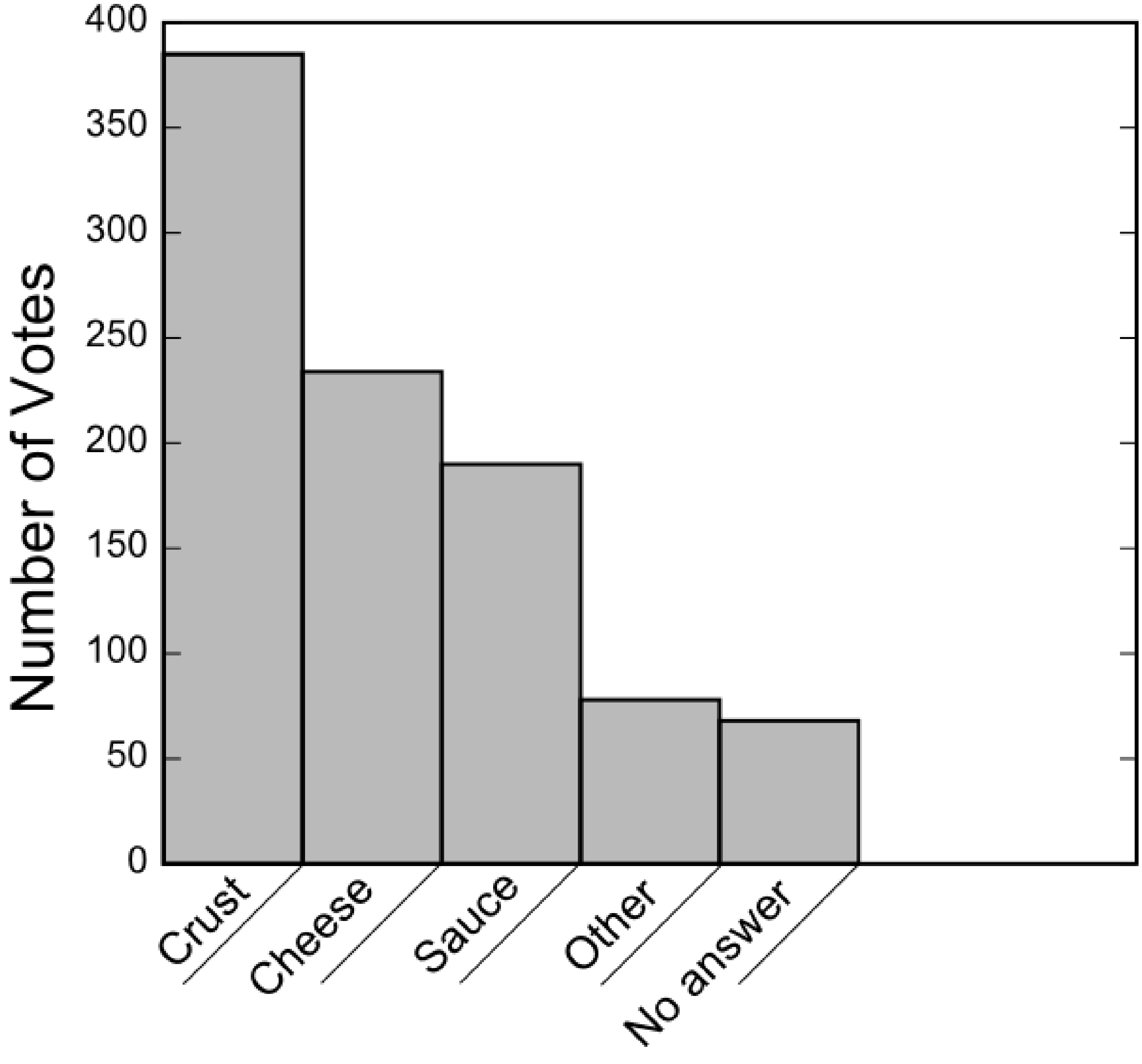

Figure 8: Answers to the question, "What is the most important part of a pizza?"

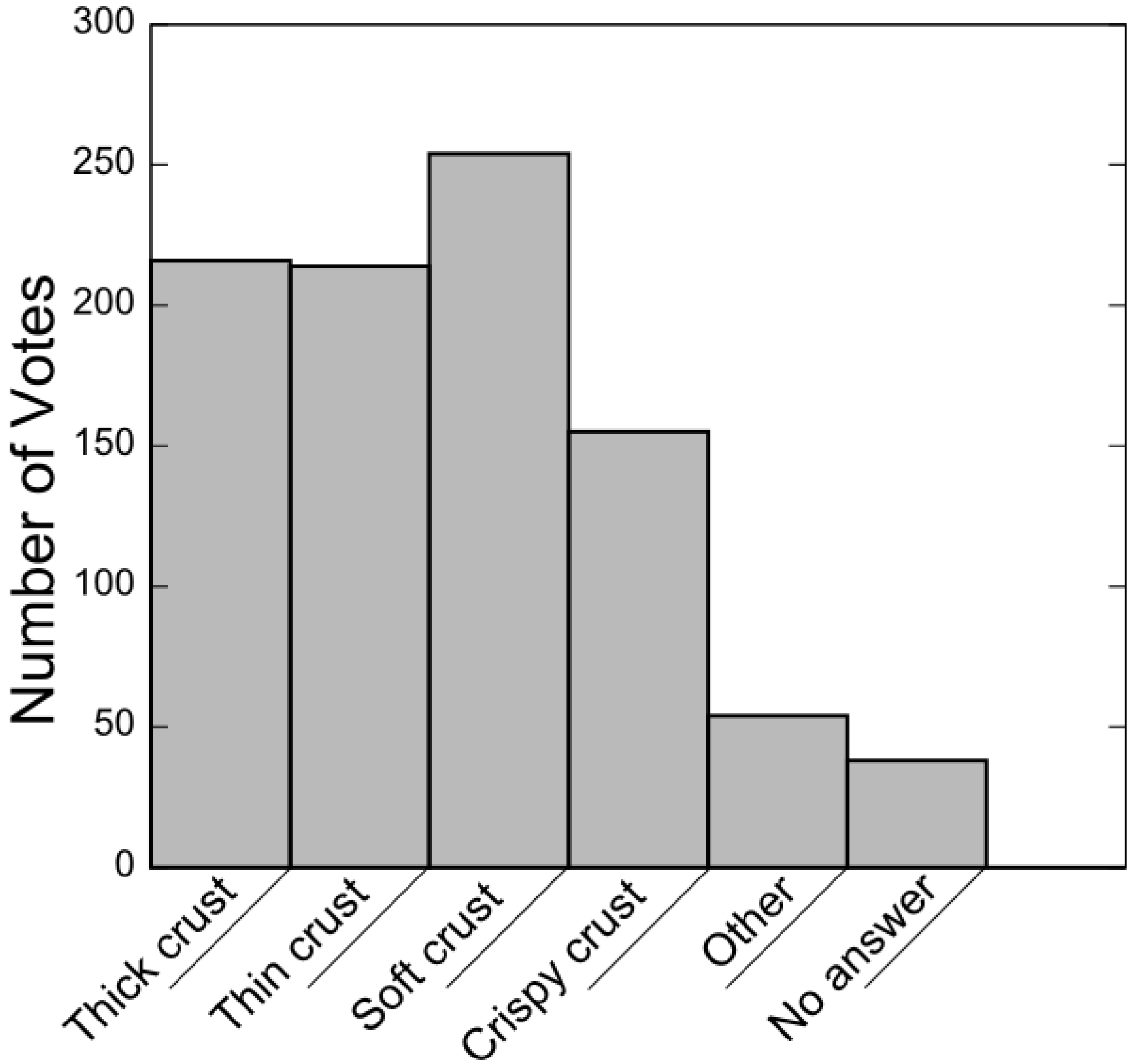

Figure 9: Answers to the question, "What type of crust do you prefer?"

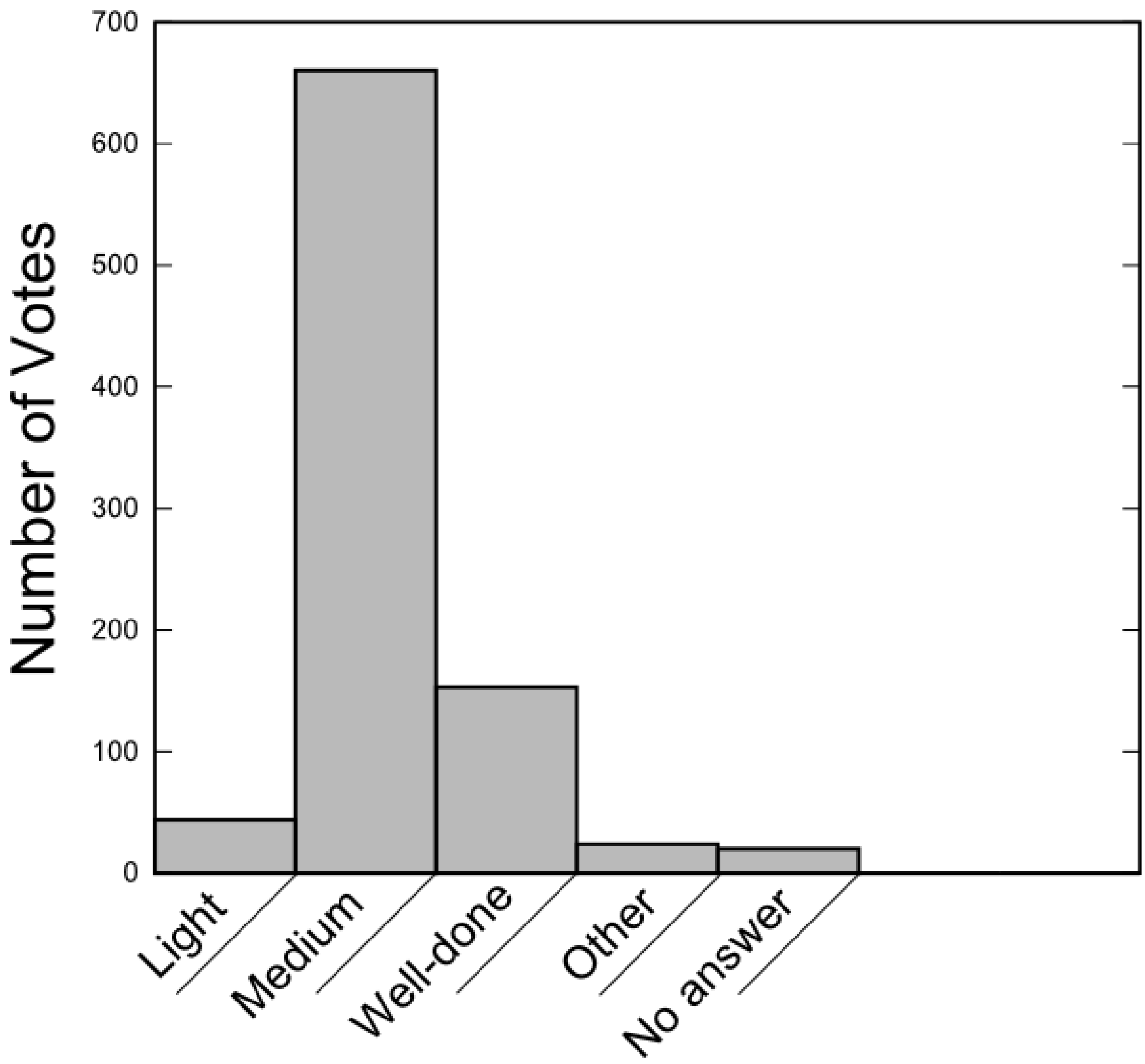

Figure 10: Answers to the question, "How do you prefer your pizza cooked?"

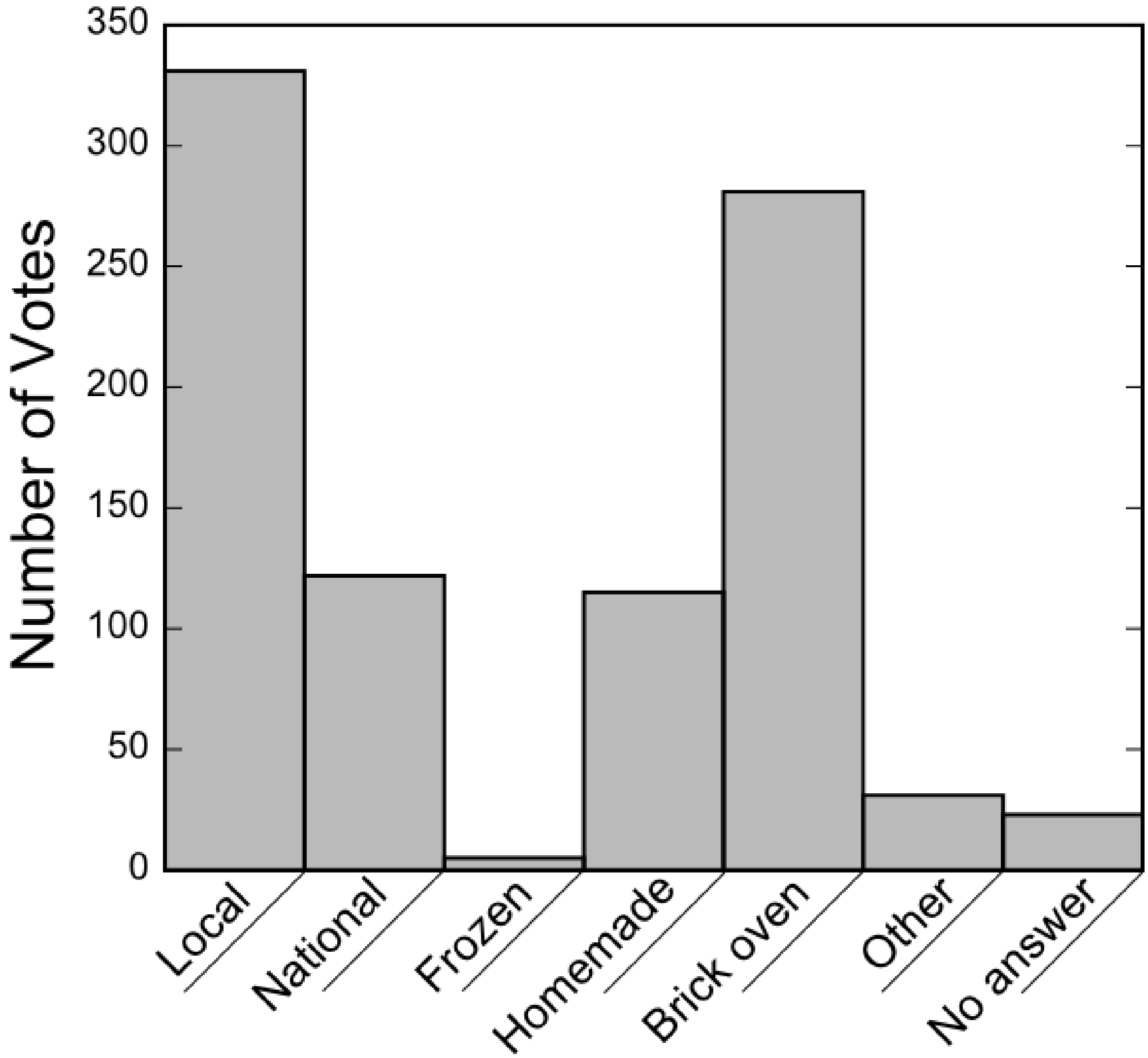

Figure 11: Answers to the question, "Which of these types of pizza do you prefer?"