Sous Vide Chicken Pasteurization Temperatures

By

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The views expressed in this paper are those of the author and do not necessarily reflect the official policy, position or views of BCIT, the Environmental Health Program or its faculty.

Abstract

Sous vide is a cooking technique which involves vacuum-packaging raw foods and placing the packages into a water bath where cooking time and temperatures can be carefully controlled. One health concern regarding sous vide is the issue of cooking at below recommended temperatures; this practice can lead to the survival of foodborne pathogens such as *Salmonella* when dealing with chicken. Because sous vide utilizes non-conventional cooking temperatures, the margin for error is smaller and more care must be taken ensure food safety.

Sous vide recipes vary greatly in terms of cooking time and temperatures, and as a result, there are a multitude of food safety concerns including the survival of pathogenic bacteria. This research project investigated one recipe which uses chicken breasts. The researcher logged the internal temperature of chicken breasts (n=30) as they were cooked according to a set recipe (66°C water bath for 23 minutes). The resulting values were then compared to time-temperature standards set by the Canadian Food Inspection Agency (CFIA) to produce a safe product.

The experiment was conducted in conjunction with the executive chef at a Burnaby restaurant who is also a member of the British Columbia Centre for Disease Control (BCCDC) Sous Vide Working Group.

A one-tailed one-sample t-test was used to determine the significance of the findings; the null hypothesis (H_o: measured temperature = target temperature) was rejected with a power of 1.00 at a p-value of 0.01. Chicken cooked under these particular sous vide conditions does not meet the guidelines for poultry set out by the CFIA.

Undercooked poultry can cause foodborne illness and it is recommended that a longer cooking time or a higher temperature sous vide process be used. Alternatively, further heat treatment may be used to achieve the appropriate temperature and dwell times.

Acknowledgments

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Introduction

Sous vide is a cooking technique that has been around since the 1970s but has only been popularized in North American in the last 15 years or so (Keller, 2008). Sous vide cooks at lower than conventional temperatures and typically requires the use of a vacuum sealer and an immersion circulator.

Sous vide as a research project was brought to the author's attention by Lorraine McIntyre of the British Columbia Centre for Disease Control (BCCDC) as an area of current interest in the restaurant profession. There is a desire within the industry to create a framework for a food safety/HACCP plan for sous vide products in the interest of public health and safety. This research project was conducted with the assistance of the executive chef of a Burnaby restaurant who is a member of the BCCDC Sous Vide Working group.

Minimum cooking temperatures are recommended by Health Canada to safeguard public health; cooking to these temperatures greatly reduces the risk of contracting foodborne illnesses. Is it possible to cook to below these temperatures and produce an item safe to consume? This research project investigated a sous vide recipe for chicken breasts and determined if it produced a safe product.

Literature Review

Sous vide is a French term that is translated to "under vacuum" and is used to describe a cooking technique where food is vacuumed-packed into plastic bags and placed in a cooking environment where time and temperature can be carefully controlled (Schellekens, 1996) - for example, a water bath or a steam oven. It is a technique that was first praised for its ability to produce an organoleptically-pleasing product before microbiological risks became the focus of research (Creed, 1995). Advocates of sous vide assert that it produces a better quality product with "better flavour, colour, texture and nutrient retention" than conventionally cooked foods (Creed, 1995). The high level of temperature control allows for food pasteurization at lower temperatures thus avoiding overcooking (Baldwin, 2008) and the vacuum-packing

prevents loss of volatile aromatic compounds and moisture (Church & Parsons, 2000 as cited by Baldwin, 2012). It is also a technique that has been widely used in the food service industry to extend the shelf-life of processed foods (Baldwin, 2012). The packaging prevents recontamination after processing (Betts & Gaze, 1995) and the reduced oxygen environment minimizes oxidation, preserving nutrients as well as extending the shelf life of the product (Rodgers, 2005).

Sous vide functions

Sous vide is capable of producing food that is raw, pasteurized or sterilized (Baldwin, 2012). While there are health hazards associated with eating raw foods, this review will only cover pasteurized sous vide foods in the interest of brevity. Sous vide can be used to make foods for various food preparations including cook-serve/cook-hold and cook-chill. The main public health concern with cook-serve or cook-hold is reaching pasteurization temperatures whereas cook-chill/cook-freeze requires additional assessment regarding temperature abuse, spore germination, long-term bacterial recovery and bacterial growth. The safest way to use sous vide is cook-serve (Baldwin, 2012) and is the focus of this review.

Foodborne illness

Foodborne illness (FBI) can be caused by a number of improper food handling practices, one of which is inadequately cooked food (BCCDC, 2009). Inadequate cooking allows the survival of pathogenic organisms which if ingested, can make the consumer ill. Thoroughly cooking food to recommended temperatures is an important step in preventing FBIs. Depending on the food in question, recommended temperatures vary and are based on the pathogens most commonly associated with that food. Beef can be cooked to 63°C and be considered safe while poultry should be cooked to 74°C (Health Canada, 2010). Sous vide can process food at a wide variety of temperatures but sous vide recipes often call for cooking and final temperatures lower (Keller, 2008) than those recommended by Health Canada.

Salmonella and Salmonellosis

Salmonella spp. is a species of FBI-causing bacteria commonly associated with chicken and can cause Salmonellosis (Health Canada, 2007a). In the United States and Canada, *Salmonella* is estimated to be the second-most common pathogen contributing to FBI (Public Health Agency of Canada, 2012) and in the United States, is the most common pathogen responsible for hospitalization as a result of FBI (Center for Disease Control, 2012). Salmonellosis is one of the more pervasive illnesses due to *Salmonella*'s low infectious dose - ingestion of just a few bacteria can cause foodborne-illness. Symptoms of Salmonellosis include diarrhea, fever and abdominal cramps and can be quite severe in high risk populations – the young, the old, the pregnant and the immuno-compromised (Health Canada, 2007a).

Foodborne illness from poultry can be avoided by cooking whole birds to an internal temperature of 85°C and poultry parts to an internal temperature of 74°C for 15 seconds (Health Canada, 2010). These values represent the temperature that is required to achieve a 7.0D lethality of *Salmonella spp.* and the temperature at which poultry is considered safe to consume. A 7.0D lethality can be translated to a 99.99999% decrease in bacteria. It is important to note that the lethal effect of heat on pathogens is not immediate; it takes time for the bacterial load to decrease. The length of time at which an internal temperature must be held (to be considered safe) is called the dwell time (Canadian Food Inspection Agency [CFIA], 2012a).

Time-Temperature relationship

Cooking safe food is based on a time and temperature relationship. While the general rule of thumb and the message dispersed by health authorities is to cook chicken until 74°C (Health Canada, 2010), there are other temperatures which also achieve the same levels of pathogen inactivation - so long as there is an appropriate dwell time. See Table 1 for CFIA-recommended holding temperatures. For example, a chicken breast (with 12% fat) held at an internal temperature of 57.8°C for 81.4 minutes will also achieve 7.0D lethality (or a 99.99999% reduction) and be considered safe to consume (CFIA, 2010).

Min. int. temp. (°C)	1% FAT	2% FAT	3% FAT	4% FAT	5% FAT	6% FAT	7% FAT	8% FAT	9% FAT	10% FAT	11% FAT	12% FAT
61.1	16.1 min	16.4 min	16.8 min	17.2 min	17.6 min	18.1 min	18.7 min	19.4 min	20.1 min	21.0 min	22.1 min	23.5 min
61.7	13.0 min	13.2 min	13.5 min	13.8 min	14.2 min	14.6 min	15.1 min	15.6 min	16.3 min	17.1 min	18.1 min	19.3 min
62.2	10.4 min	10.6 min	10.8 min	11.1 min	11.4 min	11.8 min	12.2 min	12.6 min	13.2 min	13.9 min	14.8 min	15.9 min
62.8	8.4 min	8.6 min	8.7 min	8.9 min	9.2 min	9.5 min	9.8 min	10.2 min	10.7 min	11.3 min	12.1 min	13.0 min
63.3	6.8 min	6.9 min	7.0 min	7.2 min	7.4 min	7.6 min	7.9 min	8.2 min	8.6 min	9.1 min	9.8 min	10.6 min
63.9	5.5 min	5.5 min	5.6 min	5.7 min	5.9 min	6.1 min	6.3 min	6.6 min	6.9 min	7.4 min	7.9 min	8.6 min
64.4	4.4 min	4.4 min	4.5 min	4.5 min	4.7 min	4.8 min	5.0 min	5.2 min	5.5 min	5.8 min	6.3 min	6.8 min
65.0	3.5 min	3.5 min	3.5 min	3.6 min	3.6 min	3.8 min	3.9 min	4.1 min	4.3 min	4.6 min	4.9 min	5.4 min
65.6	2.7 min	2.7 min	2.7 min	2.7 min	2.8 min	2.9 min	3.0 min	3.1 min	3.3 min	3.5 min	3.8 min	4.2 min
66.1	2.1 min	2.1 min	2.1 min	2.1 min	2.1 min	2.1 min	2.2 min	2.3 min	2.5 min	2.6 min	2.9 min	3.1 min
66.7	1.5 min	1.5 min	1.5 min	1.6 min	1.6 min	1.6 min	1.7 min	1.7 min	1.8 min	1.9 min	2.1 min	2.3 min

Table 1: *Minimum holding times for meat products containing poultry, excluding turkey, required to achieve a 7.0D reduction in Salmonella spp. Note*: Adapted from Canadian Food Inspection Agency, 2012. Meat and Poultry Products – Manual of Procedures. Retrieved from personal communication (P. Sharma, personal communication, December 12, 2012). See Appendix D for complete table.

Impact of non-conventional practices

As a result of the vacuum-packaging utilized in sous vide, anaerobic bacteria such *as Clostridium botulinum, Escherichia coli O157:H7* and *Listeria monocytogenes* are also of concern (Keller, 2008). *Clostridium* and *Listeria* are ubiquitous in the environment and can easily contaminate other foods; *E. coli O157:H7* is associated with raw beef and can also contaminate other foods in the processing area (CFIA, 2012b). Generally, addressing *Salmonella* will take care of other FBI-causing bacteria, but because non-conventional temperatures are being used in sous vide, the margin for error is smaller and care must be taken to prevent cross-contamination from occurring. Sous vide temperatures can progress slowly though the danger zone (some never leave it) which can facilitate bacterial growth or spore germination – especially if the food

is not served immediately. The danger zone is the temperature range in which pathogens can readily grow; it ranges from 4°C to 60°C and proper food handling dictates that as little time as possible should be spent in it (BCCDC, 2009).

Longer periods of cooking (i.e., hours) also add an unusual concern to cook-serve scenarios, the recovery of injured bacteria. Kim, Murano and Olsen found that in anaerobic environments, more *L. monocytogenes* survived compared to aerobic environments and that this survival was augmented by slow heating rates (1994, as cited by Hansen & Knøchel, 1996). For the purposes of cook-serve, conventional cooking procedures generally do not hold the food in the danger zone long enough for pathogens to grow (BCCDC, 2009) but some sous vide recipes cook for over 10 hours at sub-lethal temperatures (Keller, 2008). In these cases, prevention of pre-cooking contamination is the best defense.

The concern with sous vide cooking lies in the nature of the recipes which state the temperature for the water bath and either a precise cooking time or a window time for when the food is cooked. The recipes assume that the final internal temperature of the food will be the same as the water bath and that it will reach the target temperature within the specific time period. This is an unsubstantiated assumption as there are many factors which can affect the rate at which an object heats up (Silva & Gibbs, 2012). If the food is taken out of the water bath before the heat has had enough time to inactivate an adequate number of pathogenic bacteria; whoever consumes the food may develop a FBI.

In a commercial kitchen, an immersion circulator and a vessel of water are the equipment of choice; the set up can be seen in Figure 1. The immersion circulator heats the water, circulates it and measures the temperature (Keller, 2008). By this design, there is no method to monitor the internal temperature of the food while it is cooking and the chef must go by the recipe/experience to determine when the food is adequately cooked. However, Keller addresses this issue by stressing that the cooking times he provides in his recipes are based on fully-chilled foods entering a pre-heated water bath (2008).

Figure 1: Warming up a sous vide water bath with PolyScience immersion circulator

In addition to the process of sous vide, the set-up of the technique itself poses a few critical control points. Uneven temperature caused by poor water circulation and air pockets formed by water vapour in the bag should be avoided as they will affect the transfer of heat. Special consideration must also be given when portion sizes are varied (how does one proceed if the portion is larger than stated in recipe?) and if food is being cooked from frozen (Rodgers, 2005).

Factors affecting lethality of heat

The time required for the pasteurization of a food's coldest point (usually the thickest point) is called the come up time (CUT). It depends on the packaging material (if any) and the heating medium (Silva & Gibbs, 2012). The combination of vacuum-packing and heating via a water bath as done in sous vide maximizes the efficiency of heat transfer and allows greater temperature control (Baldwin, 2012). However, intrinsic properties of the food such as pH, fat content and the type of food itself also determine the CUT which can affect the rate of pathogen inactivation (Schellekens, 1996; Canadian Food Inspection System Implementation Group, 2004).

According to the CFIA, poultry with higher fat content requires a longer dwell time to bring numbers of *Salmonella spp.* down to a safe level (2010). Fat can act as a protective agent for bacteria. García-Linares, Gonzalez-Fandos, García-Fernández & García-Arias found that fish with higher levels of intrinsic fat showed a smaller microbial reduction after being cooked via sous vide. They also found a similar study concerning

beef and *added* fat that showed no relationship between microbial load reduction and fat content. However, García-Linares et al. suggested that added fat may not have the same protective qualities as intrinsic fat or simply that fish and meat react differently to heat (2004). A study by Juneja, Eblen & Marks found that fat levels in poultry affect the rate of *Salmonella* inactivation but also that the relationship was not consistent across all temperatures and fat percentages. The authors suspected that the death curves were not linear as they had assumed and proposed further clarification in future research (2001).

In another study, Juneja and Marks found that the rate at which heat is applied can affect the thermo-tolerance of *Salmonella*. They found that the slow heating seen in sous-vide has an effect similar to heat-shocking and that the more slowly heat was applied, the more thermo-tolerant *Salmonella* became (2003). Previously, Hansen and Knøchel had reported similar results with *Listeria monocytogenes* but the effect was only observed in beef in which the pH had been adjusted to be more alkaline (1996). This is noteworthy because food is often marinated prior to cooking and marinades can alter the pH of the cooking environment.

Mathematical models have been created in an attempt to account for the variables in sous vide cooking. Ghazala, Ramaswamy, Smith and Simpson developed a model and verified it with a microbial process. The authors were looking to balance sensory quality and safety and realized that each product needed to be approached differently (1995). However, in their process, many assumptions were made which makes application of their model difficult. Their model was based on uniform, brick-shaped samples of food and the verification process was broth-based and only considered pH. Very few foods can be expected to be cooked in bricks and other factors in addition to pH affect the pasteurization process (Silva & Gibbs, 2012).

Sensory Considerations

One of the main forces driving the popularity of sous vide is the quality of the end product (Creed, 1995). Different foods have different temperatures at which they are optimal from a sensory perspective and sous vide is capable of manipulating that. Fish tends to be 'cooked' to relatively low temperatures to maintain

a pleasant texture (García-Linares et al., 2004; Keller, 2008); these temperatures are not hot enough to address pathogens (Baldwin, 2012). Pork on the other hand, can be cooked above the standard recommended minimum of 74°C and maintain pleasant organoleptic qualities (Keller, 2008). From a public health perspective, it is the recipes which cook at below recommended temperatures that are of concern.

Outbreaks and Legislation

In a cooking technique where safe microbial limits are being tested, it would seem that related foodborne outbreaks would be quite likely. However, given all of the variables it should be noted that the researcher was not able to find any reports of FBI linked to sous vide and Peck, Goodburn, Betts & Stringer (2006) report that there have been no records in the academic or outbreak databases (as cited by Baldwin, 2012).

Currently, there is no B.C. legislation governing cooking temperatures; the Food Premise Regulation under the Public Health Act of B.C. simply states that "food [must be] processed in a manner that makes it safe to eat" (1999). Any kill temperatures, dwell times and minimum temperatures are simply guidelines. The Food and Drug Administration of the United States covers sous vide in its food code but the guidelines are quite general citing the need for a HACCP plan, cooking to required temperatures and maximum cold storage times (2009). Nonetheless, Health Canada has recognized the potential hazards of sous vide cooking as it is identified as a risk factor in the risk assessment of food service establishments (2007b).

Purpose of research project

Much of the existing research focuses on methods to ensure the quality and safety during the storage of sous vide foods (cook-chill). While it is known that the intrinsic properties of the food can affect the shelf-life stability of a product, most of the sous vide research challenges a food product that has already been cooked to recommended/safe internal temperatures. The researcher took this project as an opportunity to investigate the process of sous vide as foods are cooked from their raw state. The purpose of this research project was to

monitor the internal temperature of a chicken breast as it was cooked from raw using a standard sous vide recipe, to determine if pasteurization temperatures were reached and if appropriate holding times were observed to produce a safe product. The research questions addressed were:

- Does cooking chicken breasts according to a standard sous vide recipe create a product safe for consumption as defined by the CFIA? Does the chicken reach the required temperature? If so, does it remain at the required temperature for an adequate amount of time?

Methods & Materials

Materials:

- Polyscience Model 7306 Immersion Circulator
- 8L heat resistant tank
- 5L water
- 6x ACR SmartButton
- ACR SmartButton Interface cable
- TrendReader software
- PC computer
- 15x Food-grade polyethylene bags (30cmx40cm)
- Multivac vacuum sealer
- Clock
- Stopwatch
- Scalpel/knife
- 30x ~6oz chicken breast (skin on)
- Alcohol wipes
- Notebook
- Traceable® Lollipop™ waterproof thermometer
- Permanent marker
- Cooler with ice
- Scale

Methods:

ACR SmartButton

Software (TrendReader) set up

After TrendReader was installed on a PC, the SmartButton was set up as follows:

- Data collection interval: 1 minute
- Memory usage: Stop when full
- Start time: as desired, but for this project was set to be 30 minutes prior to the start time of the cooking process

Setup was accessed via the EDIT SETUP option which appears when the SmartButton is connected to the PC via the USB interface cable (ACR Systems, Surrey BC; K. Keilbart, personal communication, October 19, 2012).

Data retrieval

The SmartButton was placed into the reader and BACKUP was selected to retrieve data (K. Keilbart, personal communication, October 19, 2012). A temperature graph was produced, along with data in table format (ACR

Systems, Surrey BC) (See Figure 2). Data from the Data Table tab was then exported into NCSS and time stamps were colour-coded depending according to the stage of the experiment (pre-sous vide, sous vide and post-sous vide application); only data from the recorded start and end times were exported for statistical analysis.

Calibration

The SmartButtons are factory calibrated and are accurate to within 1.5°C from 45.5°C to 85°C. To check the accuracy of the SmartButtons, they were secondarily calibrated with the use of a Traceable® Lollipop™ waterproof thermometer in the water bath. After the immersion circulator reached 66°C, the data loggers and calibrated thermometer were allowed to sit in the bath for 5 minutes. Calibration data collected from the buttons at the end of the experiment were used to adjust for any discrepancies.

Chicken preparation

The researcher retrieved the chicken breasts from the fridge and recorded the weight before making a small cut approximately ½ inch deep into the thickest part of the chicken. The labelled data loggers were then inserted and the time was recorded. The chicken was then vacuum-packed at 60psi.

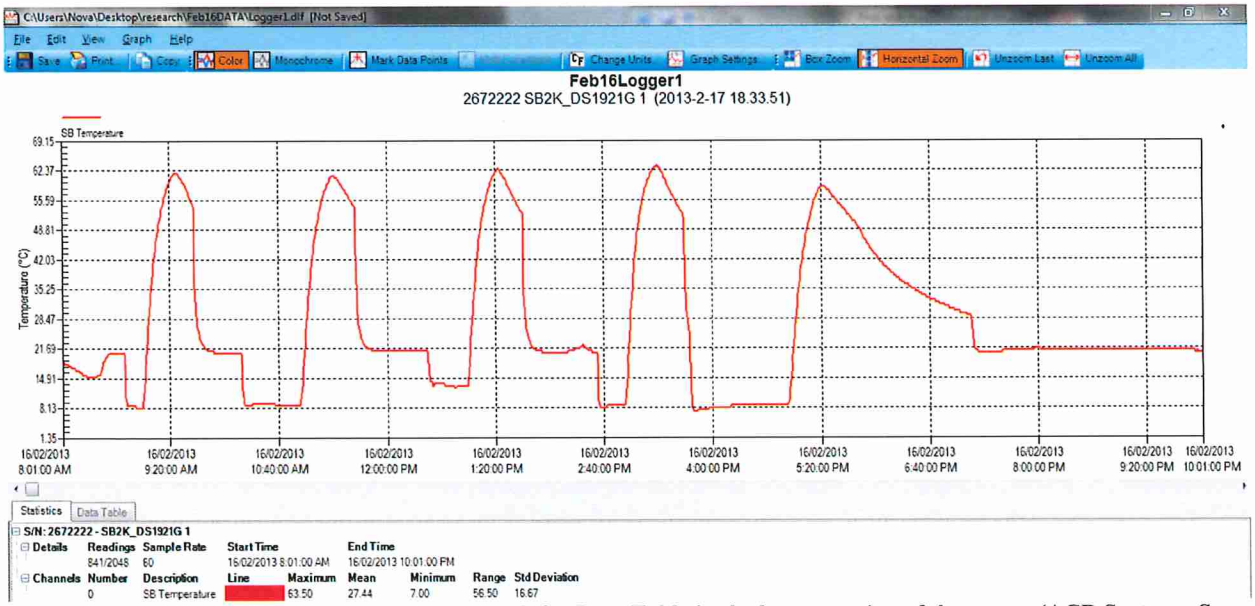

Figure 2: Screenshot of data collection graph. Note the tab for Data Table in the lower portion of the screen (ACR Systems, Surrey BC).

Immersion circulator

A tank was filled with 5L of hot water from the tap and the immersion circulator was placed along the short side of the tank.

Temperature set point

The immersion circulator was turned on and the temperature set to 66.0°C by pressing the knob once and turning the dial until the display read 66.0°C (See Figure 3). (Polyscience, Niles, IL; D. Craig, personal communication, October 24, 2012). No further action was taken until the display on the immersion circulator showed a temperature of 66.0°C.

Calibration

Calibration of the immersion circulator was carried out as detailed in section 6.1 in the Polyscience Model 7306 Immersion Circulator operation manual (Polyscience , Niles, IL). Although the circulator is calibrated monthly in the kitchen, an additional calibration was completed prior to the start of the experiment with the use of a factory-calibrated thermometer.

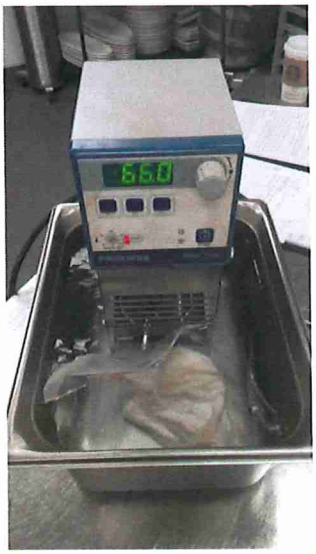

Figure 3: Sous vide set up with chicken

Vacuum sealing

The Multivac sealer was operated as directed by the manual (Multivac, Wolfertschwenden Germany). Prior to placing chicken in the polyethylene bags, the bags were trimmed to create a bag without excess polyethylene. Then, positioning the bag with the open end over the sealing bar, the bag was evacuated (K. Cummings, personal communication, November 1, 2012) at 60psi (a full seal). An adequate level of air must be removed to prevent air bubbles from developing while heating which will cause the bag to float. The sealed bags were kept in a cooler with ice until ready for use.

Experimental Procedure

The sous vide apparatus (immersion circulator and tank of water) was set up and when the water bath was at the appropriate temperature, a chicken breast was removed from the cooler and placed directly into the water. The time was recorded and a timer was set for 23 minutes. When the timer beeped, the pack was removed from the water and allowed to sit on the counter for approximately 5-10 minutes. The time was recorded as each breast was removed from the water bath and again when the data logger was removed from the chicken. At the end of the experiment, the data loggers were connected to the PC and data was extracted as detailed above.

Alternative methods and justification

Temperature logging

There are various methods for temperature logging such as probes and other wireless units. For this project, the SmartButton was chosen for its small size and ability to collect data without requiring a constant connection to a larger recording unit. Considering the design of this experiment, the use of a probe unit would have required the packaging to be punctured and water getting into the package would have been a concern.

Recipe

Other sous vide recipes could have been followed, but the recipe used in this experiment is currently in use at a restaurant in the Fraser Heath Authority area. This project was conducted in collaboration with the BCCDC Sous Vide Working Group and the chef working with the researcher has this particular recipe approved by the local health inspector (Delta Burnaby, 2011). The shorter cooking time - 23 minutes - of this recipe was also ideal because at least 30 samples had to be run for valid statistical analysis (Heacock & Crozier, 2012).

Reliability/validity of measures & calibration of instruments

A pilot study was conducted to address operational details prior to the start of the experiment. Data on 30 samples were taken to increase the reliability of results and the same researcher conducted all 30 trials with the same immersion circulator to minimize the introduction of new variables. To maintain a high level of validity, the immersion circulator was calibrated during the pilot study and prior to the experiment. The SmartButtons are factory-calibrated during manufacturing and are accurate to within 1.5°C in the temperature range the researcher was working in. Because the SmartButtons cannot be calibrated after leaving the factory (E. Durand, personal communication, November 13, 2012), the researcher completed a secondary calibration prior to the pilot study and experiment by using a factory-calibrated thermometer in the sous vide setup. The validity of measurements is also supported by the small size nature of the SmartButton which allows it to be implanted in the chicken to record an accurate internal temperature as possible.

Inclusion and exclusion criteria

Only chicken breasts with skin - approximately 6oz each – were included in this project as the guidelines for *Salmonella* are the strictest (7D reduction required) and sous vide chicken breast is a common item served in restaurants. Even though percentage fat is a factor in the cooking time, skin-on breasts were chosen because the restaurant uses skin-on chicken breasts. The researcher attempted to minimize the variability of chicken breasts selected, but faced as much unpredictability as any chef would when cooking via

sous vide. The results of this study are not directly generalizable to other meats (i.e. pork, beef, lamb) due to the nature of different proteins reaching optimal texture at different temperatures. However, information gathered from this study can be used to extrapolate guidelines to other proteins which generally require less *Salmonella* reduction or are cooked at higher temperatures.

Pilot study

A pilot study was conducted prior to the experiment (in early January 2013) to confirm feasibility of the proposed methodology and was conducted on 2 samples. During the pilot study, the researcher determined the appropriate data collection intervals (every minute) and evacuation levels (full evacuation at 60psi). It was also determined that data collection at the end of the experiment was more feasible than data collection after each trial.

Results

Table 2 shows the peak temperatures reached in each trial; all peak temperatures were achieved after removal from the sous vide process as temperatures continued to climb a few degrees while resting. No sample achieved an internal temperature equivalent to the water bath (66°C). The results obtained from experimentation were compared to '1% fat' values on the table from CFIA as a minimum threshold. On average, the 29 samples took 3.1 minutes to reach peak temperature after removal from the water bath and stayed at the peak temperature for 2.6 minutes. For sample-by-sample details, see Appendix A.

Figure 4 illustrates the temperature of SmartButton as it 1) drops as it is inserted in the chicken, 2) rises as the chicken is treated, 3) peaks and slowly drops until the data logger is removed upon which the temperature 4) quickly drops to room temperature. All loggers followed a similar pattern with the exception of sample 29 (see Figure 5).

Sample/trial	Peak Temperature (°C)	Sample/trial	Peak Temperature (°C)
1	63.5	**16**	62.5
2	60.5	**17**	64
3	60.5	**18**	64
4	61.5	**19**	62.5
5	60	**20**	62.5
6	60.5	**21**	61.5
7	61	**22**	62
8	62	**23**	63
9	61.5	**24**	64.5
10	61.5	**25**	63.5
11	63.5	**26**	62.5
12	62.5	**27**	59.5
13	61	**28**	63
14	63	**29**	62
15	61	**30**	58.5

Table 2: Peak temperatures reached by sous vide chicken

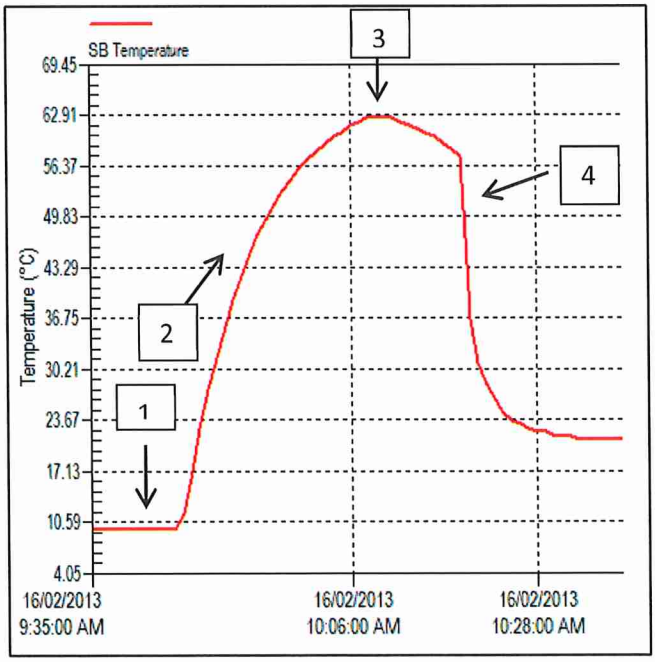

Figure 4: Graph result from SmartButton (Sample 12)

Figure 5 illustrates temperature of the SmartButton used in sample 29. Sample 29 was cooked according the methodology above but was additionally seared as it would be in a conventional cook-serve manner. The temperature dropped slightly as the chicken was removed from the water bath (1) and rose as it was seared in the pan with butter and seasonings (2). The peak temperature of sample 29 was 68°C (3) which was achieved at the end of the searing process. The SmartButton was not removed until the chicken had cooled significantly to handle so there is not the same dramatic drop seen as in Figure 4.

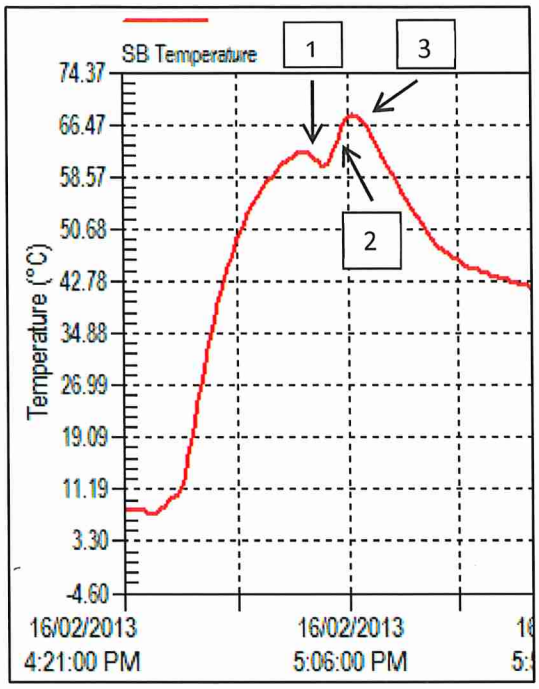

Figure 5 Graph result from SmartButton (Sample 29): Seared after sous vide process

The data collected from this experiment was in the form of temperatures and were therefore numerical and continuous (Heacock & Crozier, 2012). NCSS 8 was the statistical package used to analyse the information collected. In the following sections, a statistical analysis of the data collected is presented (see Appendix A for data collected).

Descriptive statistics

The mean of the 30 peak temperatures was 62.0°C, the mode was 62.5°C, median = 62°C, range = 6°C and standard deviation was 1.4°C. The complete NCSS descriptive statistics report is included in Appendix B.

Inferential statistics

The data were normally distributed as all three tests of assumption (Skewness Normality, Kurtosis Normality and Omnibus Normality) did not reject normality (Hintze, 2012). Because the data were normally distributed, a one-sample one-tailed t-test (a parametric statistical test) was used to determine if the null hypothesis could be rejected. The p-value was set at 0.05. A one-tailed test was used instead of a two-tailed

test because the values collected for temperature were not expected to reach above 66°C. The complete NCSS inferential statistics report can be found in Appendix B. The alternate and null hypotheses are as follows:

H_a: Chicken breasts cooked according to this recipe (23 minutes @ 66°C) will not achieve the target internal temperature of 66°C (actual temperature < target temperature)

H_o: Chicken breasts cooked according to this recipe (23 minutes @ 66°C) will achieve the target internal temperature of 66°C (actual temperature = target temperature)

A one-sample one tail t-test rejected the null hypothesis which is interpreted to mean that the chicken breasts did not reach an internal temperature of 66°C during a 23-minute sous vide cooking process (results were significant) Of note, weight of the chicken did not affect the peak temperatures reached or the time required to reach the peak temperature. The results are as follows:

	Correlation (r)	**Prob level p = 0.05**	**Reject Ho: slope = 0**	**Line formula**
Peak temperature vs Weight	-0.1871 (little to no relationship)	0.3311 > 0.05	No	peak_temp = (65.6857) + (-0.0199)
Time to peak temperature vs Weight	0.3175 (fair relationship)	0.0933 > 0.05	No	time_to_peak_temp = (-0.8286) + (0.0210)

Table 3: Linear regression results of weight vs peak temperature and time to peak temperature

The complete linear regression reports can be found in Appendix CI & CII.

Power and Type I/II Errors

The t-test had a power of 1.00 at α=0.05 and a power of 1.00 at α =0.01 (Hintze, 2012). A high power (close or equal to 1) decreases the likelihood of a type II error as power = 1 - β (Heacock & Crozier, 2011). A type II/β error occurs when there is a false negative. A type I error (when the H_o is incorrectly rejected) was not likely as the probability level was 0 and not close to 0.05

Discussion

While the results obtained in this study show that these specific conditions of sous vide do not provide a 7.0D reduction of *Salmonella*, the author was not able to find literature detailing instances of FBI caused by sous vide cooking. There are several possible explanations for this situation because while *Salmonella* are commonly associated with poultry, poultry is not always contaminated with *Salmonella*; if poultry is contaminated, it may not be at harmful populations or contact a susceptible host. Potentially, the poultry being cooked could harbour no *Salmonella* in the centre of the breast and any bacteria on the surface were appropriately addressed by heat treatment. Alternatively, a 7.0D reduction may not have been necessary to reduce the bacterial levels to non-pathogenic levels. The seared sample peaked at a temperature of 68°C which requires only a 44 second dwell time and may have been sufficient to kill any remaining bacteria.

Regarding the internal presence of *Salmonella*, Warsow, Orta-Ramirez, Booren, Ryser and Marks found that whole muscles can be considered sterile unless the surface has been punctured or abraded in some way (via brine injection or a tenderization processing)(as cited in Moza, Griffiths & Barbut, 2009). Some examples of tenderizing processes include needle or sonic tenderization - where sound waves are passed through the meat (Lorca, Claus, Eifert, Marcy & Sumner, 2003). In instances where poultry is not tenderized, the interior should be safe and it should not matter if the internal temperature reaches kill temperatures as long as the surface is fully cooked. However, poultry guidelines always make it a point to specify that *internal* temperatures should read x°C. What is the reasoning behind this specification?

Certain strains of *Salmonella* are invasive and are able to penetrate into tissue of the bird once introduced to the surface (Mead, 2004); this can be further encouraged by treatment methods such as tumbling (Moza et al., 2009) and vacuum packaging (Orta-Ramirez, Marks, Warsow, Booren & Ryser, 2005). Even if the initially-sterile muscle does not come into contact with *Salmonella*-containing fecal matter, poultry de-feathering and processing can damage the skin allowing *Salmonella* migration for later contamination (Kim,

Knabel & Doores, 1993). Regarding the extent of *Salmonella* penetration into chicken breasts, for tumbled poultry, the number of bacteria decreases as depth increases but the value does not reach zero as was found in a study by Tuntivanich, Orta-Ramirez and Booren (2006) which considered various methods of marination.

Also, while the poultry may have been sterile initially, by the time it gets to the consumer to be cooked, blood and bacteria have had opportunity to infiltrate the folds of the tissue (L. McIntryre, Personal communication, March 22, 2013). In this experimental set-up, it is difficult to speculate on the lethality of sous vide on *Salmonella* without sampling the interior of the breast after cooking.

Limitations

Limited equipment availability, time and budget made the considerations below difficult to include in the design of this project but could be incorporated into future research. As this experiment only collected temperature data, it is not possible to determine the actual lethality of sous vide cooking on *Salmonella*. While the researcher was able to ascertain the safety of the product based on CFIA guidelines, it is an indirect measure and does not provide quantitative information. As well, it might have been interesting to have several more temperature points throughout the breast, as other researchers have done in related experiments. Perhaps only the very centre of the chicken did not reach pasteurization temperature as it can be assumed that the surface reached the temperature of the water bath. Searing is also a part of the cooking process, and as realized in this experiment, contributes significantly to the internal temperature of the chicken. This experiment could have taken all the samples to sear step but there would have been too many variables to control.

Possible Bias/errors

Initially, there was concern that the varying weights of the chicken breasts would affect cooking times as a larger mass would require a longer CUT. However, as the linear regression analysis showed, while there was correlation between peak temperature and weight, there was no significant relationship - although this may not hold true for wider ranges of weight variation. Fat content may have also introduced error into the

measurements. The CFIA divides dwell times by temperature and fat content (ranging from 1-12%); while in this experiment, skin-on chicken was used to maintain congruency with restaurant practices, the actual fat content was not determined. However, the results were compared to the best case scenario (1% fat) to account for this fact.

Additional errors regarding timing may have also been made. While the samples were cooked for 23 minutes according to a timer, data is recorded on the SmartButton every minute according to its internal time-keeping system. Because the SmartButton does not have a visible clock, an external clock had to be used – this may have impacted data collection by as much as a minute.

Most sous vide recipes require that the item to be cooked be heated from fridge temperatures. In this experiment, not all samples entered the water bath at 4°C due to space limitations, most were warmer than 4°C. This may have introduced some bias as the CUT would be shorter due to a higher starting temperature.

Recommendations and Risk Management

Based on this study it is recommended that a longer cooking time or a higher temperature be used to sous vide chicken breasts and that the internal temperature be monitored for dwell time in addition to temperature. In instances of cool-chill, some literature recommends that the product be cooled down as quickly as possible but results from this experiment show that temperatures continue to climb for as much as 4 minutes after removal from the water bath. Whether it is cook-serve or cook-chill, it is recommended that the food be allowed to sit at room temperature for a few minutes after the sous vide process to allow the heating process to finish. Searing was also seen to have an impact on the internal temperature of the food being cooked so additional/further heat treatment of the chicken breast must be considered to mitigate the risk of undercooked poultry.

Due to the many variables and low temperature involved in sous vide cooking, it is also recommended that EHOs become familiar with the basic premise of sous vide cooking. While risk assessment during an

inspection is no substitute for laboratory verification through a process authority, an EHO should be able to ascertain the knowledge and food safety of the operator.

Conclusion and Public Health Implications

The results from this project show that the sous vide conditions in use do not meet the time-temperature standards set by the CFIA to achieve a 7.0D lethality of *Salmonella*. On average, the peak temperature reached was 62°C (which requires a 10.4 minute dwell time) and appropriate dwell times were not achieved. If the CFIA guidelines are applied absolutely, a safe product is not produced. However, they are guidelines only, and are non-enforceable. It is still possible to produce an end product that is safe due to the issues covered in the discussion but a process authority would be required to verify the process.

FBIs are often the result of a 'perfect storm' of poor food handling practices but these practices can usually be addressed by cooking which is a critical control step. In the case of sous vide cooking, extra care must be taken to properly pasteurize the food (externally and internally) because uncertainty regarding the internal temperature and dwell time are introduced and errors in earlier control steps may not be corrected. Additionally, for instances of cook-chill, it is even more important to ensure thorough cooking the first time as storage condition and additional processing steps increase the risk for pathogenic bacteria to flourish.

Future research suggestions

- Conduct experiment with addition of before and after cultures of *Salmonella*
- Investigate effect of bone on sous vide cooking process
- Obtain temperature readings from various sections of chicken breast with probe thermometer while cooking
- Compare water bath sous vide and steam sous vide
- Compare *Salmonella* cultures in marinated/treated vs non-marinated poultry products
    - Treated: brine injection, various methods of tenderization
- Follow sous vide with searing and modify searing variables while monitoring internal temperatures
- Investigate Sous Vide Dash, an iOS app that allows various parameters to be inputted (meat, shape, thickness, doneness) and produces a graph with external/internal temperature trajectories and pathogen destruction trends ($4.99 from the app store)

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APPENDIX A
PEAK TEMPERATURES

Sample	Peak temperature in water bath (@minute 23)	Peak temperature overall	Peak temperature reached ___ minutes after sous vide process	Time at peak temperature (minutes)	Weight of breast (grams)
1	62	63.5	3	2	170
2	58.5	60.5	4	1	190
3	58	60.5	4	5	190
4	59	61.5	4	1	190
5	57.5	60	3	3	190
6	59	60.5	2	2	180
7	58.5	61	4	2	210
8	60	62	3	3	180
9	60	61.5	2	3	180
10	59.5	61.5	3	4	200
11	62	63.5	3	3	160
12	62	62.5	1	4	180
13	58.5	61	4	1	220
14	61.5	63	3	2	170
15	59	61	3	3	185
16	60.5	62.5	3	3	180
17	62.5	64	4	1	180
18	62	64	4	1	180
19	61	62.5	3	3	190
20	61.5	62.5	2	2	180
21	58.5	61.5	5	2	180
22	60	62	3	3	180
23	61.5	63	3	2	200
24	63	64.5	3	2	190
25	62	63.5	4	1	220
26	61.5	62.5	2	4	200
27	58	59.5	2	4	180
28	62	63	2	4	180
29[1]	60.5	62	-	-	180
	Peak temperature after sear		68	1[2]	
30	56	58.5	4	4	190
AVERAGE	**60.2**	**62.0**	**3.1**	**2.6**	**187**

[1] Sample 29 was put in a pan to sear after cooking and was not allowed to rest long enough to determine a peak resting temperature prior to searing

[2] Value not used in the calculation of average time at peak temperature due to searing treatment

APPENDIX B
DESCRIPTIVE AND INFERENTIAL STATISTICAL REPORTS

Descriptive Statistics Report

Summary Section of Peak_temp

Count	Mean	Standard Deviation	Standard Error	Minimum	Maximum	Range
30	61.96667	1.419891	0.2592355	58.5	64.5	6

Counts Section of Peak_temp

Rows	Sum of Frequencies	Missing Values	Distinct Values	Sum	Total Sum Squares	Adjusted Sum Squares
30	30	0	12	1859	115254.5	58.46667

Means Section of Peak_temp

Parameter	Mean	Median	Geometric Mean	Harmonic Mean	Sum	Mode
Value	61.96667	62	61.95085	61.93494	1859	62.5
Std Error	0.2592355				7.777066	
95% LCL	61.43647	61.5	61.42065	61.40467	1843.094	
95% UCL	62.49686	62.5	62.48562	62.47444	1874.906	
T-Value	239.0361					
Prob Level	0					
Count	30		30	30		5

The geometric mean confidence interval assumes that the ln(y) are normally distributed.
The harmonic mean confidence interval assumes that the 1/y are normally distributed.

Variation Section of Peak_temp

Parameter	Variance	Standard Deviation	Unbiased Std Dev	Std Error of Mean	Interquartile Range	Range
Value	2.016092	1.419891	1.432182	0.2592355	2	6
Std Error	0.4814471	0.239761		0.04377416		
95% LCL	1.278735	1.130811		0.206457		
95% UCL	3.643448	1.908782		0.3484943		

Skewness and Kurtosis Section of Peak_temp

Parameter	Skewness	Kurtosis	Fisher's g1	Fisher's g2	Coefficient of Variation	Coefficient of Dispersion
Value	-0.3541028	2.710794	-0.373019	-0.1137512	0.02291379	0.01827957
Std Error	0.311217	0.4963646			0.002762937	

Trimmed Section of Peak_temp

Parameter	5% Trimmed	10% Trimmed	15% Trimmed	25% Trimmed	35% Trimmed	45% Trimmed
Trim-Mean	62.00926	62.02083	62.02381	62.03333	62.05556	62.08333
Trim-Std Dev	1.158127	0.9722136	0.8656816	0.6113997	0.4289846	0.2282177
Count	27	24	21	15	9	3

Mean-Deviation Section of Peak_temp

Parameter	|X-Mean|	|X-Median|	(X-Mean)^2	(X-Mean)^3	(X-Mean)^4
Average	1.137778	1.133333	1.948889	-0.9634074	10.29605
Std Error	0.1559467		0.4653989	0.9766634	4.616721

Descriptive Statistics Report

Dataset Untitled

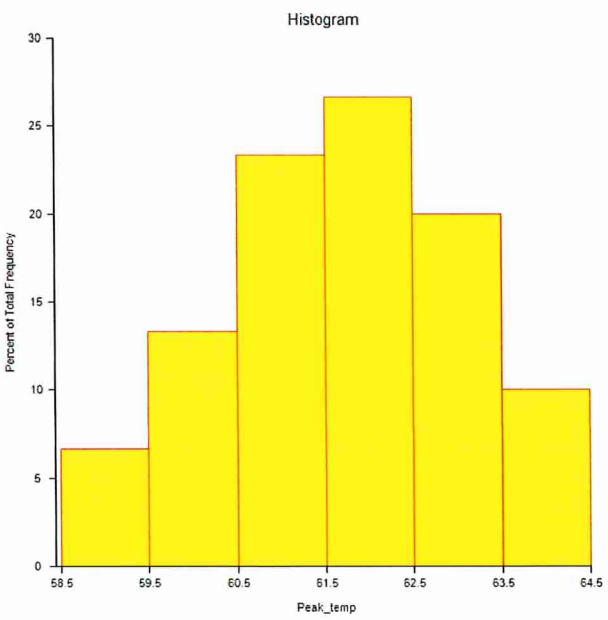
Quartile Section of Peak_temp

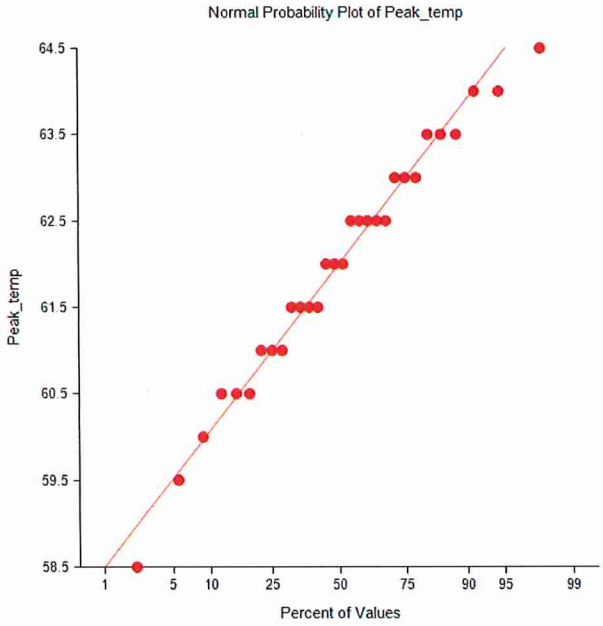
Parameter	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile
Value	60.05	61	62	63	63.95
95% LCL	58.5	60	61.5	62.5	63
95% UCL	61	61.5	62.5	64	64.5

Normality Test Section of Peak_temp

Test Name	Test Value	Prob Level	10% Critical Value	5% Critical Value	Decision (5%)
Shapiro-Wilk W	0.9786097	0.7875025			Can't reject normality
Anderson-Darling	0.2488865	0.7482912			Can't reject normality
Martinez-Iglewicz	0.9979828		1.148522	1.228175	Can't reject normality
Kolmogorov-Smirnov	0.07973197		0.146	0.159	Can't reject normality
D'Agostino Skewness	-0.9124367	0.3615389	1.645	1.96	Can't reject normality
D'Agostino Kurtosis	0.0785	0.937463	1.645	1.96	Can't reject normality
D'Agostino Omnibus	0.8387	0.657475	4.605	5.991	Can't reject normality

Plots Section of Peak_temp





Descriptive Statistics Report

Dataset Untitled

Percentile Section of Peak_temp

Percentile	Value	95% LCL	95% UCL	Exact Conf. Level
99	64.5			
95	64.225			
90	63.95	63	64.5	95.5589
85	63.5	63	64.5	96.45911
80	63.4	62.5	64	96.38612
75	63	62.5	64	96.78105
70	62.85	62	63.5	95.29077
65	62.5	62	63.5	96.43803
60	62.5	61.5	63	96.15771
55	62.5	61.5	63	95.49585
50	62	61.5	62.5	95.7226
45	61.975	61	62.5	95.44512
40	61.5	61	62.5	96.15771
35	61.5	60.5	62	96.23986
30	61.15	60.5	62	95.06309
25	61	60	61.5	96.78105
20	60.6	59.5	61.5	96.38612
15	60.5	58.5	61	96.45911
10	60.05	58.5	61	95.5589
5	59.05			
1	58.5			

Percentile Formula: Ave X(p[n+1])

Stem-Leaf Plot Section of Peak_temp

Depth	Stem	Leaves
1	58.|	5
1	59*|	
2	.|	5
3	60*|	0
6	.|	555
9	61*|	000
13	.|	5555
(3)	62*|	000
14	.|	55555
9	63*|	000
6	.|	555
3	64*|	00
1	.|	5

Unit = .1 Example: 1 |2 Represents 1.2

Inferential Statistics
One-Sample T-Test Report

Descriptive Statistics Section

Variable	Count	Mean	Standard Deviation	Standard Error	95.0% LCL of Mean	95.0% UCL of Mean
Peak_temp	30	61.96667	1.419891	0.2592355	61.43647	62.49686

T for Confidence Limits = 2.0452

Tests of Assumptions Section

Assumption	Value	Probability	Decision(.050)
Skewness Normality	-0.9124	0.361539	Cannot reject normality
Kurtosis Normality	0.0785	0.937463	Cannot reject normality
Omnibus Normality	0.8387	0.657475	Cannot reject normality
Correlation Coefficient			

T-Test For Difference Between Mean and Value Section

Alternative Hypothesis	T-Value	Prob Level	Reject H0 at .050	Power (Alpha=.05)	Power (Alpha=.01)
Peak_temp<>66	-15.5586	0.000000	Yes	1.000000	1.000000
Peak_temp<66	-15.5586	0.000000	Yes	1.000000	1.000000
Peak_temp>66	-15.5586	1.000000	No	0.000000	0.000000

Nonparametric Tests Section

Quantile (Sign) Test

Null Quantile (Q0)	Quantile Proportion	Number Lower	Number Higher	H1:Q<>Q0 Prob Level	H1:Q<Q0 Prob Level	H1:Q>Q0 Prob Level
66	0.5	30	0	0.000000	0.000000	1.000000

Wilcoxon Signed-Rank Test for Difference in Medians

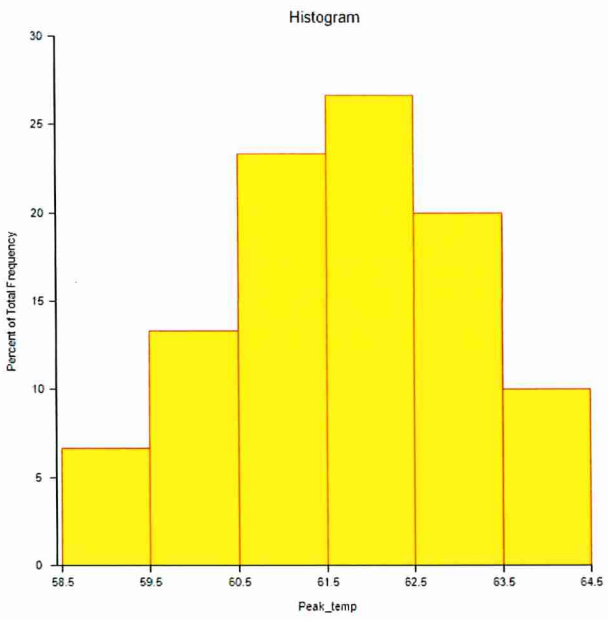
W Sum Ranks	Mean of W	Std Dev of W	Number of Zeros	Number Sets of Ties	Multiplicity Factor
0	232.5	48.55281	0	8	306

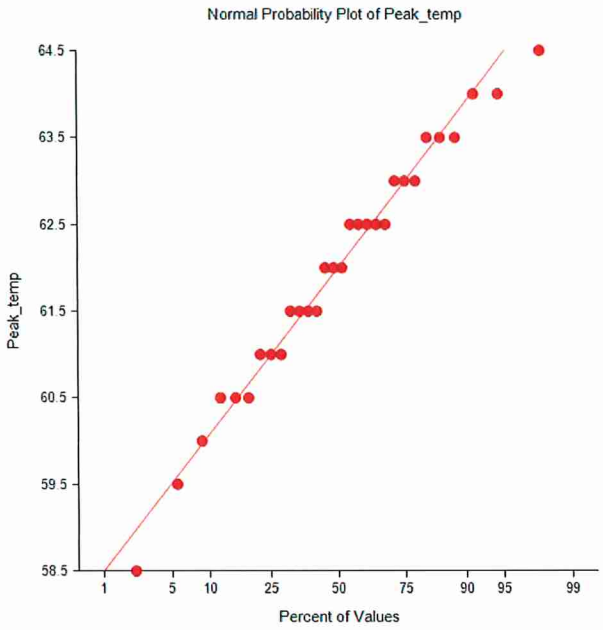
	Exact Probability		Approximation Without Continuity Correction			Approximation With Continuity Correction		
Alternative Hypothesis	Prob Level	Reject H0 at .050	Z-Value	Prob Level	Reject H0 at .050	Z-Value	Prob Level	Reject H0 at .050
Median<>66			4.7886	0.000002	Yes	4.7783	0.000002	Yes
Median<66			-4.7886	0.000001	Yes	-4.7783	0.000001	Yes
Median>66			-4.7886	0.999999	No	-4.7989	0.999999	No

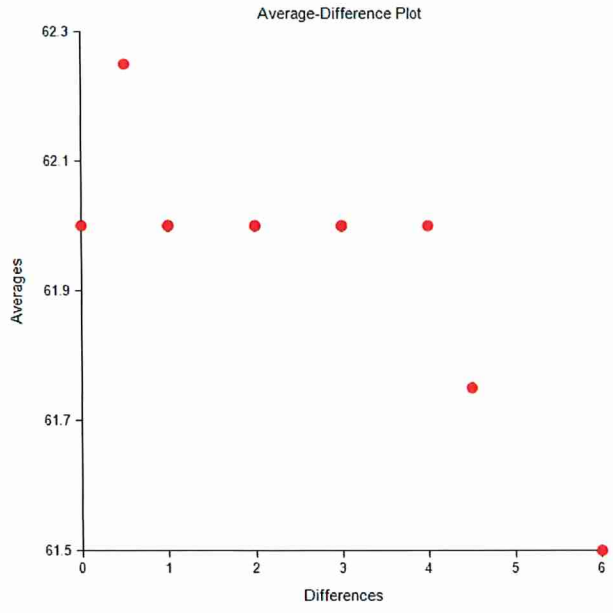
One-Sample T-Test Report

Dataset Untitled
Variable Peak_temp

Plots Section





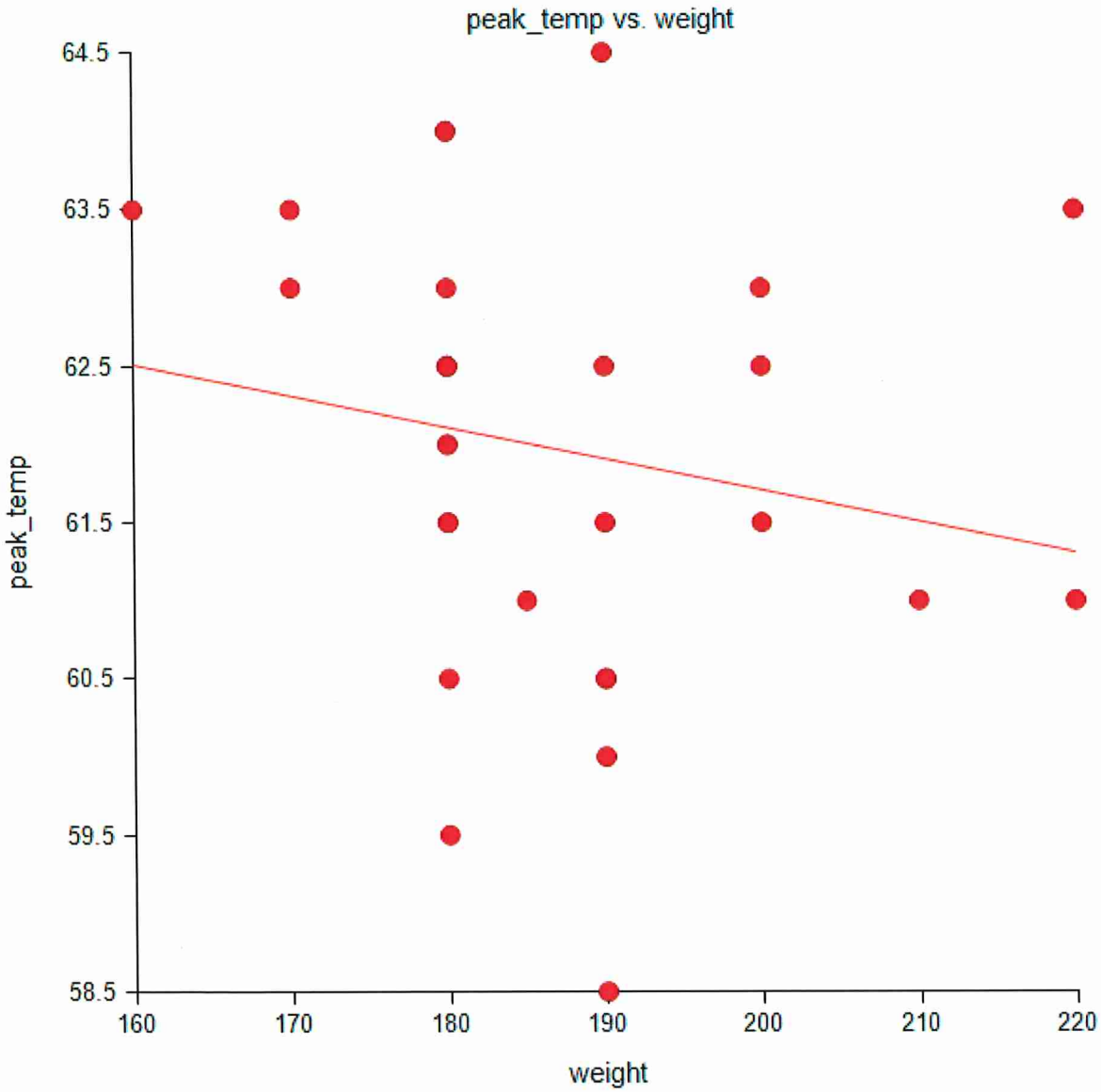


APPENDIX C (I)
LINEAR REGRESSION REPORT
PEAK TEMPERATURE VS. WEIGHT

Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Linear Regression Plot Section



Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	peak_temp	Rows Processed	29
Independent Variable	weight	Rows Used in Estimation	29
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	65.6857	Rows Prediction Only	0
Slope	-0.0199	Sum of Frequencies	29
R-Squared	0.0350	Sum of Weights	29.0000
Correlation	-0.1871	Coefficient of Variation	0.0233
Mean Square Error	2.089576	Square Root of MSE	1.445537

Summary Statement

The equation of the straight line relating peak_temp and weight is estimated as: peak_temp = (65.6857) + (-0.0199) weight using the 29 observations in this dataset. The y-intercept, the estimated value of peak_temp when weight is zero, is 65.6857 with a standard error of 3.7683. The slope, the estimated change in peak_temp per unit change in weight, is -0.0199 with a standard error of 0.0201. The value of R-Squared, the proportion of the variation in peak_temp that can be accounted for by variation in weight, is 0.0350. The correlation between peak_temp and weight is -0.1871.

A significance test that the slope is zero resulted in a t-value of -0.9898. The significance level of this t-test is 0.3311. Since 0.3311 > 0.0500, the hypothesis that the slope is zero is not rejected.

The estimated slope is -0.0199. The lower limit of the 95% confidence interval for the slope is -0.0611 and the upper limit is 0.0213. The estimated intercept is 65.6857. The lower limit of the 95% confidence interval for the intercept is 57.9538 and the upper limit is 73.4176.

Descriptive Statistics Section

Parameter	Dependent	Independent
Variable	peak_temp	weight
Count	29	29
Mean	61.9655	187.0690
Standard Deviation	1.4450	13.5960
Minimum	58.5000	160.0000
Maximum	64.5000	220.0000

Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Regression Estimation Section

Parameter	Intercept B(0)	Slope B(1)
Regression Coefficients	65.6857	-0.0199
Lower 95% Confidence Limit	57.9538	-0.0611
Upper 95% Confidence Limit	73.4176	0.0213
Standard Error	3.7683	0.0201
Standardized Coefficient	0.0000	-0.1871
T Value	17.4312	-0.9898
Prob Level (T Test)	0.0000	0.3311
Reject H0 (Alpha = 0.0500)	Yes	No
Power (Alpha = 0.0500)	1.0000	0.1592
Regression of Y on X	65.6857	-0.0199
Inverse Regression from X on Y	168.2219	-0.5680
Orthogonal Regression of Y and X	65.7267	-0.0201

Notes:
The above report shows the least-squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
(65.6857095269825) + (-.0198867421718774) * (weight)

Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Correlation and R-Squared Section

Parameter	Pearson Correlation Coefficient	R-Squared	Spearman Rank Correlation Coefficient
Estimated Value	-0.1871	0.0350	-0.2879
Lower 95% Conf. Limit (r dist'n)	0.1899		
Upper 95% Conf. Limit (r dist'n)	-0.5110		
Lower 95% Conf. Limit (Fisher's z)	0.1926		0.0879
Upper 95% Conf. Limit (Fisher's z)	-0.5181		-0.5919
Adjusted (Rbar)		0.0007	
T-Value for H0: Rho = 0	0.9898	0.9898	1.5621
Prob Level for H0: Rho = 0	0.3311	0.3311	0.1299

Notes:
The confidence interval for the Pearson correlation assumes that X and Y follow the bivariate normal distribution. This is a different assumption from linear regression which assumes that X is fixed and Y is normally distributed.

Two confidence intervals are given. The first is based on the exact distribution of Pearson's correlation. The second is based on Fisher's z transformation which approximates the exact distribution using the normal distribution. Why are both provided? Because most books only mention Fisher's approximate method, it will often be needed to do homework. However, the exact methods should be used whenever possible.

The confidence limits can be used to test hypotheses about the correlation. To test the hypothesis that rho is a specific value, say r0, check to see if r0 is between the confidence limits. If it is, the null hypothesis that rho = r0 is not rejected. If r0 is outside the limits, the null hypothesis is rejected.

Spearman's Rank correlation is calculated by replacing the orginal data with their ranks. This correlation is used when some of the assumptions may be invalid.

Analysis of Variance Section

Source	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1	111352	111352			
Slope	1	2.046963	2.046963	0.9796	0.3311	0.1592
Error	27	56.41855	2.089576			
Lack of Fit	6	11.08224	1.847041	0.8556	0.5426	
Pure Error	21	45.33631	2.158872			
Adj. Total	28	58.46552	2.088054			
Total	29	111410.5				

s = Square Root(2.089576) = 1.445537

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Tests of Assumptions Section

Assumption/Test	Test Value	Prob Level	Is the Assumption Reasonable at the 0.2000 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9842	0.930057	Yes
Anderson Darling	0.1730	0.928269	Yes
D'Agostino Skewness	-0.8836	0.376926	Yes
D'Agostino Kurtosis	0.2864	0.774580	Yes
D'Agostino Omnibus	0.8627	0.649624	Yes
Constant Residual Variance?			
Modified Levene Test	0.9201	0.345953	Yes
Relationship is a Straight Line?			
Lack of Linear Fit F(6, 21) Test	0.8556	0.542634	Yes

No Serial Correlation?
Evaluate the Serial-Correlation report and the Durbin-Watson test if you have equal-spaced, time series data.

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

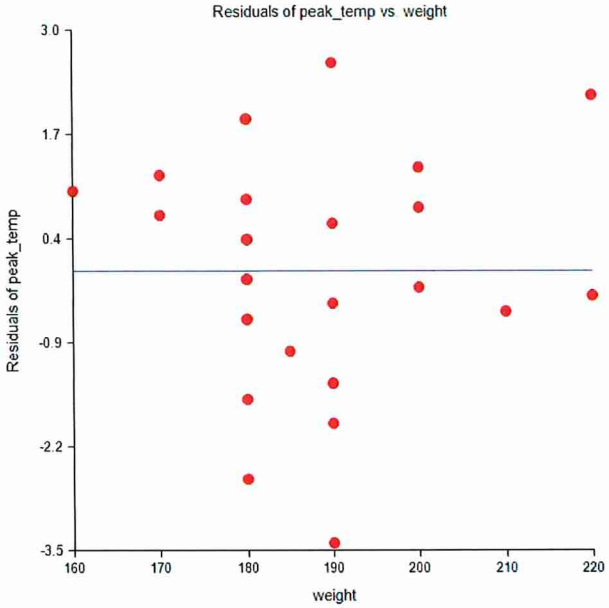
Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

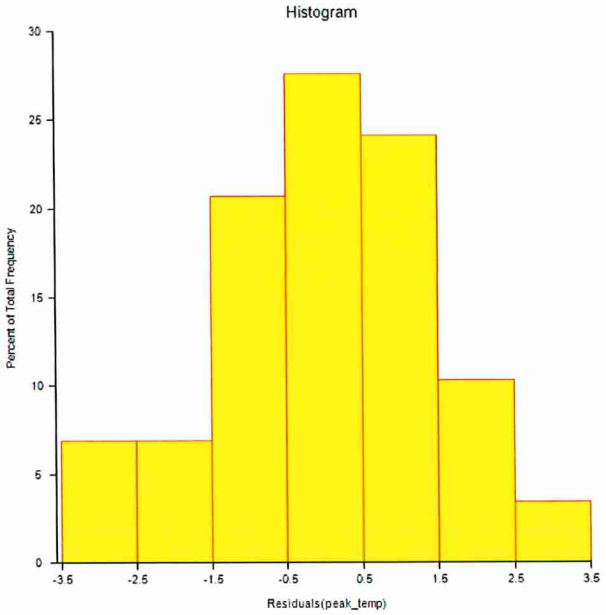
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

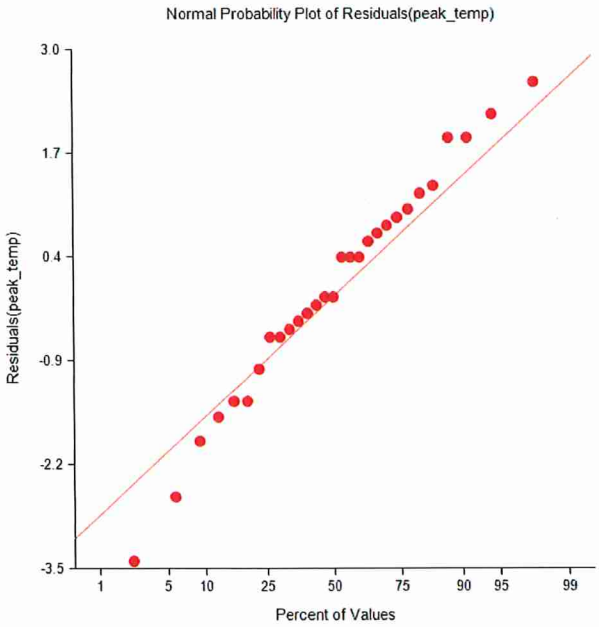
Linear Regression Report

Dataset Untitled
Y = peak_temp X = weight

Residual Plots Section





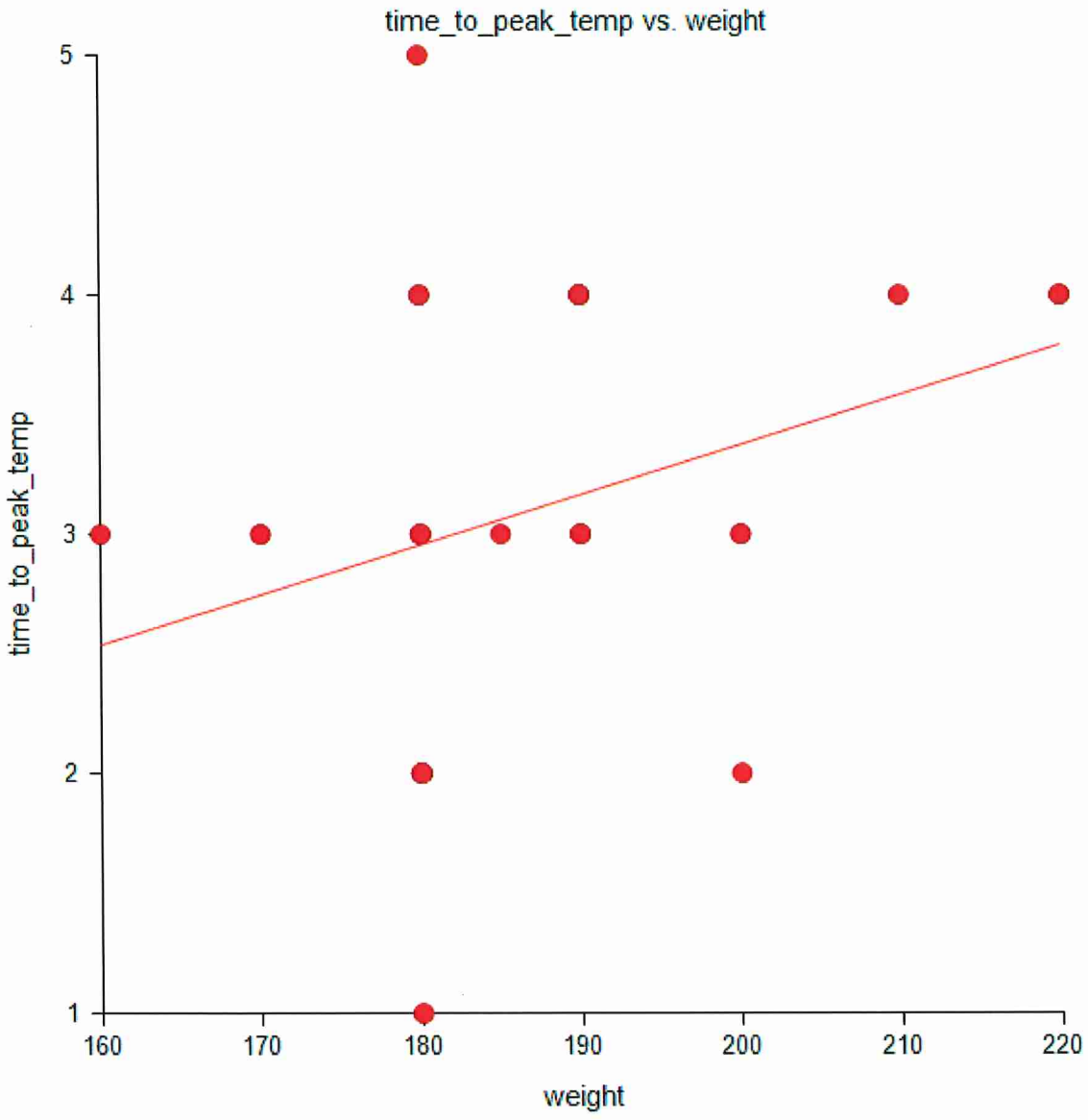


APPENDIX C (II)
LINEAR REGRESSION REPORT
TIME TO PEAK TEMPERATURE VS. WEIGHT

Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Linear Regression Plot Section



Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	time_to_peak_temp	Rows Processed	29
Independent Variable	weight	Rows Used in Estimation	29
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	-0.8286	Rows Prediction Only	0
Slope	0.0210	Sum of Frequencies	29
R-Squared	0.1008	Sum of Weights	29.0000
Correlation	0.3175	Coefficient of Variation	0.2801
Mean Square Error	0.7556629	Square Root of MSE	0.8692887

Summary Statement

The equation of the straight line relating time_to_peak_temp and weight is estimated as: time_to_peak_temp = (-0.8286) + (0.0210) weight using the 29 observations in this dataset. The y-intercept, the estimated value of time_to_peak_temp when weight is zero, is -0.8286 with a standard error of 2.2661. The slope, the estimated change in time_to_peak_temp per unit change in weight, is 0.0210 with a standard error of 0.0121. The value of R-Squared, the proportion of the variation in time_to_peak_temp that can be accounted for by variation in weight, is 0.1008. The correlation between time_to_peak_temp and weight is 0.3175.

A significance test that the slope is zero resulted in a t-value of 1.7396. The significance level of this t-test is 0.0933. Since 0.0933 > 0.0500, the hypothesis that the slope is zero is not rejected.

The estimated slope is 0.0210. The lower limit of the 95% confidence interval for the slope is -0.0038 and the upper limit is 0.0458. The estimated intercept is -0.8286. The lower limit of the 95% confidence interval for the intercept is -5.4783 and the upper limit is 3.8210.

Descriptive Statistics Section

Parameter	Dependent	Independent
Variable	time_to_peak_temp	weight
Count	29	29
Mean	3.1034	187.0690
Standard Deviation	0.9002	13.5960
Minimum	1.0000	160.0000
Maximum	5.0000	220.0000

Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Regression Estimation Section

Parameter	Intercept B(0)	Slope B(1)
Regression Coefficients	-0.8286	0.0210
Lower 95% Confidence Limit	-5.4783	-0.0038
Upper 95% Confidence Limit	3.8210	0.0458
Standard Error	2.2661	0.0121
Standardized Coefficient	0.0000	0.3175
T Value	-0.3657	1.7396
Prob Level (T Test)	0.7175	0.0933
Reject H0 (Alpha = 0.0500)	No	No
Power (Alpha = 0.0500)	0.0644	0.3890
Regression of Y on X	-0.8286	0.0210
Inverse Regression from X on Y	-35.9113	0.2086
Orthogonal Regression of Y and X	-0.8442	0.0211

Notes:
The above report shows the least-squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
(-.828614257161917) + (.0210193204530316) * (weight)

Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Correlation and R-Squared Section

Parameter	Pearson Correlation Coefficient	R-Squared	Spearman Rank Correlation Coefficient
Estimated Value	0.3175	0.1008	0.3520
Lower 95% Conf. Limit (r dist'n)	-0.0553		
Upper 95% Conf. Limit (r dist'n)	0.6052		
Lower 95% Conf. Limit (Fisher's z)	-0.0555		-0.0167
Upper 95% Conf. Limit (Fisher's z)	0.6127		0.6364
Adjusted (Rbar)		0.0675	
T-Value for H0: Rho = 0	1.7396	1.7396	1.9538
Prob Level for H0: Rho = 0	0.0933	0.0933	0.0612

Notes:
The confidence interval for the Pearson correlation assumes that X and Y follow the bivariate normal distribution. This is a different assumption from linear regression which assumes that X is fixed and Y is normally distributed.

Two confidence intervals are given. The first is based on the exact distribution of Pearson's correlation. The second is based on Fisher's z transformation which approximates the exact distribution using the normal distribution. Why are both provided? Because most books only mention Fisher's approximate method, it will often be needed to do homework. However, the exact methods should be used whenever possible.

The confidence limits can be used to test hypotheses about the correlation. To test the hypothesis that rho is a specific value, say r0, check to see if r0 is between the confidence limits. If it is, the null hypothesis that rho = r0 is not rejected. If r0 is outside the limits, the null hypothesis is rejected.

Spearman's Rank correlation is calculated by replacing the orginal data with their ranks. This correlation is used when some of the assumptions may be invalid.

Analysis of Variance Section

Source	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (5%)
Intercept	1	279.3103	279.3103			
Slope	1	2.286757	2.286757	3.0262	0.0933	0.3890
Error	27	20.4029	0.7556629			
Lack of Fit	6	3.771946	0.6286576	0.7938	0.5851	
Pure Error	21	16.63095	0.7919501			
Adj. Total	28	22.68966	0.8103448			
Total	29	302				

s = Square Root(0.7556629) = 0.8692887

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Tests of Assumptions Section

Assumption/Test	Test Value	Prob Level	Is the Assumption Reasonable at the 0.2000 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9733	0.650996	Yes
Anderson Darling	0.3983	0.365835	Yes
D'Agostino Skewness	-0.1744	0.861529	Yes
D'Agostino Kurtosis	0.6330	0.526720	Yes
D'Agostino Omnibus	0.4311	0.806081	Yes
Constant Residual Variance?			
Modified Levene Test	2.2834	0.142380	No
Relationship is a Straight Line?			
Lack of Linear Fit F(6, 21) Test	0.7938	0.585114	Yes

No Serial Correlation?
Evaluate the Serial-Correlation report and the Durbin-Watson test if you have equal-spaced, time series data.

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

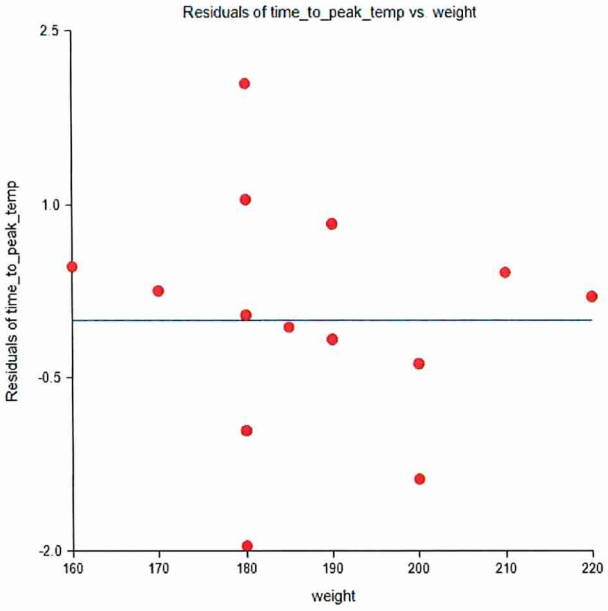
Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

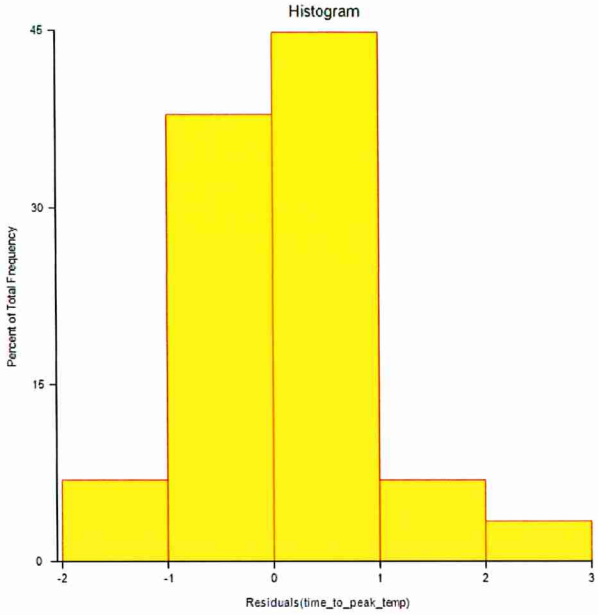
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

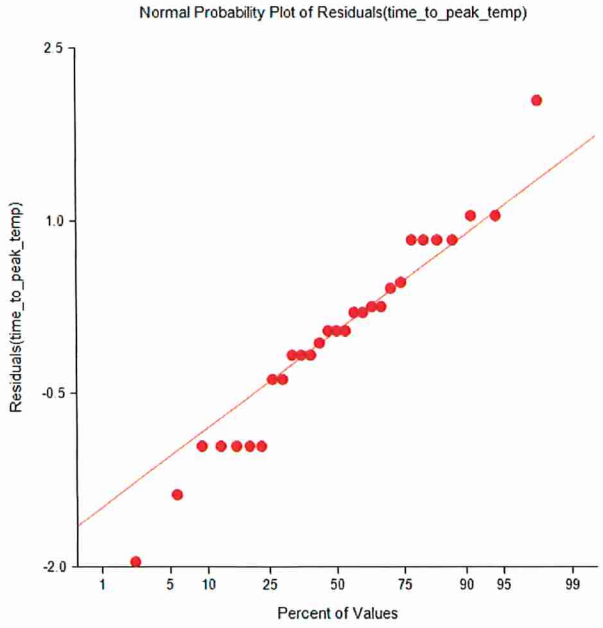
Linear Regression Report

Dataset Untitled
Y = time_to_peak_temp X = weight

Residual Plots Section







APPENDIX D
CANADIAN FOOD INSPECTION AGENCY DWELL TIMES FOR POULTRY PRODUCTS (NOT INCLUDING TURKEY)

Table 2 - Products containing chicken meat - Times for a given temperature, fat level - minimum holding time at that temperature (minimum dwell time) needed to obtain a 7.0D lethality of *Salmonella* spp

Min. int. temp. (°C)	1% FAT	2% FAT	3% FAT	4% FAT	5% FAT	6% FAT	7% FAT	8% FAT	9% FAT	10% FAT	11% FAT	12% FAT
57.8	63.3 min	64.5 min	65.7 min	67.0 min	68.4 min	69.9 min	71.4 min	73.0 min	74.8 min	76.7 min	78.9 min	81.4 min
58.4	50.1 min	51.0 min	52.1 min	53.2 min	54.3 min	55.5 min	56.8 min	58.2 min	59.7 min	61.4 min	63.3 min	65.5 min
58.9	39.7 min	40.5 min	41.3 min	42.2 min	43.2 min	44.2 min	45.3 min	46.4 min	47.7 min	49.2 min	50.9 min	52.9 min
59.5	31.6 min	32.2 min	32.9 min	33.6 min	34.4 min	35.2 min	36.2 min	37.2 min	38.3 min	39.6 min	41.1 min	43.0 min
60.0	25.2 min	25.7 min	26.2 min	26.8 min	27.5 min	28.2 min	29.0 min	29.8 min	30.8 min	32.0 min	33.4 min	35 min
60.6	20.1 min	20.5 min	21.0 min	21.5 min	22.0 min	22.6 min	23.2 min	24.0 min	24.9 min	25.9 min	27.1 min	28.7 min
61.1	16.1 min	16.4 min	16.8 min	17.2 min	17.6 min	18.1 min	18.7 min	19.4 min	20.1 min	21.0 min	22.1 min	23.5 min
61.7	13.0 min	13.2 min	13.5 min	13.8 min	14.2 min	14.6 min	15.1 min	15.6 min	16.3 min	17.1 min	18.1 min	19.3 min
62.2	10.4 min	10.6 min	10.8 min	11.1 min	11.4 min	11.8 min	12.2 min	12.6 min	13.2 min	13.9 min	14.8 min	15.9 min
62.8	8.4 min	8.6 min	8.7 min	8.9 min	9.2 min	9.5 min	9.8 min	10.2 min	10.7 min	11.3 min	12.1 min	13.0 min
63.3	6.8 min	6.9 min	7.0 min	7.2 min	7.4 min	7.6 min	7.9 min	8.2 min	8.6 min	9.1 min	9.8 min	10.6 min
63.9	5.5 min	5.5 min	5.6 min	5.7 min	5.9 min	6.1 min	6.3 min	6.6 min	6.9 min	7.4 min	7.9 min	8.6 min
64.4	4.4 min	4.4 min	4.5 min	4.5 min	4.7 min	4.8 min	5.0 min	5.2 min	5.5 min	5.8 min	6.3 min	6.8 min
65.0	3.5 min	3.5 min	3.5 min	3.6 min	3.6 min	3.8 min	3.9 min	4.1 min	4.3 min	4.6 min	4.9 min	5.4 min
65.6	2.7 min	2.7 min	2.7 min	2.7 min	2.8 min	2.9 min	3.0 min	3.1 min	3.3 min	3.5 min	3.8 min	4.2 min
66.1	2.1 min[3]	2.1 min	2.1 min	2.1 min	2.1 min	2.1 min	2.2 min	2.3 min	2.5 min	2.6 min	2.9 min	3.1 min

[3] Experimental values to be compared to this value as a minimum threshold

66.7	1.5 min	1.5 min	1.5 min	1.6 min	1.6 min	1.6 min	1.7 min	1.7 min	1.8 min	1.9 min	2.1 min	2.3 min
67.2	1.2 min	1.2 min	1.2 min	1.2 min	1.3 min	1.3 min	1.3 min	1.3 min	1.4 min	1.4 min	1.4 min	1.6 min
67.8	55.9 sec	56.9 sec	58.0 sec	59.1 sec	1.0 min	1.0 min	1.0 min	1.1 min	1.1 min	1.1 min	1.1 min	1.1 min
68.3	44.2 sec	45.0 sec	45.9 sec	46.8 sec	47.7 sec	48.6 sec	49.5 sec	50.4 sec	51.4 sec	52.4 sec	53.4 sec	54.4 sec
68.9	35.0 sec	35.6 sec	36.3 sec	37.0 sec	37.7 sec	38.4 sec	39.2 sec	39.9 sec	40.7 sec	41.4 sec	42.2 sec	43.0 sec
69.4	27.7 sec	28.2 sec	28.7 sec	29.3 sec	29.8 sec	30.4 sec	31.0 sec	31.6 sec	32.2 sec	32.8 sec	33.4 sec	34.0 sec
70.0	21.9 sec	22.3 sec	22.7 sec	23.2 sec	23.6 sec	24.0 sec	24.5 sec	25.0 sec	25.4 sec	25.9 sec	26.4 sec	26.9 sec
70.6	17.3 sec	17.6 sec	18.0 sec	18.3 sec	18.7 sec	19.0 sec	19.4 sec	19.8 sec	20.1 sec	20.5 sec	20.9 sec	21.3 sec
71.1	13.7 sec	14.0 sec	14.2 sec	14.5 sec	14.8 sec	15.0 sec	15.3 sec	15.6 sec	15.9 sec	16.2 sec	16.5 sec	16.9 sec
71.7	10.8 sec	11.0 sec	11.2 sec	11.5 sec	11.7 sec	11.9 sec	12.1 sec	12.4 sec	12.6 sec	12.8 sec	13.1 sec	13.3 sec
72.3	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	9.6 sec	9.8 sec	10.0 sec	10.2 sec	10.3 sec	10.5 sec
72.8	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec
73.3	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec	<10.0 sec