

Safety of Chinese Roast Pork as Determined by the Water Activity of the Skin and Cavity

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Abstract

Objectives: The increase in unfamiliar ethnic foods and the lack of guidelines available to evaluate their safety makes it increasingly challenging for Public Health Inspectors (PHIs) to ensure food safety. Chinese barbecued meats, for example, frequently undergo improper temperature control, causing health concerns for public health authorities. However, due to the limited studies conducted, the health implications associated with temperature abuse of this ethnic food is currently unclear. Hence, the following study assessed the safety of Chinese barbecued meats, specifically roast pork, at ambient temperature (21°C).

Methods: The temperature and water activity (a_w) of 30 samples of roast pork skin and cavity were measured. A one sample t-test was conducted to assess whether or not the a_w of roast pork surfaces are below 0.85, a standard for safe display of food at room temperature. In addition, the paired-sample t-test was conducted to determine whether a difference exists between the a_w of roast pork skin and cavity.

Results: The mean temperature that roast pork was displayed at in retailers was 30.7°C and the mean skin and cavity a_w were 0.70±0.013 and 0.81±0.009, respectively. The a_w of the roast pork skin and cavity were found to be statistically lower than the standard, 0.85 (p-value < 0.00001 and at 0.001338, respectively). In addition, statistically significant difference was found between the mean a_w of the roast pork skin and cavity (p-value < 0.00001).

Conclusion: These results indicate that the whole roast pork can be safely displayed at ambient temperature provided that it adheres to specific food safety and sanitation criteria. These results can aid health authorities with guidelines development to assist PHIs with inspections and educate operators to ensure food safety.

Key words: Chinese roast pork; water activity; temperature abuse; public health; skin; cavity

Introduction

Every year, there are more than 4 million cases of foodborne illnesses (FBIs) in Canada, many of which can be easily prevented if proper food-handling practices were followed (Health Canada, 2013). FBIs may be considered trivial by many people as they are typically mild and self-limiting; however, they can cause sequelae and even death in elderly, children, and immunocompromised individuals (Helms, Simonsen, & Molbak, 2006). With the globalization of the food industry, assuring food safety becomes increasingly challenging for Public Health Inspectors (PHIs) as they frequently encounter new ingredients, preparations, and cooking methods. Unfamiliarity with cultural food as well as the lack of guidelines available for evaluating their safety may further reduce the ability of PHIs to prevent FBIs.

Chinese barbecued (BBQ) meats, for example, have become increasingly popular in Canada. According to inspection reports from health authorities, improper temperature control of Chinese BBQ meats is a common and recurring problem (Vancouver Coastal Health [VCH], 2013). However, no reported FBIs appear to be associated with these food products

(Centre for Public Health and Zoonoses [CPHAZ], 2011) even though temperature abuse is one of the primary causes of FBIs (British Columbia Centre for Disease Control [BCCDC], 2009). Due to the limited recent research conducted, understanding of this ethnic food remains poor. Since the safety of Chinese BBQ meats has been an ongoing concern to Vancouver Coastal Health, the researcher developed this study to assess the safety of roast pork, a type of Chinese BBQ meats, displayed at ambient temperature (21°C). This study would ultimately help bridge the knowledge gap between PHIs and unfamiliar ethnic foods, aiding the health authorities with guidelines development to govern the safety of Chinese BBQ meats. With improved understanding of cultural food products, PHIs can then apply the most relevant tools and control measures to protect public health.

Literature Review

Chinese BBQ Meats

Background. Chinese BBQ meats such as pork, chicken, and duck are popular dishes that can be commonly seen hanging in a display cabinet in

restaurants and retailers (CPHAZ, 2011). Chinese-style BBQ is vastly different from the BBQ that most Canadians are familiar with as the meats are hung on hooks and roasted rather than being grilled (Georgia Department of Public Health [DPH], 2012). Chinese BBQ sauce is also very different with common basic ingredients including soy sauce, vinegar, hoisin sauce, sesame oil, and spices such as garlic, ginger, and pepper (DPH, 2012). All Chinese BBQ meats are made with similar ingredients, preparations, and cooking processes (DPH, 2012).

Preparation and cooking process. An interview was conducted with Lao, a chef who specializes in Chinese BBQ for over 25 years, to gain a thorough understanding of the preparation and cooking process of roast pork. According to Lao (personal communication, October 5, 2013), roast pork is marinated with spices such as salt, sugar, monosodium glutamate, and ginger powder in the cavity and the thin layer of exposed meat between the skin and cavity, while the skin is basted with a boiled mixture containing maltose and vinegar (DPH, 2012). Products are then left to dry on hooks in a well-ventilated area at ambient temperature between several hours to several days with a cold fan to accelerate the drying process (K. Lao, personal communication, October 5, 2013). The purpose of air drying reduces the moisture in the skin, enabling it to become crispy when cooked (DPH, 2012; K. Lao, personal communication, October 5, 2013). Roast pigs are cooked as a whole inside a roaster or an oven for approximately 1.5 hours (K. Lao, personal communication, October 5, 2013). Cooked pork is then immediately transferred and displayed on hooks in an enclosed showcase to be sold to customers (DPH, 2012). Some of these showcases may be equipped with a warming device (Ying, 2000) to hot hold food above 60°C as required by the Food Premises Regulation (1999) to prevent temperature abuse. However, hot holding is rarely used during operational hours as the Chinese food industry argues that it can render the meat texture undesirable for their customers (Ying, 2000). They also claimed that displaying Chinese BBQ meats at ambient temperature has been a traditional practice in Asia for many years, and these products have never been implicated in any FBIs (Ying, 2000).

Public Health Significance

Pathogens of Concern. FBI occurs when a person consumes food or beverage that has been contaminated with harmful micro-organisms such as bacteria, viruses, or parasites (Health Canada, 2013). Some foodborne micro-organisms that are commonly

associated with pork include *Escherichia coli*, *Salmonella*, *Yersinia enterocolitica*, and *Staphylococcus aureus* (United States Department of Agriculture [USDA], 2013). These bacteria can be a part of the pig carcasses naturally or introduced into the pork during the preparation or post-cooking stage via cross contamination with other meats, food contact surfaces, or by food-handlers (USDA, 2013). Time and temperature abuse of roast pork by hanging it at room temperature prior to and after cooking may further enable the survival and growth of pathogens, leading to FBIs. However, most bacteria associated with roast pork can be easily destroyed by thorough cooking and reheating (USDA, 2013) with the exception of heat-stable toxins produced by *S. aureus*, and thus, they are the most concerning pathogens (Montville, Matthews, & Kniel, 2012).

Humans are natural carriers of *S. aureus*, with the bacteria commonly present in their nostrils and skin; thus, poor personal hygiene is responsible for most *S. aureus* intoxications (Montville, Matthews, & Kniel, 2012). Since there are lots of handling in the pork preparation process, *S. aureus* may be introduced. When food is contaminated with *S. aureus*, bacterial cells can multiply to high numbers to produce enterotoxins, which causes food poisoning or “intoxication” (Montville, Matthews, & Kniel, 2012). Although heat can destroy the bacteria, the toxins remain potent, causing illnesses (Montville, Matthews, & Kniel, 2012). *S. aureus* can also outcompete other microbes due to their ability to survive and grow in adverse environments such as low water activity (a_w) and pH (Notremans & Heuvelman, 2006).

Although roast pork may be exposed to *S. aureus* by food-handlers while time and temperature abuse may allow bacteria to multiply to produce enterotoxins, other parameters must be met in order to cause intoxication. Firstly, *S. aureus* would have to multiply to one million cells per gram of pork, which would take many hours even under ideal conditions, and food-handlers can only introduce approximately 10 bacteria (Snyder, 2005). Secondly, a healthy individual has to consume 100-200ng of toxins (~30g of contaminated pork) in order to become ill (Montville, Matthews, & Kniel, 2012). Lastly, in addition to time and temperature, other factors such as a_w and pH have to be favourable for pathogen growth and toxin production.

Factors affecting pathogen growth. The ability for pathogens to grow and replicate in food is influenced by the environment such as the temperature, time, a_w , and pH, which are all interdependent (Ray & Bhunia,

2008). Microbes grow best when these factors are at ideal levels (Ray & Bhunia, 2008).

Temperature and time. Every microbe has an optimum temperature for growth (University of Missouri-St. Louis [UMSL], 1999). The time that bacteria require to double in number increases as temperature decreases from the optimum range (UMSL, 1999). Similarly, as temperature rises beyond the optimum temperature, the doubling time also increases, plateaus, and then reaches zero when the heat is sufficient to kill the cells (UMSL, 1999). Since most bacteria grows best between 25-40°C, holding food containing pathogens in the danger zone (4-60°C) enables microbes to grow and multiply rapidly, generating many cells in a shorter duration (UMSL, 1999). Therefore, when roast pork is held at room temperature, time and temperature may interplay to facilitate the growth of pathogens. Hence, to prevent microbes, the Food Premise Regulations (1999) require potentially hazardous food to be held at $\leq 4^\circ\text{C}$ or $\geq 60^\circ\text{C}$.

Water activity. Water activity refers to the amount of water available in food for microbial growth, and it is expressed as the ratio of vapour pressure of food to the vapor pressure of pure water (ranges from 0.1-0.99) (Ray & Bhunia, 2008). Although food may contain water, it is not always available for pathogen growth as some of it is in the bound form used for purposes such as dissolving solutes and hydrating food molecules (Ray & Bhunia, 2008). Water that is in the free form is for biological functions, and represents the amount that is available for microbial activities (Ray & Bhunia, 2008). Free water is necessary for pathogen growth as it facilitates functions such as nutrient transport, waste removal, enzymatic and biochemical reactions, as well as material synthesis (Ray & Bhunia, 2008).

Although microbes favour food with high water content, and grow best at their optimum a_w levels, they can still grow in a diverse range (Ray & Bhunia, 2008). However, when the a_w is reduced below their minimum tolerance level, microbial growth is suppressed; hence, low a_w has important implications in micro-organism control (Ray & Bhunia, 2008). The a_w of food can be reduced by removing water via adding solutes such as salt and sugar, drying, and freezing (Ray & Bhunia, 2008). Most pathogens cannot grow in food with an a_w below 0.85; hence, food with such a_w levels is considered safe when held at ambient temperature (United States Food and Drug Administration [FDA], 2013). Whether or not roast pork has a safe a_w is currently unknown, however, the marinating, drying, and roasting process may have

effectively reduced the a_w to inhibit microbial growth. This unknown factor may provide explanations regarding why FBIs are rarely associated with Chinese BBQ meats, and thereby, it is worthy to look into further.

pH. The pH refers to the concentration of hydrogen ions or acid in a system such as food and it usually ranges from 0-14 (Ray & Bhunia, 2008). Acidity is inversely related to pH, and hence, the higher the acidity, the lower the pH (Ray & Bhunia, 2008). All micro-organism have an optimum pH that they grow best in as well as a pH range that they can tolerate (Ray & Bhunia, 2008). For example, bacteria generally grow best in pH 6-8, but they can grow between pH 4.6-9 (Ray & Bhunia, 2008). Moving away from their optimum pH in either direction will slow down microbial activities. When pH is reduced below the minimum level required for pathogen growth, the cells will lose their viability and stop growing (Ray & Bhunia, 2008). Since most pathogens cannot grow below pH 4.6, foods with such pH levels can be safely held at room temperature (FDA, 2013). Limited studies have been conducted to determine the pH of roast pork, and therefore, this factor is currently unknown. However, the vinegar used in the roast pork may have altered the pH to adequate levels to limit microbial activities. Thus, the a_w and/or pH level may be the determining factors of whether or not roast pork can be safely held in the danger zone.

Surveillance data. The safety of Chinese BBQ meats has always been a concern to PHIs, but a lack of published and recent studies have been undertaken to assess it. In addition, data has shown an unexpected relationship between FBIs and Chinese BBQ meats. Despite concerns regarding the lack of time and temperature controls of these ethnic foods, few FBIs have been associated with them in Canada (Ying, 2000). Between 1975-1993 (the only period with available records), approximately 7% of the 16,634 reported FBI cases in Canada were suspected to be caused by Chinese food and less than 0.1% specifically implicated Chinese BBQ meats (Ying, 2000). Given that these surveillance data are from many years ago, it is uncertain whether the low numbers are due to under-reporting of FBIs, or a true indication of food safety. The literature review conducted by Ying (2000) provides further insight into this subject matter.

Assessing the safety of Chinese BBQ meats. In Ying's literature review, she provided an overview of the findings in two studies conducted by different researchers. Common methods used in these studies

were inoculation of bacteria such as *E.coli*, *Salmonella*, and *S. aureus* on the surface of Chinese BBQ ducks for 22 hours at 30°C (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). Although results from these studies showed a major discrepancy in their bacterial counts at the end of the 22 hour incubation, there were some common findings significant to public health. When challenged with a number of pathogens, the outer surface of the BBQ duck was able to delay or stop microbial growth for the first 5 hours of incubation at 30°C (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). Furthermore, ducks that were aseptically transferred from the oven and held as a whole in the display cabinet promptly after cooking showed no or minimal microbial growth even after 5 hours at room temperature (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). In contrast, ducks that had been handled post-cooking such as chopped or packaged demonstrated an increased level of *E. coli* and coliforms (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). This suggests that BBQ meats that do not undergo further handling post-cooking can be safely displayed at room temperature for up to 5 hours. Since the ingredients, preparations, and cooking processes of all BBQ meats are similar, these results observed on BBQ ducks will likely be similar to those for roast pork.

No or minimal signs of microbial growth on Chinese BBQ meats may be attributed to the conventional preparation and cooking processes (Ying, 2000; CPHAZ, 2011). For example, the State of Victoria Department of Health has recognized that basting the pork with a hot boiling mixture kills microbes on the surface, while the vinegar alters the pH, and the seasonings as well as air drying reduce the a_w to limit pathogen growth (Ying, 2000; CPHAZ, 2011). This suggests that the skin is the protective factor against foodborne micro-organisms, and both a_w and pH may play a significant role in safeguarding against FBIs. In addition, the roasting process produces an internal temperature sufficient to destroy pathogens that may be present on the flesh (Ying, 2000; CPHAZ, 2011). Traditional trade practices also prevent BBQ meats from causing food poisoning. For example, products are usually cooked in the kitchen, then immediately transferred to a separate area for display, which is vital in safeguarding against cross contamination between cooked and raw meats (Ying, 2000). Lastly, retailers tend to make their products in small batches to ensure they are sold quickly (Ying, 2000). All of these conventional practices help ensure the safety of BBQ meats. Although Ying's literature review provides significant information regarding Chinese

BBQ food safety, one limitation is the timeliness of the research, which dates back to year 2000, reviewing studies that were conducted over 30 years ago. Therefore, the relevance of Ying's research is questionable.

Guidelines Regarding Chinese BBQ Meats

Currently, no established guidelines are available in BC health authorities to provide inspection guidance to PHIs or educational resources to operators to ensure the safety of Chinese BBQ meats. However, Vancouver Coastal Health has been trying to develop one for many years (M. MacLeod, personal communication, October 8, 2013). Despite the lack of guidelines available locally, other health authorities have gradually recognized the safety of Chinese BBQ meats, and developed recommendations to address the risks associated with them. For example, both NSW Health and Toronto Public Health have regarded BBQ meats as low risk products and free of foodborne micro-organisms until they are cut up for sale (NSW Food Authority, 2008; CPHAZ, 2011). Hence, Toronto Public Health allows whole Chinese BBQ meats, specifically ducks and pork, to be displayed at room temperature for up to 4 hours provided that they adhere to specific food safety and sanitation criteria such as proper internal cooking temperature and immediate transfer of cooked meat into the display cabinet after roasting (CPHAZ, 2011). The Capital Health region in Alberta has also validated the safety of BBQ meats, allowing Peking duck to be held at 50°C subjected to specific conditions such as following proper sanitation practices and selling the products within the same day (Hislop et al., 2008 as cited in CPHAZ, 2011). BC health authorities may have different standards with regards to food safety and may not be able to use the same guidelines as these health authorities. However, similar guidelines are necessary to assist PHIs with inspections and the education of operators on food safety assurance. Perhaps, more research that adds knowledge on Chinese BBQ food safety could further assist health authorities with guidelines development.

Role of Public Health Inspectors

PHIs are responsible for inspecting the food facilities that prepare and sell Chinese BBQ meats, and ensuring operators' compliance to the Food Premises Regulation. Food premise inspections are integral components of food protection, allowing PHIs to prevent violations that may cause FBI outbreaks. PHIs are also educators, enhancing the knowledge of operators, food-handlers, and consumers of the potential health implications in Chinese BBQ meats.

To effectively ensure ethnic food safety for consumers, it is crucial that PHIs identify unsafe food-handling practices, follow evidence-based inspection guidelines, and educate operators with relevant educational materials. However, the lack of guidelines available in BC health authorities may make it increasingly challenging for PHIs to inspect Chinese BBQ food premises, leading to inconsistent inspections. Furthermore, non-comprehensive resources on the safety of Chinese BBQ meats may make PHIs less able to educate operators on proper food-safety and handling practices.

Purpose

Limited recent research has been conducted to assess the safety of Chinese BBQ meats, making it difficult to develop relevant inspection guidelines for PHIs and educational materials for operators. Therefore, it is uncertain whether improper time and temperature control of these products have potential health implications. Hence, the purpose of this study is to evaluate the safety of Chinese BBQ meats to determine whether this ethnic food can be safely displayed as a whole product at ambient temperature. Since most studies that were conducted assessed the safety of BBQ duck, it is unknown whether results observed on ducks can be applied to other meats even though they have similar ingredients, preparations and cooking processes. Thus, this study focused on roast pork. Provided that the a_w of roast pork is currently unknown, and previous studies suggest the meat surface to have micro-organism control, this study examined the a_w of 30 samples of roast pork surface (skin and cavity) from 30 retailers. The data collected was statistically analyzed with a one sample t-test and paired-sample t-test to determine whether the a_w is below 0.85, and whether the skin a_w differ significantly from the cavity a_w , respectively. The ultimate goal is to reduce the knowledge gaps between PHIs and Chinese BBQ meats, and provide science-based research to BC health authorities to develop guidelines that would enhance PHIs' ability to inspect food premises and educate operators on food safety.

Materials and Methods

Water activity tests were conducted to determine the safety of Chinese roast pork. A total of 30 samples of roast pork from 30 retailers were assessed within 2-4 hours after the skin and cavity reached 21°C. Since the roast pork was packaged into foam boxes upon purchase, holes were immediately punctured on the lid to prevent excess moisture from condensation. Prior to each experiment, all measuring instruments

were calibrated according to the standard manual. The minimum and maximum temperature of roast pork surfaces were measured at the time of purchase to determine the average temperatures they were displayed at in the retailers.

The knife, cutting board, and mortar and pestle were washed with detergent and warm water, and then dried with paper towels. Before food sample preparations, hands were washed with soap and warm running water and latex gloves were worn. All of these procedures were conducted between each sample and new disposable gloves were worn for each sample test. The temperature of the roast pork was monitored with the InfraPro4 thermometer and samples were prepared and measured within 2-4 hours after the pork surfaces reached 21°C. For each roast pork sample, the skin and cavity were removed with a clean knife and the fat attached to the skin was removed by hands. The skin was then chopped into small pieces, and further crushed with a mortar and pestle to obtain a representative sample. Then the sample cups were filled with the sample to no more than half full, ensuring the bottom of the cup was completely covered (Figure 1). This procedure was repeated to prepare samples of the roast pork cavity.

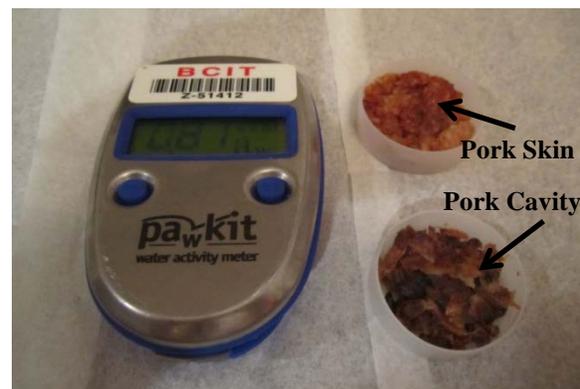


Figure 1. The Pawkit a_w Meter and the roast pork skin and cavity samples.

New disposable sample cups were used for each sample test and they were rinsed with deionized water prior to taking measurements. In between samples, the sample chamber was cleaned with deionized water and Kimwipes® to remove residues. The a_w measurements were obtained with the Pawkit a_w Meter, in the manners described in the standards of operational manual. Measurements were recorded to be used for statistical analysis. To validate the accuracy of the sample measurements, standard salt solutions were measured at the end of each sampling day to determine if measurements deviated. In addition, the a_w sample chamber was cleaned with the

Pawkit cleaning solution and Kimwipes®. Lastly, statistical analyses were conducted to assess whether or not the a_w is maintained within the safety standards, and to determine if a difference exists between the a_w of roast pork skin and cavity.

Reliability and Validity of Measures

To ensure the results obtained from the study are reliable, the same equipment were used and administered by one researcher in a consistent fashion (Heacock & Sidhu, 2013c). Each sample was prepared in the same manner and they were measured within 2-4 hours after the exposed surfaces reached 21°C to control for any potential variation in time and temperature. To prevent addition moisture introduced into the food samples, aseptic practices were strictly followed throughout the study. For the a_w tests, 30 samples of roast pork skin and cavity were analyzed to increase the power and strengthen repeatability (Heacock & Sidhu, 2013c).

To ensure validity of the study, the measuring instruments were calibrated according to their respective standard manuals before each experimental trial, and they were compared with standards at the end of each day (Heacock & Sidhu, 2013c). The standard of operation of the instruments were also rigorously followed by the researcher to increase accuracy of data collected, and thereby, increasing internal validity (Heacock & Sidhu, 2013c).

Inclusion and Exclusion Criteria

Only Chinese-style roast pork was eligible for the experimental procedures. Other meat products or preparation and cooking methods that deviate from the conventional Chinese-style BBQ were excluded from this study (Table 1).

Table 1. Summary of the inclusion and exclusion criteria

Inclusion	Exclusion
Chinese-style roast pork	Non-Chinese BBQ style
	Poultry
	Beef
	Other meats

Ethical Consideration

Since this study was not human or survey based, ethical consideration was not applicable.

Pilot Studies

With the same materials and procedures, the a_w of 3 samples of roast pork skin, the exposed meat surfaces between the skin and cavity, as well as the cavity were assessed. The results of the exposed meat surfaces and cavity were the same, possibly as both areas are marinated with the same ingredients and prepared and cooked in the same manner. In addition, both areas are meat; hence they are expected to have the same a_w . Due to the difficulty in purchasing pork samples with the exposed meat surfaces, only the skin and cavity are assessed in the actual study. The pilot study allowed the researcher to ensure that the proposed method is reliable and valid prior to conducting the actual experiment, test for potential experimental errors, and become familiar with the use of the instruments as well as sample preparations.

Statistical Analysis

Description of Data

In this study, the a_w of the roast pork skin and cavity were analyzed at 21°C to determine whether or not they are within the safety standards to be displayed at ambient temperature. The types of data that were collected during the experiment include temperature and a_w , which are continuous numerical data (Heacock & Sidhu, 2013a). Microsoft Excel (Microsoft Corporation, 2010) was used to create descriptive statistics while the Number Cruncher for Statistical Systems (NCSS Version 9.0) (Hintze, 2013) was used to generate and analyze inferential statistics.

Descriptive Statistics

The sample size used was 30 and the mean, standard of deviations, mode, median, and ranges of the roast pork surface temperature, skin and cavity a_w were obtained.

Inferential Statistics

In this study, three independent null (H_0) and alternate hypotheses (H_a) were established:

- 1) H_0 : The a_w of roast pork skin is ≥ 0.85 .
 H_a : The a_w of roast pork skin is < 0.85 .
- 2) H_0 : The a_w of roast pork cavity is ≥ 0.85 .
 H_a : The a_w of roast pork cavity is < 0.85 .

The one-sample t-test was conducted to assess whether or not the a_w of roast pork is below 0.85 to determine if this ethnic food can be safely displayed at ambient temperature. Specifically, the one-sample t-test was chosen because previous studies suggest that the meat surface has micro-organism control;

Table 2. The descriptive statistics for the temperature, skin, and cavity a_w .

Measurement	Mean	Standard Deviation	Mode	Median	Range
Temperature ($^{\circ}\text{C}$)	30.7	6.098	N/A	30.85	26
Skin a_w	0.70	0.072	0.73	0.725	0.28
Cavity a_w	0.81	0.054	0.85	0.83	0.21

Table 3. Z-test results for the skin and cavity a_w .

Water Activity	Z-value	P-value	Reject H_0	Power ($\alpha = 0.05$)
Skin	-11.4237	< 0.00001	Yes	1.0000
Cavity	-3.0027	0.001338	Yes	0.96753

hence, the direction of the difference is identified in advance.

3) H_0 : There is no difference between the mean a_w of the roast pork skin and cavity ($\mu_1 - \mu_2 = 0$).

H_a : There is a difference between the mean a_w of the roast pork skin and cavity ($\mu_1 - \mu_2 \neq 0$).

Different ingredients and preparation methods are used to marinate the roast pork skin and cavity; therefore, the paired-sample t-test was used to determine if a difference exists between the a_w of roast pork skin and cavity.

Results

Interpretation of Data

The mean surface temperature of roast pork was 30.7°C and the mean a_w of the skin was 0.70 ± 0.013 , which is lower than the mean a_w of the cavity (0.81 ± 0.009) (Table 2). With the exception of the range, both the mode and median of the skin a_w were lower than those for the cavity a_w . A comparison of the a_w measurements between the skin and cavity is illustrated in Figure 2.

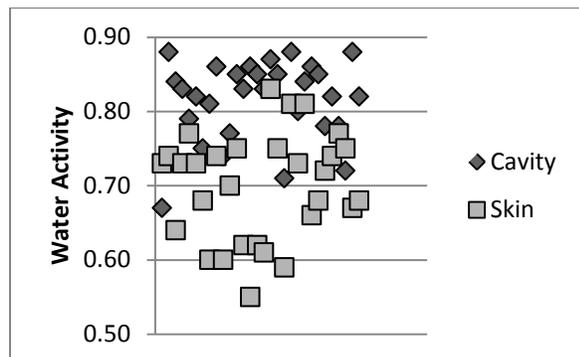


Figure 2. A comparison of the a_w measurements between the roast pork skin and cavity.

In the one-sample t-test, the parametric test was used to determine whether or not the roast pork skin a_w is below 0.85. In contrast, the non-parametric test, Wilcoxon Signed-Rank test was used to analyze the results of the cavity a_w because the normality test was rejected. According to Table 3, the p-value for the a_w of skin was < 0.00001 at $\alpha = 0.05$. Therefore, the H_0 can be rejected, concluding that the a_w of roast pork skin is statistically lower than the standard, 0.85, and hence, it can be safely stored at ambient temperature (21°C) provided that the cavity a_w is also within the safety standards. Likewise, the p-value for the cavity a_w was 0.001338 at $\alpha = 0.05$ (Table 3); thus, the H_0 can be rejected, indicating that the a_w of the cavity is statistically lower than the standard, 0.85. Therefore, roast pork can be safely held at ambient temperature given that the skin a_w is also within the safety standard. In this case, both the a_w of the skin and cavity were below 0.85, supporting that the display of roast pork at ambient temperature is safe.

In the paired-sample t-test, all the assumptions were within normality; therefore, the parametric test was used to analyze whether a difference exists between the mean a_w of the roast pork skin and cavity. The 95% confidence intervals around the mean a_w of the skin and cavity were 0.67-0.73, and 0.79-0.83, respectively (Figure 3). The p-value was < 0.00001 at $\alpha = 0.05$; thus, the H_0 can be rejected, concluding that there is statistically significant difference between the mean a_w of the roast pork skin and cavity.

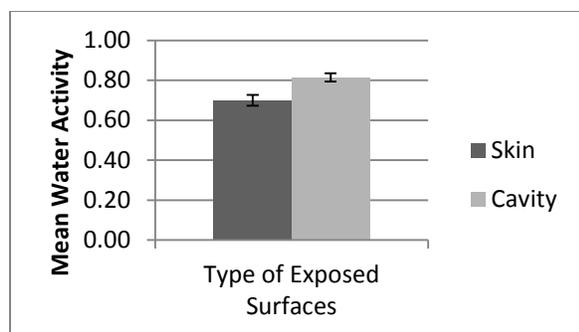


Figure 3. A comparison of the mean a_w of the pork skin and cavity with 95% confidence intervals.

Alpha and Beta Error

The p-values obtained from the one-sample t-tests for the skin and cavity a_w , and the paired-sample t-test were < 0.00001 , at 0.001338, and < 0.00001 , respectively (Table 4). With such low p-values, there is minimal potential for alpha errors to occur. Since the non-parametric test for the cavity a_w one-sample t-test does not indicate a power, the power from the parametric test was analyzed as they are expected to be similar. The power of the tests at $\alpha = 0.05$ for the skin and cavity a_w were 100% and 96.8%, respectively. Similarly, the power of the paired-sample t-test was 100%. Since the power is high for all three tests, there is a strong probability of correctly rejecting the null hypothesis.

Discussion

Most studies related to Chinese BBQ meats assessed the safety of BBQ duck, while studies on other meat products such as roast pork are lacking. However, since the ingredients, preparation, and cooking processes of all BBQ meats are similar, results observed on ducks are expected to be similar to roast pork, which was confirmed by this study. For example, BBQ duck was shown to be able to resist microbial growth for up to 5 hours when inoculated with pathogens at 30°C (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000) while roast pork surfaces were found to have a safe a_w to suppress pathogen growth. Both studies illustrate that BBQ meats have the capability to limit pathogen growth. Previous studies have attributed the suppression of microbial growth in BBQ meats to the seasoning and air drying process, which reduce the a_w of the skin, and thus, providing it with antimicrobial properties (Ying, 2000; CPHAZ, 2011). This was confirmed by the results found in this study as the a_w of the skin and cavity of roast pork were both below 0.85, indicating that the surfaces can limit pathogen

growth at room temperature. Since it is demonstrated that the antimicrobial properties of BBQ duck and pork are similar due to their similarity in ingredients, preparation and cooking methods, this study confirmed that findings from Chinese BBQ duck studies can potentially be extrapolated to Chinese roast pork. These results together provide insight regarding why few foodborne illnesses were associated with BBQ meats even though they commonly undergo time and temperature abuse. Furthermore, these results illustrate that Ying's (2000) findings regarding BBQ duck safety are still relevant even though her research was conducted many years ago, which suggests that the traditional recipe of Chinese BBQ meats and conventional trade practices remain consistent over time.

In addition, results of this study show that the a_w of roast pork skin and cavity differ significantly due to the different ingredients and preparation processes used, which indicates that different ingredients and preparation process can significantly affect the opportunity for pathogens to grow. For example, if a recipe is only capable in reducing the skin a_w to less than 0.85, but the cavity a_w is above 0.85, the ingredients and preparation process of the cavity can be adjusted to become similar to those of the skin to achieve a a_w that is below 0.85. This ensures both external surfaces of roast pork are at a safe a_w to be displayed at room temperatures.

In addition, past studies have suggested that roast pork and BBQ duck can be safely held at room temperature for up to 4 hours provided that they adhere to specific food safety and sanitation criteria (CPHAZ, 2011). Based on the analysis of the roast pork skin and cavity a_w , they were below 0.85, indicating that they can be safely held at room temperature, which is consistent with previous studies (CPHAZ, 2011). However, these results observed in roast pork are only applicable to specific conditions. Firstly, since the implications of time on a_w was not examined in this study, the duration that roast pork can be safely held at ambient temperature is unknown. Thus, the 4 hour period suggested by previous studies cannot be verified by this study.

Secondly, these results are only relevant to roast pork that is displayed as a whole since it is subjected to increased food handling and opportunities of contamination when cut up for sale. As demonstrated in previous studies, an increased amount of *E.coli* and coliforms were observed in ducks that had been handled post-cooking such as cut or packaged (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). In contrast, ducks that were transferred

aseptically from the oven immediately after cooking and held as a whole in a display cabinet showed no or minimal microbial growth even after 5 hours at room temperature (Stiles & Ng, 1977; Robinson & Matthews, 1990, as cited in Ying, 2000). Hence, results from this study are only applicable to whole roast pork that follows traditional recipe and safety measures such as immediately transferring the pork to the display cabinet after roasting and reaching the proper internal cooking temperature.

Lastly, this study particularly focused on the a_w of the external surfaces of cooked roast pork, which provided conclusions regarding the health implications associated with post-cooking temperature abuse of roast pork. Specifically, any pathogens that are introduced to roast pork post-cooking cannot survive or grow due to the low a_w of the external surfaces, and hence, there is a low probability for it to cause FBIs. However, roast pork is also time and temperature abused during the preparation process when it is left to air dry on hooks in a well-ventilated area at ambient temperatures for several hours up to several days (DPH, 2012). Any heat-sensitive pathogens that are present or introduced during the preparation process can be destroyed via the cooking process. However, the heat-stable toxin producing pathogen, *S. aureus*, may survive when introduced during the preparation process. When roast pork contaminated with *S. aureus* is displayed at room temperatures post-cooking, the heat-stable toxins can potentially cause FBIs (Montville, Matthews, & Kniel, 2012). Since the a_w of the external surfaces of roast pork during the preparation process is not assessed, it is inconclusive whether *S. aureus*, can survive during the preparation process. Therefore, the findings of this roast pork study is only relevant to whole roast pork that was not time and temperature abused during the preparation process and follows the aforementioned food safety and sanitation criteria.

Limitations

Although measures were taken to ensure the results were valid and reliable, limitations of the study may have affected the accuracy of the results. For example, time, temperature, and a_w are all interdependent, but the amount of time that the roast pork was displayed at ambient temperature cannot be controlled. Thus, the effects of time and temperature on a_w cannot be delineated. Additionally, although there is a traditional recipe for roast pork, the preparation and cooking techniques may differ between cooks, which may lead to inconsistent results. Since it is unknown

if non-traditional recipes were used, any discrepancy in the recipes were not considered.

Recommendations

Based on this study, in order to safely display whole cooked roast pork at room temperatures, it is recommended that the following conditions are met:

- Prepare roast pork according to conventional methods including using traditional seasoning such as vinegar and maltose, air drying the pork, and basting the skin with a hot boiling mixture prior to cooking to ensure the a_w is reduced to limit pathogen growth
- Air dry the pork in a cooler at 4°C or below rather than at ambient temperatures to prevent the potential growth of *S. aureus*.
- Cook the roast pork to an internal temperature of 74°C.
- Transfer the whole roast pork from the oven immediately after roasting to a clean and enclosed display cabinet that is separate from the preparation and cooking area.
- Remove the cut pork from the display cabinet to a different display unit that is capable to maintain the internal temperature to 60°C or above.
- Ensure food handlers understand the potential risks associated with roast pork and follow basic standards of operations such as adequate sanitizing of equipment and food contact surfaces, and proper hand washing after activities that may contaminate hands.

These food safety and sanitation criteria should be included in the guidelines developed by health authorities. In addition, operators can provide a sample of their pork to a Process Authority or lab for a_w testing to demonstrate that the a_w of their product is at or below 0.85 and thus, can be safely displayed at room temperatures provided that they follow the same recipe each time.

Future Research Suggestions

To further understand Chinese BBQ meats, it would be worthwhile to conduct studies in the following research topics:

- Assess the safety of other Chinese BBQ meats such as BBQ pork and soy sauce chicken at ambient temperature.
- Determine how long Chinese roast pork can be safely displayed at ambient temperature by assessing how a_w of roast pork changes with time.

- Determine whether the vinegar used to marinate roast pork has reduced the pH to ≤ 4.6 to provide the exposed surfaces with antimicrobial property.

Conclusion

Results from this study show that the mean temperature of roast pork is 30.7°C, which is below the required hot-holding temperature of 60°C, and thereby, confirming that this ethnic food often undergoes temperature abuse. However, the results illustrate that the skin and cavity a_w of pork are both below 0.85, supporting that the display of it at ambient temperature is safe. Therefore, the temperature abuse of whole cooked roast pork is not expected to have health concerns provided that all safe food handling procedures were followed. The results of this study can bridge the knowledge gap that PHIs have with regards to BBQ meats, providing them a better understanding of the health implications associated with time and temperature abuse of this food. In addition, these results can aid the health authorities with guideline development to assist PHIs with inspections and the education of operators on food safety assurance.

Acknowledgement

The author would like to thank Bobby Sidhu for providing ongoing support, advice, and guidance for conducting this study and writing this research paper; Fred Shaw for providing all the required equipment for this study; and Helen Heacock for offering her expert knowledge on conducting statistical analysis. The author is also appreciative towards Elden Chan, who suggested the research topic for this study. A special thanks to Kevin Lau for editing this research paper.

Competing Interest

The authors declare that they have no competing interests.

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