ASSESSING MICROBIAL STABILITY AND QUALITY OF GREEN BEANS USING VARIOUS HOME CANNING METHODS

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ABSTRACT

Today many consumers follow processing methods recommended either from family members or the internet, which they interpret as being safe. Processing temperature profiles, survival of *B. stearothermophilus* spores, texture, and color of green beans processed under four home canning methods were assessed. The products were processed using pressure, boiling water bath, steam, or oven canning methods. Pressure canning produced the greatest microbial reductions but this method resulted in the lowest bean quality. The boiling water bath, steam, and oven canning were found to be less safe because the product temperature never achieved 100°C and the resulting microbial counts, >1.7 log CFU/ml, were observed after processing. However, green bean quality was better than pressure canning, with beans from steam canning having the firmest texture and best green color. Although better green bean quality results were observed from internet or family based methods, their safety is questionable considering the high microbial survival.

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1. LITERATURE REVIEW

1.1. Green Beans *(Phaseolus vulgaris*, L.*)*

Green beans are a nutritious vegetable commonly grown in home gardens and canned at home to extend their shelf life. Green beans require a shorter growing season (harvest 50-60 days after planting) and are relatively easy to maintain, which makes it an ideal crop for home gardens (Taber 2009). The proximate composition (Figure 1) of green beans is 90.3% water, 7.1% carbohydrate, 1.8% protein, 0.7% ash, and 0.1% fat (USDA 2011). In addition, green beans are a good source of nutrients such as phosphorus, niacin, calcium, riboflavin, potassium, and protein (USDA 2011). Furthermore, green beans are a very good source of vitamins A, C, and K, dietary fiber, and manganese and are low in cholesterol, sodium, and saturated fat (USDA 2011). Green beans are a low acid vegetable with a pH of 4.9-5.5 and are one of the many vegetables that are consistently canned in the industry and at home (Downing 1996, Landry and others 2001, Anonymous 2009a). The combination of nutrients and low acidity makes green beans a potential food source for many microorganisms.

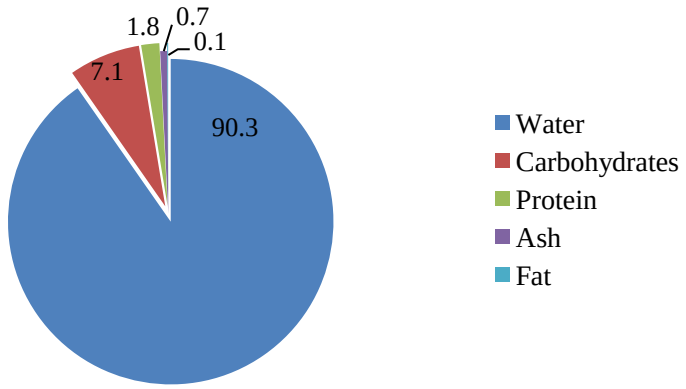

Figure 1. Green bean proximate % composition from the USDA Nutrition Database (USDA 2011).

1.2. Heat Transfer

Most food processes involve the heating or cooling of the food products. Therefore, heat transfer is an important concept to understand, even in home canning. Heat is defined as an energy transfer resulting from a temperature difference (Fellows 2003). The end result of heating is a temperature or phase change (Fellows 2003). The three forms of heat transfer are radiation, conduction, and convection (Fellows 2003). Radiation is heat transferred through space by infrared radiation (Rao 2006). An example of this type of heat transfer is an oven. The heat is generated by a heating element in the top or bottom of the oven and transferred to the food products/pans through the air. Conductive heat transfer is heat that is transferred from one solid object or material to another (Rao 2006). An example of conduction is the heat transferred from the stove top to the metal of a pot. The third type of heat transfer is through convection. Convection is the transfer of heat between a solid and fluid surface or within a fluid that is not the same temperature with the assistance of bulk fluid flow (Rao 2006). Bulk fluid flow relates to the density of the liquid, for example hot water is less dense then cool water. In a pot of boiling water, the hot water from the bottom rises to the top and displaces the cooler water, which then goes to the bottom and is heated. This water then returns to the top once heated and the cycle continues. This bulk fluid flow accelerates the heat transfer because of the movement of the fluids.

Thermal conductivity (k) is a factor that also is an important aspect of conductive heat transfer. Each type of material has a different thermal conductivity and this can influence how rapidly heat is transferred through a material, and in the end how, long it takes to heat a product. A higher k value indicates that the material transfers heat at a higher rate than a lower k value (Fellows 2003). In canning processes, important k value data relates to heating medium and

processing equipment (Table 1). Food materials are also important because the composition of the food will dictate the thermal conductivity of the food and how fast it can transfer heat (Fellows 2003, Sweat 1986). Mathematical formulas to determine a product's thermal conductivity from its proximate composition values have been developed (Sweat 1986).

Table 1. Thermal conductivity (k) values for various materials.

Material	k value (W/m-K)
Air	0.0314
Water	0.68
Steam Vapor	0.027
Stainless Steel	16.7-24
Glass	0.8-1.4
Olive Oil	0.17
Apple Juice	0.56
Green Beans	0.55

In the canning process, thermal conductivity is a factor that influences how fast the heat is transferred into the jar and how long it stays at a certain temperature. Convective heat transfer and bulk fluid flow inside the jar is responsible for accelerating the heat transfer within the jar. Having this knowledge also helps determine microbial death kinetics, which is needed to determine if a food product is safe.

1.3. Microbiology of Home Canning

Contamination by pathogenic microorganisms is the main safety issue in thermally processed food products. Pathogenic microorganisms important to the canned foods industry can produce spores, which are resistant to many stress factors. Spores are dormant cells and can be the cause of foodborne illnesses or food spoilage after a food has been processed. Toxic chemicals, acidity, moisture removal, UV radiation, and high temperatures are stress factors

spores can resist (Downing 1996). In turn, the spores can germinate into active, toxin-producing vegetative cells.

In the early 1900's, scientific principles were developed to ensure the safety of thermally processed foods. However, it was not until the 1940's that mathematical models were developed, which greatly increased the safety of canned foods (Andress and Kuhn 1998). *C. botulinum* spores are pathogenic and small amounts of their toxins are able to kill humans and thus these mathematical models were developed with the destruction of *C. botulinum* spores in mind (Andress and Kuhn 1998, Montville and Matthews 2008). However, a basic understanding of how heat destroys spores did not occur until the 1980's (Coleman and others 2007). Coleman and others (2007) found that when vegetative cells sporulate at higher temperatures, the spores become more heat resistant. A high level of dipicolonic acid (DPA) is present in the spore's core, which chelates with calcium and this is thought to initiate germination (Barton 2005). DPA is usually lost and significant protein and enzyme damage occurs when spores are killed by heat (Coleman and others 2007). If DPA is still present in the spore after processing, the spore can germinate, but cannot advance into the outgrowth step after germination (Coleman and others 2007). Today, there is not a full understanding of how spores are killed in moist heat conditions; however, research is still being done in this area to gain the full understanding of the mechanisms by which bacterial spores are killed.

1.3.1. Thermal Death Kinetics

Thermal death kinetics is a concept that is used in processing to calculate the amount of heat processing required to kill pathogenic microorganisms and/or spores that could be pathogenic if they germinate. The death rate curve is a mathematical model where the curve shows the interval of time it takes to kill 90% of the microorganisms (1 log reduction) present in

the product (Potter and Hotchkiss 1998, Montville and Matthews 2008). This time interval is known as the D value which differs depending on the microorganism and temperature (Fellows 2003, Montville and Matthews 2008). Higher D values indicate the microorganism is more heat tolerant (Fellows 2003, Montville and Matthews 2008). A heat treatment process in the industry implements a 12D process, which means that the product needs to be heated for 12 times the D value to sufficiently reduce the number of microorganisms (Ball and Olson 1957, Stumbo 1973, Pflug and Odlaug 1978, Pflug 1987). Therefore, a 12D process would be one that causes a 12 log reduction in microorganisms.

A thermal death curve uses D values over a temperature range for a specific microorganism and the linear slope of the thermal death curve is called the z value (Ball and Olson 1957, Pflug and Nicholas 1962). The definition of the z value is the number of degrees (°C) it takes to get a 1 log reduction of the microorganisms' D value (Ball and Olson 1957, Potter and Hotchkiss 1998, Montville and Matthews 2008). The D and z values for *C. botulinum* and *B. stearothermophilus* can be found in Table 2.

Table 2. Approximate D and z values for *C. botulinum* and *B. stearothermophilus* (Montville and Matthews 2008).

Microorganism	**D value (min) at:**		**z value**
	100 °C	**121 °C**	**(°C)**
C. botulinum	50	0.1-0.2	10
B. stearothermophilus	3,000	4.0-4.5	7

The D and z values can vary depending on the physical and chemical conditions of the food medium to which microorganisms are placed and the strain type of the microorganism. Therefore, these mathematical models are more theoretical than practical especially for the food industry (Iciek and others 2006). Another factor that can cause these mathematical model

predictions to vary is the fact that difference of physiological states within the spore population, some spores being activated, while other spores are dormant, and some are in a super dormant state (Iciek and others 2006). These factors can change curve type from linear to curvilinear, which can affect the D and z values (Iciek and others 2006). Another factor that can affect the D and z values, that has more recently come to light, is the type of process, such as a batch process or continuous process. Dogan and others (2009) found that a continuous processing system is more lethal than a batch heating system and the two systems have significantly different inactivation parameters. It can be seen from more recent studies that thermal death kinetics are not as simple as it was once thought and this will affect research as well as the industry (Dogan and others 2009).

1.3.2. The Hurdle Concept

The hurdle concept is a theory that suggests a combination of factors or parameters to inhibit microbial growth are better than only one parameter (Leistner and Gorris 1995, Montville and Matthews 2008). In practice, processors will use both intrinsic factors, e.g. salt content and water activity, and extrinsic factors, e.g. temperature and pressure, to reduce microbial growth in food products (Leistner and Gorris 1995, Montville and Matthews 2008). This concept has been used for centuries; however it was mostly unconsciously done (Leistner and Gorris 1995). Then in the 1980's, the meat industry started purposefully putting in hurdles to make products more shelf stable (Leistner and Gorris 1995). The hurdle concept has become very important to the canning industry to the point of the USDA incorporating it into federal regulations for the industry (Montville and Matthews 2008). For example, industry is now required to record pH as well as water activity. Along with it being incorporated into industry, the hurdle concept also

has been incorporated into the home canning guidelines for inhibiting *C. botulinum* (Montville and Matthews 2008).

1.3.3. *Clostridium botulinum*

Clostridium botulinum is rod shaped, gram-positive, and anaerobic bacteria (Montville and Matthews 2008). Microorganisms such as *C. botulinum* will produce spores during the stationary phase of growth (Montville and Matthews 2008). *Clostridium botulinum* produces eight distinct neurotoxins of which four, Type A, B, E, and sometimes F, can cause botulism food poisoning (Rhodehamel and others 1992). *Clostridium botulinum* is commonly found in nature, for example in the soil and sediment under bodies of water, mostly in its spore form (Rhodehamel and others 1992). In an aerobic environment, the *C. botulinum* vegetative cells cannot survive and therefore cannot produce the toxins. The spores under anaerobic environments, which low-acid canned goods provide, can germinate into vegetative cells that can then produce toxins (Montville and Matthews 2008).

Home processed foods such as meat, vegetables, and fish are the cause of most botulism cases in the United States due to improper canning methods, storage, or handling (Rhodehamel and others 1992, Oomes and others 2007). Chemical or physical treatments are used in combination to control *C. botulinum* in processing (Rhodehamel and others 1992, Coleman and others 2007, Oomes and others 2007). Chemical treatments to control *C. botulinum* include lowering the pH, adding NaCl, and adding nitrites (Rhodehamel and others 1992, Oomes and others 2007). Physical treatments to control *C. botulinum* include drying, thermal sterilization, pasteurization, and irradiation (Rhodehamel and others 1992). The safety concern of *C. botulinum* has minimized the number of researchers studying this microorganism. Instead,

microorganisms that do not produce deadly toxins, yet are good models of *C. botulinum*, are favored for processing studies.

1.3.4. *Bacillus stearothermophilus*

Bacillus stearothermophilus, also known as *Geobacillus stearothermophilus*, is a thermophilic aerobic spoilage microorganism that is typically used in research to determine if processes will be able to kill *C. botulinum* spores (Periago and others 1998, Rudra and others 2010). *Bacillus stearothermophilus* produces spores that can survive higher temperatures than *C. botulinum*; however, *B. stearothermophilus* does not produce toxins that cause foodborne illnesses so it is less hazardous to work with in processing schemes compared to *C. botulinum* (Periago and others 1998). The D values for *B. stearothermophilus* at 100°C and 121°C are 3,000 and 4.0-4.5 minutes, respectively (Montville and Matthews 2008). *B. stearothermophilus* has a z value of 7°C (Montville and Matthews 2008). The benefit of using *B. stearothermophilus* as an indicator organism is that since it is more heat resistant, other microorganisms that have lower D and z values also will be killed. *Bacillus stearothermophilus* is in the flat sour spoilage microorganism group (Ghani and others 2002, Montville and Matthews 2008). Therefore, elimination and use of this microorganism as a model is significant in regards to food spoilage. Leguérinel and others (2007) found that *B. stearothermophilus* heat resistance was dependent on sporulation temperature. When sporulation occurs at higher temperatures, the spore is more heat resistant during thermal processing, which will change the D and z values (Leguérinel and others 2007).

1.4. Green Bean Quality

The texture quality of the end product is an attribute important to consumers and may be a reason why the consumers have repeat purchases (Stolle-Smits and others 1995, Stolle-Smits

and others 1997). Textural losses in green beans are attributed to the breakdown of the polysaccharides in the plant cell walls (Stolle-Smits and others 1995, Shiga and Lajolo 2006). Three major cell wall polysaccharides are present in fresh green beans. These include pectin, cellulose, and hemicellulose and can be degraded through a thermal process (Stolle-Smits and others 1995). With these components being degraded, the structure of the green bean is weakened (Stolle-Smits and others 1995). Leadley and others (2008) reported that the texture also depended on the type of process, with the high-pressure sterilized samples being firmer than the pressure canned samples. The texture was tested again after 7 months of storage and the difference in firmness between samples remained the same; however, all samples were softer than right after processing (Leadley and others 2008).

Maintaining color is important to manufacturers and can be used for determining the end quality of a vegetable (De La Cruz-Garcia and others 1997). Chlorophylls and carotenoids are the two most common pigments found in plant tissues (De La Cruz-Garcia and others 1997). De La Cruz-Garcia and others (1997) reported that steam cooking fresh green beans caused a greater loss in these pigments than pressure cooking, boiling, or microwaving fresh green beans. Leadley and others (2008) reported darker color of green beans processed with high pressure sterilization than in the USDA recommended pressure canning, which is not a favorable quality.

1.5. Home Canning

Home canning in the United States is a popular method of preserving homegrown foods because of the perishability of fresh fruits and vegetables. Home canning has become more popular in the last ten years because of the cultural movement toward growing vegetables in home gardens and buying food locally through farmers markets. D'sa and others (2007) reported that the two most popular sources for instructions on canning were family or friends, and

cookbooks, accounting for 51.2% and 16.7%, respectively. With most consumers getting information from these sources there is a high probability that methods being given out are not recommended by the USDA because they do not reach temperatures high enough to kill *C. botulinum*. In a 2005 survey, D'Sa and others (2007) reported that 30.5% of consumers did not follow the recommended methods. The results of this survey indicate that consumers need to be more aware and educated in the food safety concerns of canning, especially between acid and low acid products (D'Sa and others 2007).

Canning will remove oxygen and this greatly decreases the number of microorganisms that can grow in the anaerobic environments. The USDA stated that after canning about 2% oxygen is left in the jar, which makes the environment anaerobic (Anonymous 2009a). Only certain microorganisms can grow in an anaerobic environment, of which the major food safety concern is *C. botulinum* (Landry and others 2001). Other home canning food safety concerns include under processing and inadequate sealing of the jars by the end of the process (Landry and others 2001). In addition to microbial reductions, enzymes in fresh food are denatured during the canning process. For the best end product, fresh foods of good quality need to be used. Good quality is indicated by absence of mold, disease spots, and wilt.

Historically in the United States, home canned foods are the vehicle for most cases of botulism (Anonymous 2012a). One of the worst botulism outbreaks in the United States occurred in Grafton North Dakota (Allen and Ecklund 1932). Thirteen people of the seventeen people present at a meal died of botulism poisoning because they ate a cold vegetable salad that contained home canned peas (Allen and Ecklund 1932). The reason the peas were unsafe was because they were not cooked again before they were put in the salad (Allen and Ecklund 1932). At this time, the recommendations for home canning included boiling the vegetables for 15

minutes before consuming them; however, because this was not done, *C. botulinum* cells were not killed and the toxin was not inactivated. Between 1996 and 2008, 18 botulism outbreaks were caused by home canned vegetables (Anonymous 2012a). Symptoms of foodborne illness usually occur between 12 and 38 hours after consumption, but can show up as early as 6 hours or as late as 10 days after consumption (Anonymous 2012a). If consumed, *C. botulinum* can cause drooping eyelids, dry mouth, slurred speech, muscle weakness, blurred vision, paralysis, or death (Anonymous 2012a). Medical care should be sought immediately if any of these symptoms are present (Anonymous 2012a).

1.5.1. The History of Canning

Canning history started with Napoleon Bonaparte and his understanding of military strategy. He was losing fewer troops to battle compared to diseases such as malnutrition and scurvy, which was a major concern for the French government (Featherstone 2012). In 1795, 12,000 francs were offered as a reward for developing a preservation method for large quantities of food (Featherstone 2012). Nicolas Appert answered Napoleon's request with his method for preservation called canning. Canning was first invented by Appert in the 1790's. He thought canning was effective because no air was present in the jars (Downing 1996; Anonymous 2002, Featherstone 2012). The industrial pressure canner, which can raise temperatures higher than boiling water (100°C) during the canning process, was patented in 1851 by Raymond Chevalier-Appert (Anonymous 2002). Three years later, in 1854, Louis Pasteur made significant progress in the understanding of how microorganisms can cause food spoilage, but it would not be until the 1920's that the relationship between the pressure canner and microorganisms would be fully understood (Downing 1996, Anonymous 2002, Featherstone 2012).

The first government publication that addressed home canning was published in 1909, under the title Farmer's Bulletin 359 (Breazeale 1909). The type of process recommended was called fractional sterilization, which could take up to three days. This bulletin also indicated the causes of spoilage in canned products (Breazeale 1909). This first bulletin only covered vegetables while the second bulletin, Farmers' Bulletin 839, gave recommendations for vegetables, fruits, and meats (Benson 1917). These recommended processes included boiling water bath, pressure canning, and a water seal process (Benson 1917). A few months later, the Farmers' Bulletin 853 declared pressure canning as the only way to can low acid foods (Creswell and Powell 1917, Downing 1996). In 1921, the Farmers' Bulletin 1211 replaced the previous bulletins on home canning and gave more information about the "whys" of processing (Anonymous 1921). Some of the most important points to come from this bulletin include (1) processing does not necessarily mean sterilization, (2) the process needed heat sufficient enough to destroy the bacteria that could grow in the absence of air, (3) open kettle canning may not be a reliable method, and (4) vacuum in the container is desirable (Anonymous 1921). This bulletin also recommended three processes: pressure canning, continuous boiling water bath, and intermittent boiling water bath (Anonymous 1921).

In the 1920's, research on the technology and science of home canning was abundant and many methods were evolving and changing during this time period (Andress and Kuhn 1998). This was the time frame that the area of bacteriology was just getting started and heat penetration studies were being established (Andress and Kuhn 1998). In the 1910's and 1920's, *C. botulinum*'s basic toxicological and biological characteristics were determined by major researchers (Dickson 1917, Burke 1919, Weiss 1921, Esty and Meyer 1922). It was clear that *C. botulinum* needed to be controlled in canned foods (Downing 1996). Bigelow and Cameron

(1932) identified the relationship between spore heat resistance and pH, which was the basis for the high and low acid food classifications.

The heat penetration research that was going on at the same time included applied physical laws to calculate lethal values in the time-temperature curves (Thomson 1919). Bigelow and others (1920) continued Thompson's type of research and included formulas to take into account initial temperature and container size. Magoon and Culpepper (1922) added the research that cooling curves were not the same as the heating curves as Thompson and Bigelow had thought. In 1923, Ball developed a more flexible formula for process determination which could be adapted to all container sizes and retort temperatures. The basis of modern thermal process determination methods are from Ball's research and concepts (Andress and Kuhn 1998).

In 1926, the Farmers' Bulletin 1471 was the first to only recommend pressure canning for low acid vegetables (Stanley 1926). In the Farmers' Bulletins between the years of 1936 and 1944, steam canning, oven canning, and open kettle canning were still approved for fruits and tomatoes despite the research showing the methods were not safe (Stanley and Steinbargar 1936, Stanley and others 1942, Anonymous 1944). However, in the later publications there were explicit warnings about the safety of these three methods (Anonymous 1944). Between 1944 and 1946, the USDA revised and made new recommendations for home canning low acid vegetables (Andress and Kuhn 1998). The USDA still uses these recommendations for most vegetables in the current home canning guides (Andress and Kuhn 1998). Many changes have been made over time to improve the safety and ease of use of canned foods, but the basic process is still the same.

1.5.2. Canning Methods

Methods used in the 1800's were entirely different than the current methods recommended by the USDA. The open kettle method was a well-liked method because of its ease and lack of extra equipment (Andress and Kuhn 1998). This method consisted of boiling the product and pouring it into the jar, which is known today as hot pack (Andress and Kuhn 1998). The thought behind this method was that the hot liquid sterilized the inside of the jar and lid (Williams 1943, Andress and Kuhn 1998). Other methods used early in canning include boiling water bath, steam, and oven methods (Williams 1943, Andress and Kuhn 1998). Boiling water bath methods are still recommended today for high acid foods, but not for low acid foods (USDA 2011).

Today, beginning canners use many different sources for information including family recipes, friends, blogs on the internet, the USDA, and cookbooks (D'sa and others 2007). However, some of these sources use older information and since that time scientists have researched and found those recommendations to be unsafe, while other methods have not been researched thoroughly by scientists. Methods that are used for canning green beans by consumers, which are not USDA recommended, include the boiling water method (which can be used for high acid foods but not low acid), the dry oven method, and the steam canning method (Anonymous 2009a). Although the *C. botulinum* vegetative cells may be killed, these methods are not recommended by the USDA because the processing conditions do not reach a high enough temperature to kill *C. botulinum* spores. In fact, the temperatures in these methods may be sufficient to stress the spores, which in turn can lead to germination once the product is cooled sufficiently (Montville and Matthews 2008).

1.5.3. Pressure Canning

Pressure canning in the home was not possible until the early 1900's, when a small pressure canner was invented for home use (Anonymous 2012b). In 1917, the USDA announced that pressure canning was the safest and only way to can low acid food products (Downing 1996). The USDA recommends pressure canning for green beans because they are a low acid food (Anonymous 2009a). The reason for the pressure requirement is that with low acid foods a temperature of 116°C (240°F) is required to kill *C. botulinum* spores and no other home canning method will allow water to reach temperatures above boiling. A gauge pressure of 11 psi (76 kPa) is required to achieve a temperature of 116°C when processing with a pressure canner at sea level (Fellows 2003, Rao 2006). Higher temperatures can be achieved by increasing pressure; however, gauge pressures above 15 psi (100 kPa) are not recommended due to safety issues with high pressure (Anonymous 2012b). Consumers can be wary of using this method because the actual pressure canners were not safe. Today's pressure canners have safety measures built into them so they will not explode in a consumer's kitchen. If the consumer follows the canner directions and safety recommendations from the USDA, there is no need to worry about the safety of the current canners. If the consumer acquires a used pressure canner with a dial gauge, it is best to get it checked by a county extension office or pressure canner manufacturer so that the consumer knows the dial gauge is working properly.

One thing to note is that venting is an important step in pressure canning. This step allows air to escape from the canner, which is advantageous because an air/steam mixture (Table 3) will have a lower temperature than steam alone at any given pressure (Esselen 1944, Esselen and Fellers 1948, Walsh and Bates 1978). This means that the gauge would show one pressure;

however, it might not be at the corresponding temperature so the product will be under processed and not safe to eat.

Table 3. Temperature change in steam-air mixtures at 10.3 psi.

Steam %	Air %	Temperature (°C)
100	0	115.6
95	5	114.0
90	10	112.4
85	15	110.6
80	20	108.9
70	30	104.9

1.5.4. Boiling Water Bath Canning

The boiling water bath method is a method that is used for canning high acid food products, such as fruit, jams, jellies, and pickled products (Anonymous 2009a). However, it is not suitable for low acid food products such as tomatoes, vegetables, meats, and seafood (Anonymous 2009a). The process starts with boiling a pot of water and then adding the full jars to the pot. More water is added until the jars are covered in 1 to 2 inches of water. The processing time starts when the water is at a full boil again. If there is less than 1 inch of water above the jars at any time during processing, more water is added. The jars are taken out and placed at room temperature to cool down.

This method was one of the methods used for these types of products before the pressure canner was made for home use in the early 1900's. In blogs such as "Hillbilly Housewife" (Anonymous 2009b), the author does not recommend the boiling water bath method however, it is in the comments section from others that the method is used. Commenters such as "shaw" and "Backwoodsgirl", indicate that old family recipes, older family members/friends, or old cookbooks have been used for canning this way for decades (Anonymous 2009b). These

commenters usually state that their reasoning for still using this method was because "no one has gotten sick from their family member's products" in the decades that they have been canning (Anonymous 2008, Anonymous 2009b). A variety of different processing times are used by consumers with the boiling water bath method. These times range from 25 minutes, from consumers thinking it is acceptable to use the same time as the pressure canning method, to 3 hours, from an old family recipe (Anonymous 2008, Anonymous 2009b).

1.5.5. Oven Canning

The dry oven method is a method that was recommended by the USDA from 1931 to 1942. However, after several studies indicated the danger of jar explosion, the dry oven method was removed from the recommended methods. The USDA reported studies on heat penetration during oven canning resulting in variations of oven temperature, initial food temperature, and consistency (Steinbarger 1931). Tanner (1934, 1935) did several heat penetration studies during oven canning and showed that the time to get to maximum temperature was over 90 minutes and the maximum internal temperature reached was 100°C. These are just examples of the studies done in the 1930's on oven canning, which all demonstrated that oven canning was not safe.

Today the oven canning method is usually found in old family recipes and cookbooks. As pointed out in a comment on "Hillbilly Housewife" (Anonymous 2009b) blog, people may use this traditional method because there may be an emotional connection. It is the way their family has been canning for decades and no one has gotten sick, so they see no reason why they should not continue using this method (Anonymous 2009b). The process for the dry oven method involves placing jars in an oven with temperatures ranging from 250°F to 300°F (Williams 1943; Anonymous 2009b). The next step varies between leaving the oven on the specified temperature for an hour after putting jars in the oven to turning the oven off as soon as

the jars are placed in the oven. The consumers appear to know that the internal jar temperature needs to reach 240°F (115°C), but they believe that the temperature of the food in the jars will reach the oven temperature, which is not true. Water under normal atmospheric pressure cannot reach temperatures above 212°F (McCarty and Morris 2002). For example, one commenter, Nancy on "Hillbilly Housewife" stated that "My thoughts are this: the boiling point is 212 degrees F. 250 degrees for 4 hours allows plenty of time for the center of those jars to be, not only hot enough, but fully (fully!) cooked". McCarty and Morris (2002) stated the reason dry oven canning does not work is because of basic law of physics. The oven is not a pressurized chamber, therefore the materials in the jar can only reach the boiling point of water (100°C or 212°F) no matter how high the oven temperature (McCarty and Morris 2002). Another factor to consider is that hot dry air is a slower heating method than using boiling water or steam (Fellows 2003). The lower thermal conductivity and convective heat transfer coefficient for air versus water is the basis for the slower heat transfer. Air has a thermal conductivity of 0.0314 W/mK while water has a thermal conductivity of 0.68 W/mK (Fellows 2003). Higher thermal conductivity indicates a faster rate of heat transfer. Therefore, the rate of heat transfer is slower for the oven method compared to a water bath. The convective heat transfer within the jar is the final factor to consider and can affect how long the jar is kept at its highest temperature.

1.5.6. Steam Canning

The steam canner consists of a pan with a fitted rack inside which the jars sit on top. The second part of the equipment is the dome, which sits on the top of the pan and is tall enough to fit quart jars inside. The dome has two holes near the bottom which allows the steam to escape. The manufacturer promotes this method because the steam canner uses less water and energy than a standard boiling water method and it is seen as a "greener" method (Anonymous 2012c).

The instruction manual for a commercial steam canner does state that the canner should not be used for low acid foods; however, consumers do not always read or follow instruction manuals (Anonymous 2012c, Nummer 2005).

The steam canning method has not been as thoroughly researched by scientists even though it is just as old as other methods. The USDA recommended steam canning until 1936, when it was excluded from recommendations without any documentation of reasoning behind the exclusion (Andress and Kuhn 1998). The first studies done on steam canning were around 1918. Limited results indicated that the internal jar temperatures were lower than those achieved in a boiling water bath when processed for the same time (Denton 1918, Castle 1919). Pflug and Nicholas (1962) studied the effects of different steam-air mixtures on the heating rates and found that the steam-air mixture was less efficient than pressure (super saturated) or boiling water bath canning. This experiment was not done with home canning equipment, but the information can still be applicable to the home canning industry (Pflug and Nicholas 1962). Research at Pennsylvania State University indicates that the steam canner heat penetration is not as consistent as the boiling water bath and pressure canning method (Nummer 2005, Anonymous 2012d). However, Utah State University research demonstrated that steam canners had the same effect as boiling water baths (Nummer 2005). Another study done by Samida and others (2005), compared steam and hot water bath canning and concluded that the two methods were equally safe to use. However, this study only used high acid foods with different densities, which limits the results and conclusions that can be made from this research. Ramakrishnan and others (1987) found that steam canning can be more efficient, but only for high acid foods. With these conflicting studies, more research is needed for a more definitive conclusion.

Nummer (2005) commented that the steam canning method does not get to the high temperatures required to kill microorganisms in low acids foods. Several reasons that consumers give to justify using this type of system include ease of use, not as labor intensive and faster than the boiling water bath or pressure canning methods (Anonymous 2008). The problem with this method is the same concept as with the dry oven method. The thermal conductivity (0.027 W/mK) of steam vapor (at 100°C) is less than that of water resulting in slower rates of heating (Fellows 2003). The home canning study by Ramakrishnan and others (1987) showed this effect with the difference between the steam and water bath processing times for the different products they tested. They found the water bath canning method took less time to process food compared to the steam canning method (Ramakrishnan and others 1987). Samida and others (2005) compared temperature profiles of the internal jar temperatures and canner temperatures between boiling water bath and steam canning methods and found that internal jar temperatures took a longer time to reach maximum temperatures in steam canners compared to boiling water bath canning.

2. MATERIALS AND METHODS

2.1. Materials

Fresh green beans were acquired from a local food service company. The green beans were harvested four days before being received at the local food service company. Beans used for each replication were purchased four days before canning. *Geobacillus stearothermophilus* (ATCC 12016) was the surrogate microorganism used for sterilization. The pressure canner (Figure A1) was a 23 quart dial gauge from Presto (Eau Claire, WI) with the product dimensions of 44.5 L x 32.4 W x 33.7 H centimeters. The boiling water bath canner (Figure A2) dimensions are 29.8 D x 21.6 H centimeters. The steam canner (Figure A3) was from Back to Basics (West Bend, WI) and its dimensions are 33 L x 38 W x 23.5 H centimeters. The data loggers used were Track-It™ Rugged Temperature Data Logger which has thermocouple temperature sensors that are placed approximately in the middle of the data logger (Monarch Instrument, Amherst, NH).

2.2. Methods

2.2.1. Experimental Design and Statistical Analysis of Data

Fresh green beans were subjected to various home processing methods. Samples to evaluate effective processing were based on *B. stearothermophilus* survival. Beans that were used for quality evaluation were prepared in separate batches in a food safe lab (i.e. non-spiked samples). Beans with or without *B. stearothermophilus* were subjected to the approved processing method of the USDA and the non-approved steam canning, water bath canning, and dry oven canning methods. The non-approved methods were taken from examples of those used by consumers. The data collected after each method included *B. stearothermophilus* counts, temperature of processing conditions, and texture and color of the green beans.

The number of jars processed depended on how many fit into the canner, each canner was filled to capacity for the non-spiked and spiked replications (Figure 2). There were 3 replications of each of the non-spiked and spiked samples. Replications consisted of three separate lots of green beans purchased and processed on separate days. The data collected was subjected to ANOVA (with F-protected LSD test at a 5% significance level).

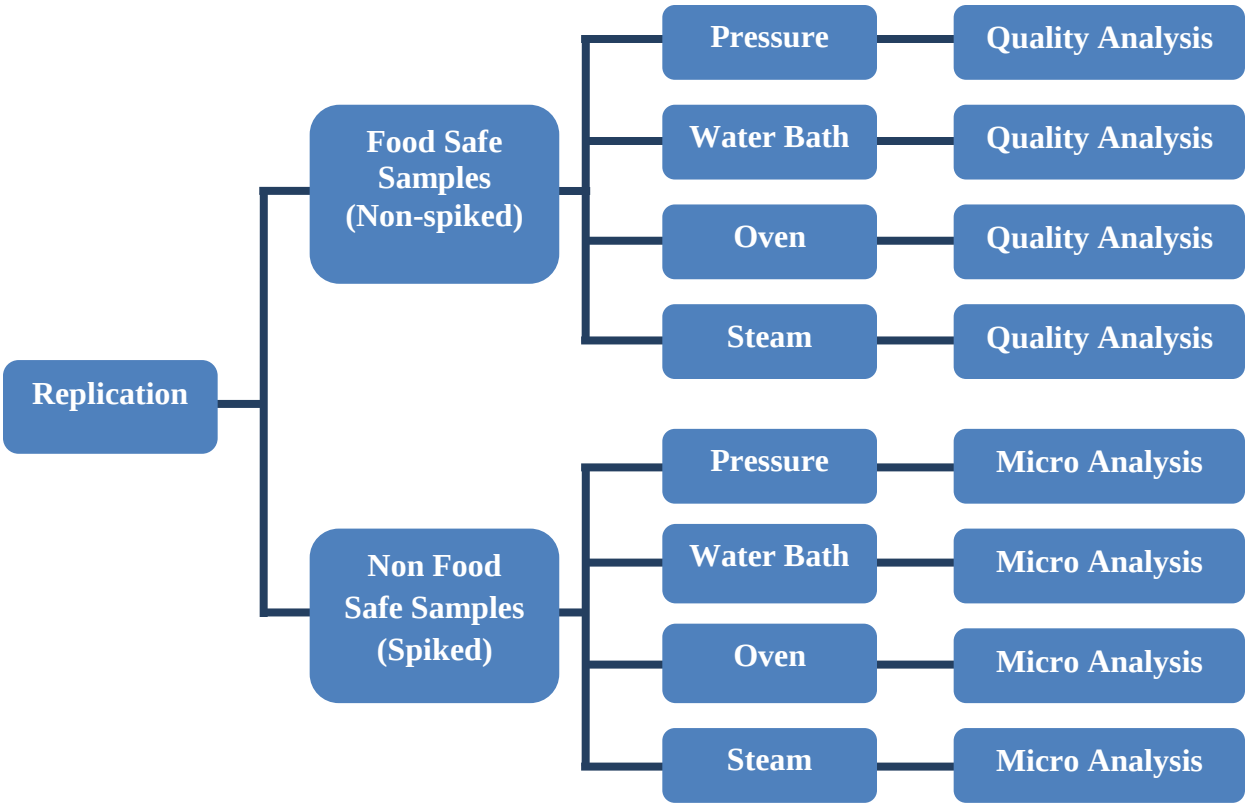

Figure 2. Replication design flow chart.

2.2.2. *B. stearothermophilus* Sporulation

The *B. stearothermophilus* sporulation followed the method of Kim and Naylor (1966) with some alterations. *B. stearothermophilus* was incubated at 55°C for 24 hours in pre-sporulating broth (1% tryptone (Difco) containing 0.5% yeast extract (Difco) and 0.2% K_2HPO_4

(pH of the medium 7.2)). Pre-sporulated broth (2 ml) was then spread on sporulation agar (0.8% nutrient broth, 0.4% yeast extract, 10 ppm $MnCl_2$, 2% agar-agar, pH 7.2) and incubated for 48 hours at 55°C. The petri plate was then flooded with sterile distilled water and spores were collected. The final spore count was 1 x 10^6 CFU/ml. The spore suspension was then stored at 4°C until needed for canning. The jars for experiments involving the inoculation of samples were labeled as non-food safe. The inoculation was done in a non-food grade lab under aseptic conditions. The samples were then processed on a stove top/oven designated for the non-food grade processing. The samples were stored in the non-food safe lab until they were sub sampled for subsequent analysis (Figure 3).

2.2.3. Canning of Green Beans

The fresh green beans were cut into approximately one inch pieces and rinsed with tap water. The hot pack method was used for canning. The green beans were blanched in boiling water for 5 minutes. The green beans and hot water were then transferred to the pint size jars and sealed with two-part self-sealing lids. The samples were then processed according to each processing method. Samples processed in the food safe laboratory had quality evaluations completed three days after processing. Samples, in the hot packed jars, for inoculation were transferred to the non-food grade lab prior to the inoculation. After inoculation, the jars were sealed and subjected to one of four processing conditions. The *B. stearothermophilus* survival was tested two days after canning following the method described below (Section 2.2.4).

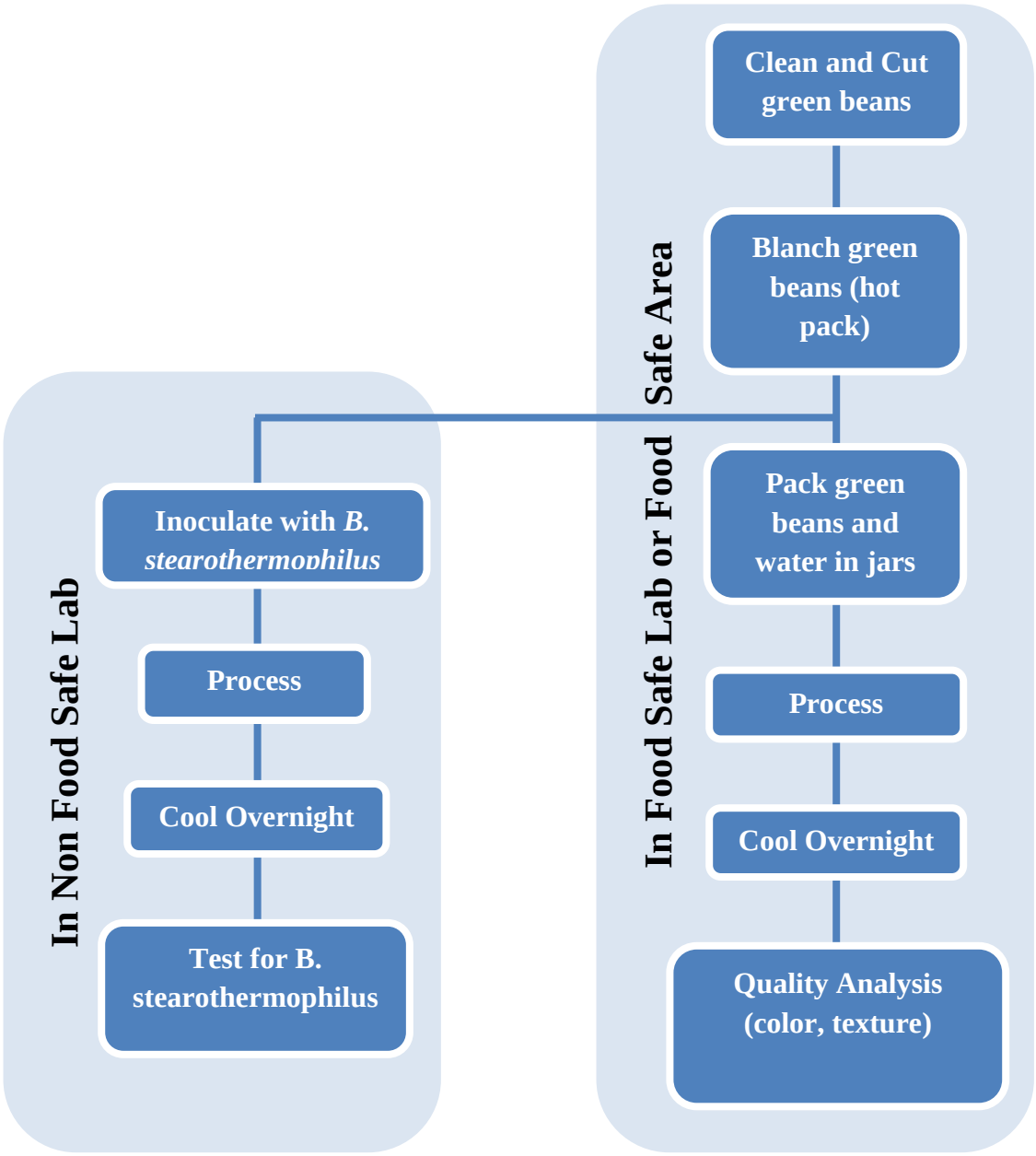

Figure 3. Experimental process flow.

2.2.3.1. Pressure Canning

Pressure canning followed the method recommended by the USDA for green beans. Seven samples (enough pint jars to fill the canner) were placed in the canner. The canner was

sealed and then vented for ten minutes. Then the pressure regulator was put on top of the vent and pressure in the canner was brought to 11 psi on the dial gauge. Samples were then processed for 20 minutes and then the heat turned off (Anonymous 2009a). Samples were allowed to cool naturally (without the aid of cold water) until the pressure drop was sufficient to allow for the lid to be removed. Samples were removed and cooled overnight at room temperature prior to microbial and quality testing.

2.2.3.2. Boiling Water Bath Canning

The water bath canning method required that jars containing product be placed in a boiling water bath. Six green bean samples (enough jars to fill the canner) were placed in the boiling water bath. Additional boiling water was added until the water level was 1-2 inches above the top of the jars. The lid was placed on the pot and the heat turned up so the water boiled continuously. The jars were in the boiling water bath for 90 minutes and then taken out and set on a cooling rack to cool overnight at room temperature prior to microbial and quality testing.

2.2.3.3. Oven Canning

The dry oven method used involved placing samples in a preheated 250°F oven. Green bean samples (4 jars per replication) were placed on a baking sheet before placement in the oven. The oven was turned off after the samples had been in there for 60 minutes and the samples were allowed to cool for 120 minutes in the oven. Then the samples were placed on a cooling rack and allowed to cool at room temperature overnight prior to microbial and quality testing.

2.2.2.4. Steam Canning

Prior to processing, the steam canner was preheated to bring the water at the bottom section of the canner to a boil. Seven green bean samples (enough pint jars to fill the canner)

were placed on a rack in the canner and the lid was placed on top. Once the steam was flowing out of the vent holes (10 to 15 minutes), the 30 minute processing time was started. After the processing time was completed, the jars were taken out of the steam canner and allowed to cool to room temperature overnight prior to microbial and quality testing.

2.2.4. Temperature Data on Canning Methods

The temperature data loggers (Monarch Instrument, Amherst, NH) were placed in several locations during processing. A temperature data logger was placed inside one of the jars (Figure 4) and surrounded by green beans and water to record the temperature throughout processing. The temperature sensor is in approximately the middle of the data logger. A second temperature data logger was placed inside the canner to record the canner temperature outside the jar during processing. Both data loggers recorded the temperature every 2 seconds.

Figure 4. Data logger placement in jar.

The data from the temperature data loggers were used for sterilization calculations. Predicted log reduction spore counts from each canning method was determined as follows:

$$F = \sum[10^{-(121-T)/z} * t]$$

Where T = temperature in jar (°C), z = microbial z value (°C), and t = time (min).

2.2.5. *B. stearothermophilus* Presence and Survival in Green Beans

The canned green beans were tested for *B. stearothermophilus* after canning. The method of Casillas-Buenrostro and others (2012) was followed. The samples were heated to 80°C for 10 minutes to kill any vegetative cells and heat shock any *B. stearothermophilus* spores that were present. The samples were serially diluted and plated onto nutrient agar plates. The plates were incubated at 55°C for 48 hours prior to enumeration.

2.2.6. Quality Analysis on Processed Green Beans

The texture analysis followed the method from Krebbers and others (2002). The firmness of 15 processed green beans was measured by the Texture Analyzer (Brookfield, Massachusetts, USA) set up as a three point bend with the TA7 blade. The color of the green beans was analyzed by the CR-300 colorimeter (Konica Minolta, Tokyo, Japan) and the L*, a*, and b* color analysis was recorded. L* is a value from 0 to 100 and measures black to white, respectively. The a* value measures red to green with red being a positive number and green being negative. The b* value also will read positive to negative numbers, which measures yellow to blue, respectively.

3. RESULTS AND DISCUSSION

3.1. Temperature

The temperature was recorded in two places during processing: inside the jar and in the canner. The temperature difference observed between the canner environment and inside the jar can indicate the heat transfer rate between the heating medium and product. Figures 5 - 8 show the temperature profiles from the pressure, boiling water bath, oven, and steam canning methods, respectively. The highest temperatures recorded in the canner and jar for each of the processing methods indicates some unique observations (Table 4). The oven and pressure canner reached high enough temperatures; however, only the jar inside the pressure canner reached sufficient temperatures considered safe for processing of low acid food products. The green beans from the three other treatments (boiling water, oven, and steam) did not go over 100°C.

Table 4. Highest temperature recorded in jar and canner for the various processing methods.

Method	**Canner Temperature (°C)**	**Jar Temperature (°C)**
Pressure Canning	119	117
Boiling Water Bath Canning	100	98
Oven Canning	122	98
Steam Canning	100	98

The temperature profile shows that pressure canning elevated the temperature both inside the canner and inside the jar above 115°C and stayed above 115°C for 18 minutes (Figure 5, Table 4). The data logger for the pressure canner was put in the canner before the boiling water was added thus the curve starts at room temperature (Figure 5). It elevates quickly after the boiling water was added to the canner, which is true for the product temperature as well (Figure 5). The data logger was placed in the jar before the products, then after venting the canner pressure was applied, which can be seen around the 30 minute mark (Figure 5). Right before the

60 minute mark, the pressure canner was taken off of the stove top to allow to cool (Figure 5). At 115 minute all pressure was lost and the canner was opened and the jars were taken out to cool (Figure 5).

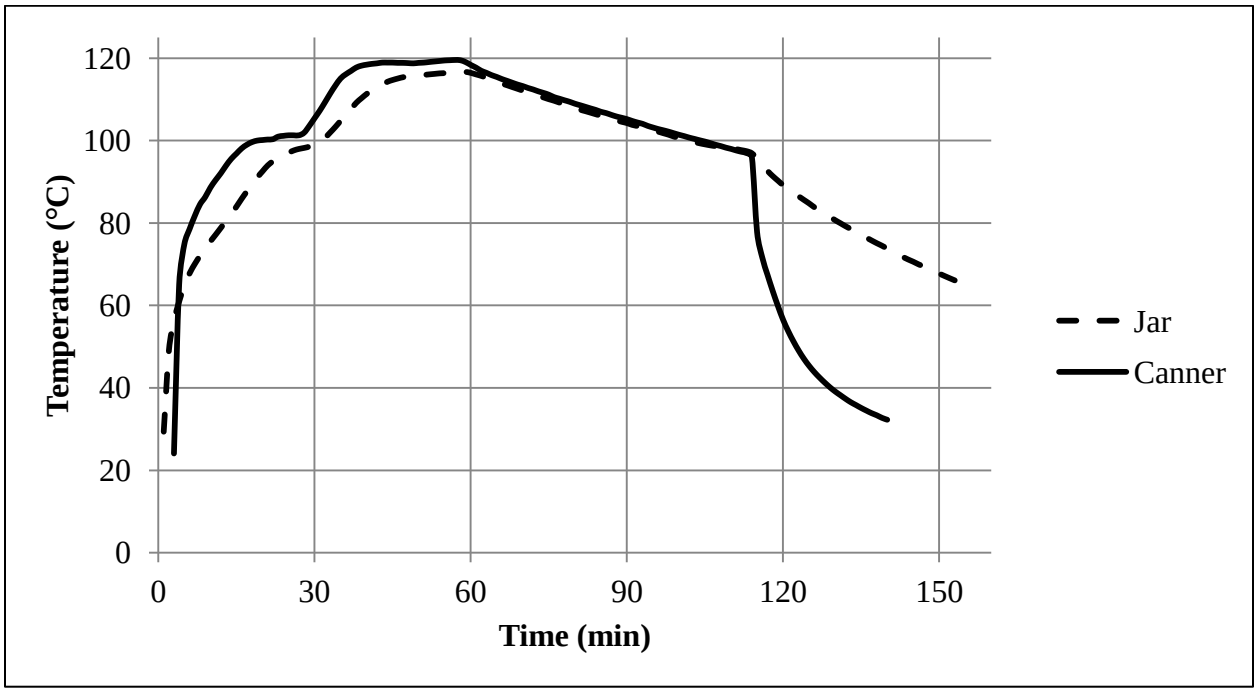

Figure 5. Typical pressure canning time-temperature profile.

The temperatures of 100°C and 98°C were recorded in the boiling water and jars of product, respectively (Figure 6). This temperature difference was consistent throughout the entire canning time, which was 64 minutes. The data logger was placed in the jar prior to the green beans being added and the data logger in the canner was placed in the canner along with the jars (Figure 6). After processing, the data logger was taken out of the canner with the jars and the jars were allowed to cool (Figure 6).

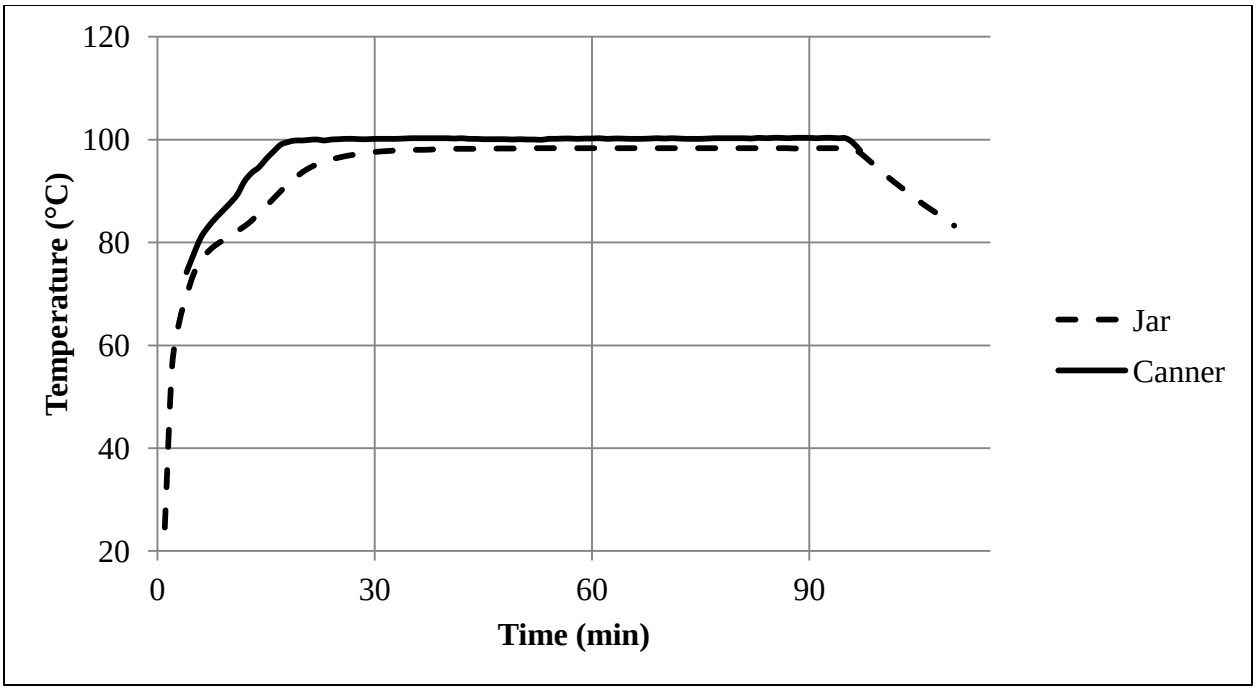

Figure 6. Typical boiling water bath canning time-temperature profile.

The temperature profile for oven canning (Figure 7) shows that the oven reached 122°C; however, the internal jar temperatures did not go above 100°C. This result is consistent with observations that under normal atmospheric conditions water cannot reach temperatures higher than 100°C regardless of the oven temperature (McCarty and Morris 2002). In addition, this result does not support the consumers' thought of the jar reaching the same temperature as the oven. For example, one commenter, Nancy on "Hillbilly Housewife" (Anonymous 2009b) stated that "My thoughts are this: the boiling point is 212 degrees F. 250 degrees for 4 hours allows plenty of time for the center of those jars to be, not only hot enough, but fully (fully!) cooked". The temperature profile for oven canning also shows that the oven lost heat when jars were placed in the oven and that the oven had a heating cycle (Figure 7). Furthermore, the temperature stayed above 98°C for 28 minutes as observed in the oven canning temperature profile (Figure 7).

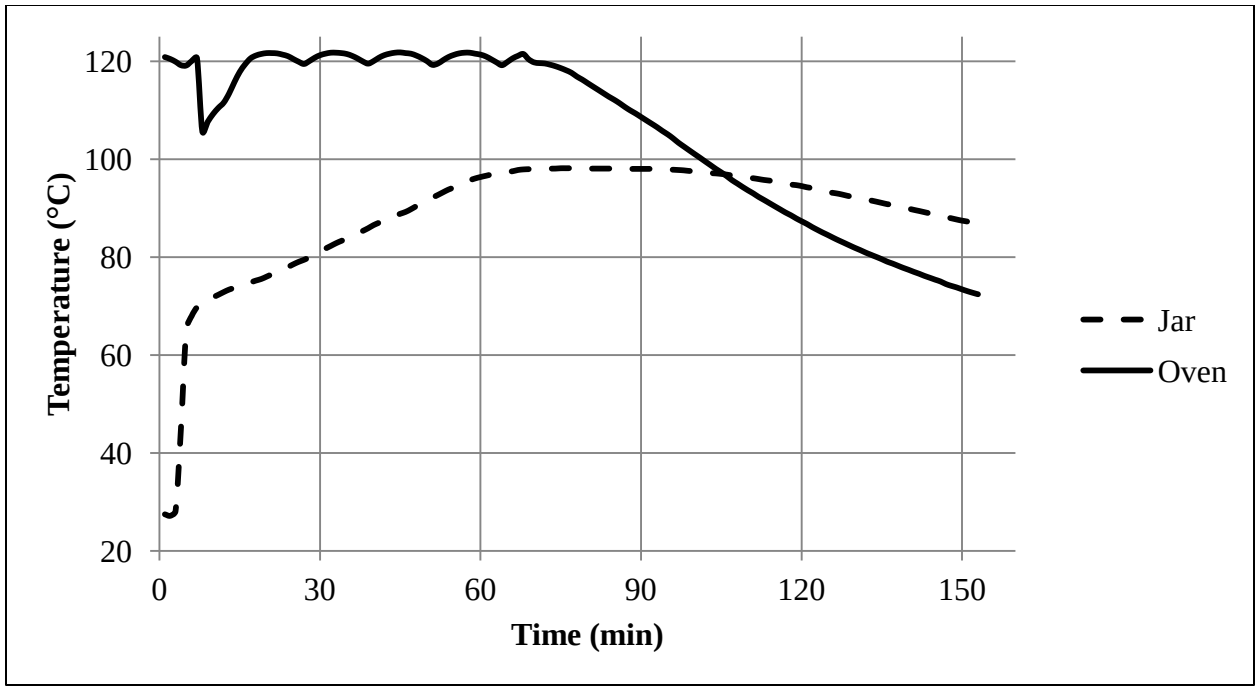

Figure 7. Typical oven canning time-temperature profile.

In steam canning, the canner temperature reached 100°C, but the internal jar temperature never achieved 100°C, with the highest internal temperature being 98°C. The internal jar temperature stayed at this high temperature for 27 minutes. The data loggers were not placed in the steam canner until after the addition of the jars; however, the water was gently boiling before the jars were placed in the canner (Figure 8). These temperature results were similar to the boiling water bath. The difference between the boiling water bath and steam canning processes was the time that the products were processed. This temperature result is consistent with the Pflug and Nicholas (1962) study that found that the steam-air mixture was less efficient than pressure (super saturated) or boiling water bath canning.

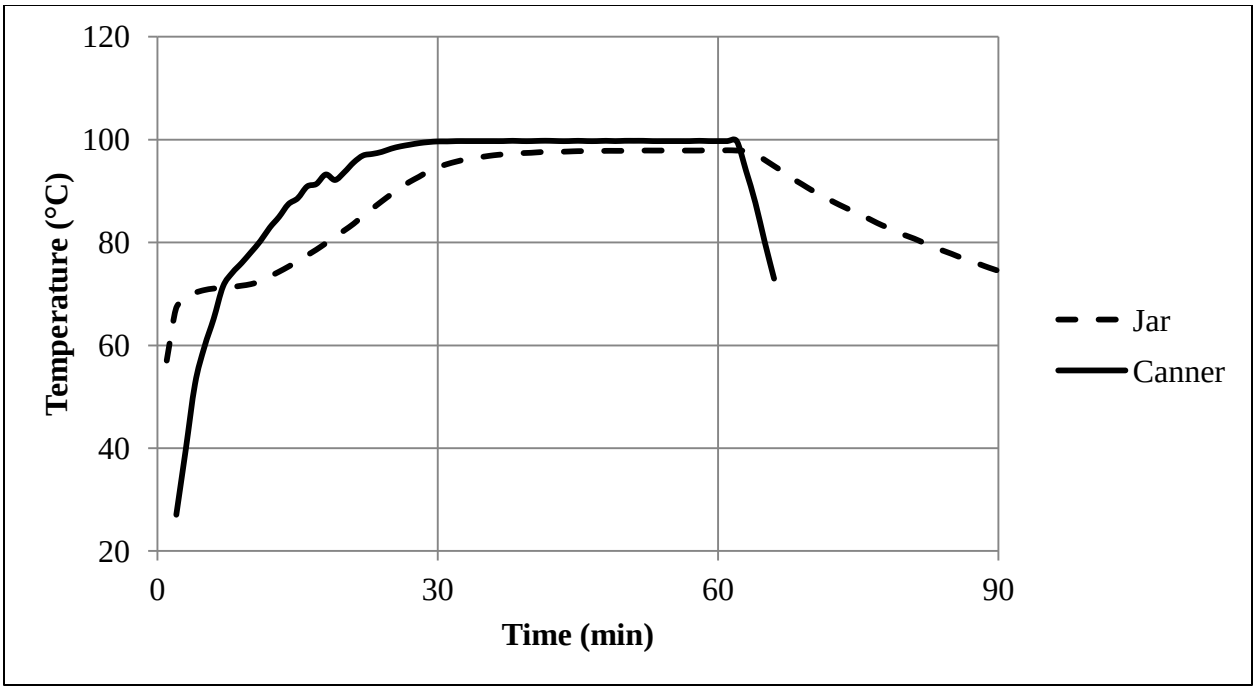

Figure 8. Typical steam canning time-temperature profile.

In addition to temperature, time required to reach high processing temperatures and rate of cool down are important for total processing (Anonymous 2009a). The green beans were processed for 59 minutes before the highest temperature was achieved in the oven canning method. The green beans were processed for one minute before the oven was turned off according to the reported method (Anonymous 2009b). Products in the steam canner reached their highest temperature at 37 minutes after being placed in the steam canner. The time it took for the product to reach the highest temperature during boiling water bath canning was 31 minutes, which was 1/3 of the time that the product was in the canner. In pressure canning, after pressure was applied, the green beans reached their highest temperature after 30 minutes.

The time required to heat the product was related to the type of heat transfer and thermal conductivity of the material surrounding the jar (Sweat 1986). Boiling water bath had the fastest increase in internal jar temperature because of the convective heat and the thermal conductivity

(0.68 W/m-K) of water (Sweat 1986). Steam has a thermal conductivity of 0.027 W/m-K, which partially explains why it took almost 45 minutes to heat the product in the steam canner. The convective heat transfer between the steam/air mixture and the jar could be another partial explanation for the length of time it took to heat the product. Air has the lowest thermal conductivity (0.0314 W/m-K) and is likely the reason for the almost 60 minutes required to heat the product to its highest temperature in the oven.

The D values for *B. stearothermophilus* (Table 2) at 121°C and 100°C is 4.0-4.5 and 3,000 minutes, respectively, to achieve a 90% (1 log) reduction of microorganisms present. The significant difference between these two D values demonstrates the importance of the achieved temperature in a process and the influence it has on the bacterial spore counts in the final product. A 12 log reduction is a typical process goal that is used and for a 12 log reduction at 121°C the processing time will be 48 minutes, while at 100°C the processing time will be 600 hours. This time required at 100°C for a 12 log reduction process (or even a 1 log reduction) is impractical for consumers who use home canning. In all of the temperature profiles, the pressure canning method requires the least amount of time to kill the highest number of microorganisms because of the higher temperature achieved in the process. Furthermore, pressure canning uses heat and pressure, which has been found to have a synergistic affect when killing spores (Meyer and others 2000; Leadley and others 2008). However, the boiling water bath, oven, and steam canning methods would require much more time to achieve a sufficient microorganism reductions because of the lower temperature achieved in these methods. The pressure canning method is the one method that was close to being a 12 log reduction process, but none of the other methods came close to having even a 1 log reduction process. These D values for *B.*

stearothermophilus at different temperatures show how important temperature and the length of time in a processing method can be.

Thermal death kinetics can be studied in several different ways including the predictive microbiology, using a mathematical model, and the application of predictive mathematical models. The mathematical model is more theoretical but allows for greater variability in product, additives, or other environmental factors to be determined (Periago and others 1998). The application of the microbial model involves spiking products with indicator organisms, such as *B. stearothermophilus*, and taking microbial counts after processing. This type of study is more realistic and can give a better indication as to the process that will work best for the type of product.

Two previous studies have examined processing times for steam canning versus other home canning methods; however, both of these studies only examined high acid foods (Ramakrishnan and others 1987, Samida and others 2005). The directions from the manufacturers manual recommends using the same times that are recommended for boiling water bath canning (Anonymous 2012c). Since the microorganisms associated with high acid foods are killed at lower temperatures, 82°C was the target temperature for both of these studies. Samida and others (2005) found that for the internal product temperature to reach 180°F (82°C) was 30 minutes in a boiling water bath canner. Ramakrishnan and others (1987) estimated that the processing time for tomatoes in a boiling water bath canner was 34 minutes. Sliced peaches processed by steam canning took 25 minutes (Samida and others 2005) while tomatoes processed by steam canning took 38 minutes (Ramakrishnan and others 1987). These results are inconclusive because of the inconsistency in the processing times observed between products and processing methods.

3.2. *B. stearothermophilus* Survival

B. stearothermophilus survival coincided with the peak temperature and duration of processing methods (Figure 9). The spore counts were not found to be significantly different; however the data does show a trend. Without processing (control), almost all spores survived. The slight reduction may be related to the initial hot pack that was completed or plating method. However, processing clearly reduced the spore numbers with pressure canning (0.25 log CFU/ml remained after processing) being the best method. The observed log reduction (3.1 CFU/ml) was slightly more than other studies that report conventional thermal processing caused 1.2-2.7 log reductions in *B. stearothermophilus* spore counts (Feeherry and others 1987; Ananta and others 2001; Rajan and others 2006). The results of this study were comparable to these other studies because the log reduction (3.1 CFU/ml) was near this range. With the temperature-time data as well as the known D and z values of *B. stearothermophilus* and *C. botulinum*, the log reductions can also be predicted using sterilization calculations can be made and are reported in Table 5. This calculation indicated a 4.12 D process for pressure canning and *B. stearothermophilus*, which is higher than the 3.1 log reduction determined by the plate count. When comparing the processing time to the D value for *C. botulinum* (0.1-0.2 min), the pressure canning method completed a 29.78 D process, which is a sufficient method for processing green beans.

Table 5. Results of sterilization calculations for processing methods.

Processing Method	**Calculated log reduction for:**	
	B. stearothermophilus	***C. botulinum***
Pressure Canning	4.12	29.78
Boiling Water Bath Canning	0.41	0.49
Oven Canning	0.36	0.37
Steam Canning	0.19	0.20

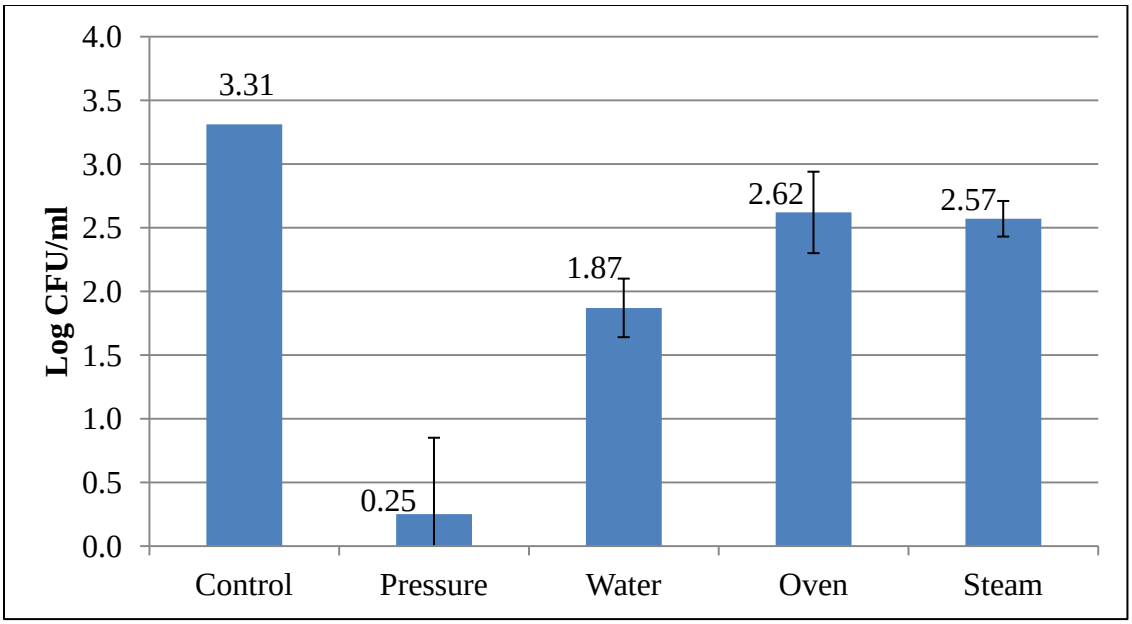

Figure 9. Log *B. stearothermophilus* CFU/ml counts before and after processing treatments.

Boiling water bath canning caused a 1.4 log reduction in spore count. Although a reduction in spore counts was observed, the oven and steam canning methods still retained high spore counts (Figure 9). However, these three methods i.e. boiling water bath, oven, and steam canning would require 200 minutes (~3.3 hr) at the temperatures they were processed (98°C) to meet a 1 log reduction for *B. stearothermophilus*. For a 1 log reduction of *C. botulinum* at the temperatures these three methods were processed (98°C), they would have to be heated for 159 minutes (~2.65 hr). The predicted log reductions (Table 5) for all three methods were less than 0.5 for both *B. stearothermophilus* and *C. botulinum*, which were all lower than the reduction in spore counts. The predictions and plate counts both demonstrate that the boiling water bath, oven, and steam canning methods do not reach high enough temperatures or long enough processing methods to produce safe products.

Few or no studies have been published using some of the methods used in the current study. Two studies that have specifically researched steam canning (Ramakrishnan and others

1987, Samida and others 2005) did not actually use microorganisms, but instead used thermobacteriological estimates with the D and z values. Both of these studies focused on estimating safe processing times and used acid foods. Therefore, the theoretical estimates may not be correct for all products. Several factors can influence the D and z values, such as the product being canned, additives such as salt, and the number of jars in the canner.

Mackey and Derrick (1987) observed that a temperature rise of less than 2°C/min could cause an increase in the thermotolerance of the *Salmonella typhimurium* instead of killing the bacteria during processing. Therefore, the same principles could apply to *B. stearothermophilus* (Mackey and Derrick 1987). The temperature profiles from both the steam and oven canning methods support that the temperature within the jars did not rise more than 2°C per minute. Pressure and boiling water bath canning both increased the jar temperatures at a rate of 1°C per minute and 0.6°C per minute, respectively. Even though the pressure canner did not rise more than 2°C per minute, Meyer and others (2000) found that pressure and temperature have a synergistic effect when dealing with spore inactivation. The slow heating rate of the other canning methods could cause the microorganisms to become more thermo-stable rather than killing them.

3.3. Texture

Texture is an important quality parameter that consumers take into consideration when they are making or consuming food products. Textural changes are caused by both chemical and enzymatic processes, which result in cell wall polysaccharide breakdown. The amount of textural changes is dependent on the severity of the treatment and length of treatment. The firmness of the green beans was measured after the processing treatments. Pressure canning caused the greatest softening of the green beans, which had a mean firmness value of 97.6 g

(Table 6). Pressure canning was the most severe processing method, i.e. high temperature and pressure, which broke down the cell wall polysaccharides and resulted in a softer texture (Stolle-Smits and others 1995, Shiga and Lajolo 2006). The pressure canning results were similar to results for conventional thermal processing (Krebbers and others 2002). However, these results were not similar to Stolle-Smits and others (1995) or Leadley and others (2008), but this is most likely because of the analysis method used in these studies. The green beans from the pressure canning were not significantly different from the boiling water bath or oven canning methods with mean firmness values of 172.7 g and 139.1 g, respectively. These texture numbers indicate that even though the temperatures were not as high as pressure canning, long processing likely caused cell wall polysaccharides to break down. Steam canning produced green beans with a mean firmness value of 255.6 g, which was significantly firmer than green beans processed using pressure canning and oven canning. This texture data shows that the shorter processing time greatly influences the final product texture. The temperature also may influence the texture of green beans, for example, the green beans from the boiling water bath, oven, and steam canning methods were firmer than the pressure canning method, which could result from the lower temperature that they achieved during processing.

Table 6. Mean firmness of green beans after processing.

Treatment	Mean Firmness (g)
Pressure Canning	97.6^{a} ± 9.5
Boiling Water Bath Canning	172.7^{ab} ± 24.0
Oven Canning	139.1^{a} ± 40.8
Steam Canning	255.6^{b} ± 65.1

Note: Samples sharing the same superscripted letter were not significantly different ($P > 0.05$) from one another.

Neither Ramakrishnan and others (1987) or Samida and others (2005) examined product quality in their studies on steam canning. No other studies have been published to compare the green bean quality. These quality results could possibly explain a reason why some consumers like steam canning more than the USDA recommended pressure canning. The steam canning samples had better texture than pressure canning. Several studies (Stolle-Smits and others 1995, Stolle-Smits and others 1997, Krebbers and others 2002) have found that thermally processing green beans had significantly lower firmness compared to fresh or blanched samples.

3.4. Color

Consumers also consider the quality parameters when evaluating food products. Heat processed green beans changed the initial bright green to a darker olive green color because the chlorophyll is being broken down into pheophytins (Schwartz and others 2007). Magnesium is replaced with hydrogen ions to change chlorophyll to pheophytin within the first five to seven minutes of processing (Schwartz and others 2007). This replacement also induces the color change from bright green to olive brown (Schwartz and others 2007). The pheophytin then turns into pyropheophytin after 15 minutes of processing (Schwartz and others 2007). Color differences were observed in the processed green beans (Figure 10).

Figure 10. Green beans from various processing methods. a. control, b. pressure canning, c. boiling water bath canning, d. oven canning, e. steam canning.

The L* values for green beans from all of the processing methods were not significantly different (Table 7). The a* value of the green beans obtained from pressure canning was found to be significantly different than each of the other methods. The high a* value shows that more chlorophyll was degraded in pressure canning than the other processing methods. The greatest negative a* value indicated greenness; thus, the least negative a* value supports a reduction of green color of the green beans processed by pressure canning. The green beans from boiling water bath canning and oven canning did not have significantly different a* values. The a* values for the green beans from the boiling water bath canning and oven canning methods were -7.15 and -6.81, respectively, which indicates that they retained much of their green color compared to the pressure canning method. Finally, green beans from steam canning had a significantly different a* value (-8.69) compared to all other processing methods. This number indicates that green beans from the steam canning method had the most green color, which could be due to the shorter processing time or temperatures achieved during processing.

Table 7. Mean L* a* and b* color values of green beans after processing.

Treatment	L*	a*	b*
Pressure Canning	61.94[a]	-4.77[a]	19.91[a]
Boiling Water Bath Canning	62.90[a]	-7.15[b]	22.46[b]
Oven Canning	63.13[a]	-6.81[b]	21.79[b]
Steam Canning	61.37[a]	-8.69[c]	20.32[a]

Note: Samples sharing the same superscripted letter in the same column were not significantly different ($P > 0.05$) from one another.

The b* values, which measure yellow to blue, indicates a sample is less yellow color as the value is closer to zero. The green beans from the pressure and steam canning were found to have the most yellow color at b* values of 19.91 and 20.32, respectively, and were found not be significantly different from each other. However, these two were significantly different from

green beans processed using boiling water bath and oven canning, which had b* values of 22.46 and 21.79, respectively. Green bean b* values from the water bath and oven canning methods were not significantly different.

4. SUMMARY AND CONCLUSION

Home canning has grown in recent years because of the promotion of growing, buying, and eating more local foods. The internet has become a wealth of information but most of this information is scientifically untested, which could lead to unsafe canning practices. Many different factors influence the safety of the final product including the type of product, type of processing method, and length of processing time. The temperature profiles revealed that only the pressure canning method elevated the temperature of the green beans above 100°C, while the green beans from the other processing methods did not achieve 100°C. This study showed that the *B. stearothermophilus* spore counts coincided with the temperature profiles, with the oven and steam canning methods having the highest spore counts while boiling water bath canning had similar counts. This indicates that for green beans (and probably other low acid foods) these three methods are not recommended to consumers for home canning. The USDA recommended method of pressure canning, however, reduced the spore counts, which justifies it being the recommended USDA method. Consumers can also preserve green beans safely by other techniques and Figure A4 contains the instructions for these other preservation techniques.

The texture and color quality parameters that were tested indicated the green beans with the lowest a* value (best greenness) and firmest texture resulted from the steam canning method. The pressure canning method resulted in green beans with the highest a* value (worst greenness) and softest texture. These results also coincide with the temperature profiles showing that higher processing temperatures and longer processing times will result in a qualitatively less desirable product. Through this study, it has been demonstrated that methods found on the internet and passed down from older family members may have consumer desired final product qualities, however these processes do not reach high enough temperatures to achieve a safe product.

Therefore, only the USDA recommended method is recommended for producing safe canned green beans. Remember that the USDA method for canning green beans in pint jars is pressure canning for 20 minutes at 11 psi (Anonymous 2009a).

5. FUTURE RESEARCH

Future research could include several areas of focus. The first area would be to investigate other canning methods (Figure A4 in appendix) that consumers are using or use the same ones in this study under different conditions. Another area to consider is canning other foods using the steam canning method, such as high acid foods as well as several different consistencies of foods (big food particles, small food particles, and pureed fruits/vegetables). A third area is to test food additives, such as salt and sugar, to determine if additives have any effects on bacterial counts.

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APPENDIX

Figure A1. Pressure canner.

Figure A2. Boiling water bath canner.

Figure A3. Steam canner.

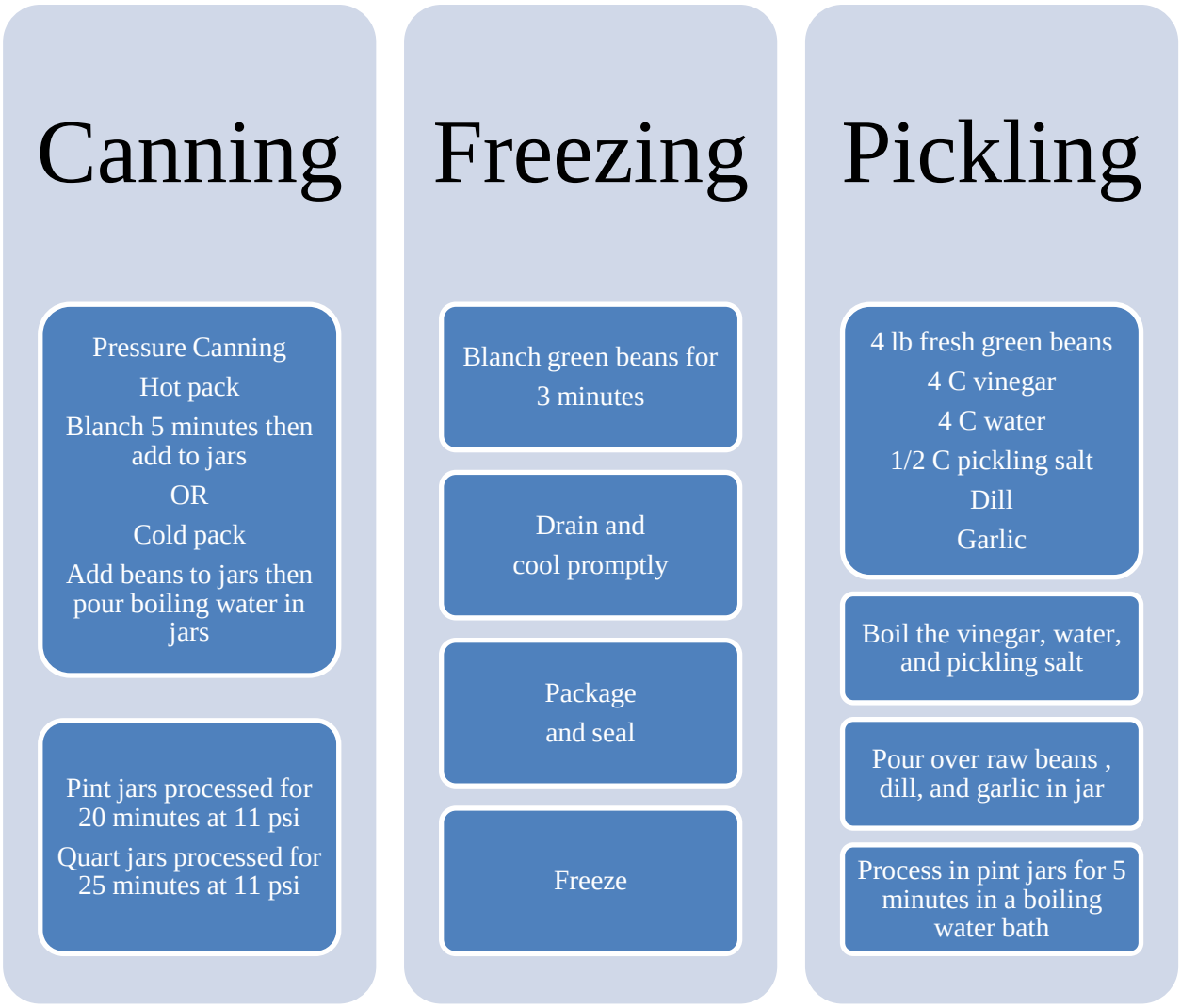

Figure A4. Methods to preserve green beans.*
*At altitudes between 0 and 1,000 ft above sea level.